IMPLICATIONS OF HYDROBIOLOGY AND NUTRIENT DYNAMICS ON TROPHIC STRUCTURE AND INTERACTIONS IN COCHIN BACKWATERS

Thesis Submitted to

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfilment of the requirements for the Degree of

Doctor of Philosophy

in

Marine Sciences

Under the Faculty of Marine Sciences

By

RADHIKA.R
Reg. No.2544

Department of Chemical Oceanography
School of Marine Sciences
Cochin University of Science and Technology
Kochi-682016

February- 2013

To my sweet daughter baby Anamika.....

Cochin University of Science and Technology

School of Marine Science
Department of Chemical Oceanography

Dr. Sujatha C.H
Reader

Fine Arts Avenue

Cochin, Kerala – 682 016, India

Certificate

*This is to certify that the thesis entitled "**Implications of Hydrobiology and Nutrient dynamics on Trophic structure and interactions in Cochin Backwaters**" is an authentic record of the research work carried out by Mrs. Radhika R, under my guidance and supervision at the Department of Chemical Oceanography, School of Marine Sciences, Cochin University of Science and Technology, Kochi, in partial fulfillment of the requirements for PhD degree of Cochin University of Science and Technology and no part of this has been presented before any degree in any University.*

Kochi-16
February, 2013

Dr. Sujatha. C.H
(Supervising Guide)

Declaration

*I hereby declare that the thesis entitled ""**Implications of Hydrobiology and Nutrient dynamics on trophic structure and interactions in Cochin backwaters**" is an authentic record of the research work carried out by me, under the guidance and supervision of Dr. Sujatha C.H, Reader and Head, Department of Chemical Oceanography, School of Marine Sciences, Cochin University of Science and Technology, and no part of this work has previously formed the basis of the award of any degree, diploma, associateship, fellowship or any other similar title or recognition.*

Kochi -16
February, 2013

Radhika.R

Abbreviations

A	Abundant
Alk-OP	Alkali Soluble Organic phosphorous
ANOVA	Analysis of Variance
ASOP	Acid Soluble Organic Phosphorous
BOD	Biochemical Oxygen Demand
C	Common
Ca-IP	Calcium Bound Inorganic Phosphate
CBW	Cochin Backwater
Chl a	Chlorophyll a
Chl b	Chlorophyll b
Chl c	Chlorophyll c
CHO	Total Carbohydrate
DO	Dissolved oxygen
E^h	Redox potential
F	Few
Fe-IP	Iron bound Inorganic Phosphate
H	Shannon Diversity Index
J^1	Pielou's eveness index
LPD	Total Lipid
MON 09	Monsoon 2009
ND	Not Detected
No.	Number
Pheo	Pheophytin
POM 08	Postmonsoon 2008
POM 09	Postmonsoon 2009
PRE 09	Premonsoon 2009

PRE 10	Premonsoon 2010
PRT	Total Protein
R	Rare
Res-P	Residual Phosphorus
S	Similarity
S.R	Sedgewick Rafter cell
sp.	Species
TN	Total Nitrogen
TOC	Total Organic Carbon

Acknowledgement

I deeply indebted to my supervising guide and Head of the Department ***Dr. Sujatha C.H*** *Reader and Head, School of Marine Sciences, for her sustained interest and valuable guidance in my work. Without her support and scientific advices this thesis would not have been materialized.*

I am thankful to ***Prof. (Dr) Sajan. K,*** *Dean, School of Marine Sciences, for providing the necessary facilities to carry out my research.*

There are no words to express my sincere gratitude to ***Dr.Chandramohanakumar****, for his valuable and very precious worships, continuous help, his valuable advises and suggestions and facilities provided to me throughout the work. I am grateful to our teachers* ***Prof (Dr).Jacob Chacko, Prof (Dr).S.Muraleedharan Nair,*** *for their advices and timely support.*

I take this opportunity to thank ***Dr. Rosamma Stephen, Scientist F (Rtd), National Institute of Oceanography, Regional Centre, Kochi*** *for her valuable suggestions for timely completion of this thesis.*

I gratefully recall the valuable help and support of ***Dr. Ratheesh Kumar*** *and* ***Mr. Salas P.M*** *for the completion of my thesis. I express my sincere gratitude to my colleagues,* ***Ms. Manju M.N, Mrs. Resmi P, Ms. Renjitha Raveendran*** *and* ***Mr. Sanil Kumar,*** *for the timely support and cooperation. I am deeply thankful to my friend* ***Dr (Mrs). Bindu Sunil , Dr.Nisha P Aravind and Dr. Sheeba P,*** *for her valuable advises and suggestions. Samples used in the present study were collected in the King Fisher and my thanks extent to* ***Mr. Anilajan and Mr. Suresh*** *for the help they provided for the collection of samples.*

My heartfelt thanks to all especially ***Dr (Mrs). Mini Sekharan****, and all my colleagues for their timely help and support during this work.*

My sincere thanks to ***Dr. M.P. Prabhakaran, Mr. Rahul R., Mr. Shaiju P, Mr. Deepulal P M, Mr. Anoop.P.P, Mr. Gireesh Kumar T R., Mrs. Nebula Murukesh, Mrs. Dayala Joby, Mr .Baiju.P, Mr.Akhil P.S*** *and all other research scholars of this department. I sincerely thank Mr.* ***A. Arumukhadas,*** *Former Section Officer,* ***Mrs. Geetha*** *and other staff of the Department of Chemical Oceanography, for their timely service. I thank Mr.* ***P.J. Manuel,*** *Librarian, and other staff, School of Marine Sciences Library for their valuable cooperation.*

I am indebted to my parents especially to my mother, who encouraged me a lot, my husband ***Mr. Dilip Mohan*** *and my sweet daughter baby* ***Anamika*** *who always prayed for me and gave generous support.*

I thank ***Dr. M.P.Rajan, Principal,*** *N.S.S.Hindu College, Changanassery for his encouragement. I wish to pronounce my gratitude to* ***Prof. R.Prasannakumar****, Secretary, N.S.S.College's Central Committee,* ***N.S.S Management,*** *Prof.* ***Dr. Sarala Nair, Prof. Sobhanakumari, Prof (Dr). Geetha, Prof (Dr). Gopakumar, Prof (Dr). Renukadevi, Mrs. Ampily M, Dr. Sreejaya R, Smt. Sreevidya J*** *faculty members of the Department of Zoology, N.S.S.Hindu College, Changanasserry,* ***Dr.K,K Hemalatha, Dr. Balakrishnan, Dr. Sushama.S , Dr.Laksmi.R.Chandran and Dr.Umadevi*** *for their support and constant encouragement. I also wish to express my gratitude to* ***Prof. V.Sethumadhavan*** *former head of the Department of Zoology, and* ***Dr.Saraswathiamma*** *former Principal, N.S.S.College , Nemmara for their encouragement. I am very much thankful to my friend* ***Miss Praveena,K*** *Assistant Professor in Economics, N.S.S.Hindu College, Changanasserry for her*

timely and valuable help. This work would not have been completed without the support of many generous and knowledgeable people.

There are no words to express my gratitude to ***CSIR for providing Senior Research Fellowship*** *and* ***University Grants Commission*** *for providing* ***FIP*** *for the completion of my work. I thank each and every person who had directly or indirectly helped me to complete this thesis in time.*

Above all, I thank the god almighty for blessing me with the potential for the successful completion of my work.

Radhika R.

PREFACE

Estuaries are dynamic water bodies characterized by variations driven by tidal currents, meteorological factors and river discharge. Due to alterations in the physico-chemical, biological and meteorological conditions experienced in aquatic environments with respect to seasons; a detailed study of each estuarine system is a prerequisite to establish the effects of these parameters on the distribution and abundance of the fauna and flora. Cochin backwater system is facing ecological threats like environmental degradation, nutrient enrichment, habitat degradation, biodiversity loss and changes in overall functioning of the ecosystem due to urbanization and industrialization. In addition, during the past decades this ecosystem has been subjected to severe encroachment. Of late great emphasis is given to study the impact of habitat alteration in coastal areas that are beyond self-purification by the ebb and flow of tides and by seasonal flushing by the monsoonal rains. Baseline study on physical, chemical and biological alterations are lacking from Cochin backwater system, the largest estuary along the southwest coast of India. Comprehensive studies explaining the dynamics by interlinking physicochemical and biological characteristics of the estuarine systems are limited due to its complex nature. Random collections and time series studies were carried out by eminent researchers from various institutions. The present study provides a systematic approach regarding the influence of physicochemical parameters, nutrient dynamics and sedimentary parameters on different trophic levels. This type of investigation in the study region is not so far been conducted by interlinking all prominent levels of biotic and abiotic components. As all aquatic ecosystems are facing deterioration in quality and life threat, this study helps to assess the overall health of Cochin estuarine

system and can create an awareness in people the importance of conserving this natural ecosystem.

Globally more than 10 million people die every year due to either starvation or malnutrition. At this crucial time there arises the need for regular monitoring, conservation and management of fishery resources which in turn connected to phytoplankton and zooplankton potentials of the water bodies. The significance of plankton (both phytoplankton and zooplankton), in the food chain and fishery potential of the sea or any other water bodies has been realized even a century ago. Investigations on influence of the hydrobiology, nutrient dynamics and trophic level interactions would go long way in improving the quality of water resources that reflect the properties of the environment. The present work would be immensely useful for the people to implement corrective measures and would serve as a standard reference for the further studies in the Cochin estuarine system.

In the present thesis entitled" ***Implications of Hydrobiology and Nutrient dynamics on Trophic structure and Interactions in Cochin backwaters",*** an attempt has been made to assess the influence of general hydrography, nutrients and other environmental factors on the abundance, distribution and trophic interactions in Cochin backwater system. The study was based on five seasonal sampling campaigns carried out at 15 stations spread along the Cochin backwater system. The thesis is presented in the following 5 chapters. Salient features of each chapter are summarized below:

Chapter 1- General Introduction: Provides information on the topic of study, environmental factors, back ground information, the significance, review of literature, aim and scope of the present study and its objectives.

Chapter 2- Materials and Methods: This chapter deals with the description of the study area and the methodology adopted for sample collection and analysis.

Chapter 3- General Hydrograhy and Sediment Characteristics: Describes the environmental setting of the study area explaining seasonal variation in physicochemical parameters of water column and sediment characteristics. Data on hydrographical parameters, nitrogen fractionation, phosphorus fractionation and biochemical composition of the sediment samples were assessed to evaluate the trophic status.

Chapter 4- Nutrient Dynamics on Trophic Structure and Interactions: Describes primary, secondary and tertiary production in Cochin backwater system. Primary production related to cell abundance, diversity of phytoplankton that varies seasonally, concentration of various pigments and primary productivity. Secondary production refers to the seasonal abundance of zooplankton especially copepod abundance and tertiary production deals with seasonal fish landings, gut content analysis and proximate composition of dominant fish species. The spatiotemporal variation, interrelationships and trophic interactions were evaluated by statistical methods.

Chapter 5- Summary: The results and findings of the study are summarized in the fifth chapter of the thesis.

References are given at the end of each chapter. The papers published and presented are listed at the end of thesis.

Contents

Chapter 1

GENERAL INTRODUCTION

Contents

Kerala, one of the southernmost state of India, situated in between lattitude 8^{o} 15'and 12^{o} 45'N and longitude 74 ^{o} 50' and 77 ^{o} 30'E comprising an area of about 38,863 km^2 and is bestowed with coconut trees, lakes, ponds, estuaries, reservoirs, streams, rivers, backwaters, and mangroves. The eastern boundary of the state -Western Ghats is the site of origin of 44 rivers. Most of these rivers empty into the backwaters before opening into the Arabian Sea, which form the eastern boundary. It is generally accepted that estuaries or backwater systems are the most likely environment in which the first signs of life evolved and in the course of several millions of years animal life slowly adapted itself to a land living and air - breathing existence. Backwater systems of Kerala support as much biological productivity and diversity as tropical rain forests. They are responsible for the rich fishery potential of the State. Distributed along the east and west coast of India, there are a number of estuaries covering an area of approximately two million hectares, though many of them are being used for fishing and transportation very few are advantageously and scientifically managed for optimum utilization.

1.1 Significance of estuaries

Estuaries are defined as semi-enclosed bodies of water, situated at the interface between land and ocean, where seawater is measurably diluted by the inflow of freshwater (Hobbie, 2000). The term "estuary," derived from the Latin word *aestuarium*, means marsh or channel (Merriam-Webster, 1979). Based on salinity estuaries are defined as semi-enclosed coastal bodies of water that have a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage (Pritchard, 1967). These are among the highly dynamic biodiverse and productive ecosystems in the world with high carrying capacity and ability to support not only a resident population but also many migratory fishes and invertebrates. They provide a direct resource for commercially important species of fishes and shellfish, but they also provide shelter and food resources for commercially important shelf species that spend some of their juvenile stages in estuarine marshes. These are also regarded as economically important ecosystems for fisheries in tropical regions (Kawabata et al., 1993) and act as transitional zone between land and sea (Bardarudeen et al., 1996).

The estuaries are always considered as biologically active zones (Kibirige and Perissinotto, 2003). Different types of trophic relationship between the phytoplankton and zooplankton have been established in estuarine systems (Perissinotto et al., 2000; Tan et al., 2004). Studies on the hydrological features of the marine and estuarine environment is of great importance since the general distribution, migration and relative abundance of marine and estuarine organisms are greatly influenced by the physico-chemical parameters.

It has been reported 61% of the world population lives along the coastal margin (Alongi, 1998) and are facing the difficulties as well as the benefits of living near the sea. The estuarine ecosystems have an outstanding direct socio economic importance for many tropical coastal regions (Aksornkoae et al., 1993; Uthoff, 1996).

1.2 Productive nature and trophic status of estuarine systems

Phytoplanktons are widely distributed in the estuarine environments. By photosynthesis these green organisms use solar radiation to transform carbon dioxide and water into carbohydrates or high energy organic compounds. The synthesis of organic material by photosynthesis is termed primary production. Since phytoplanktons are the major producers in the aquatic ecosystems, their role in the food chain is of paramount importance. Phytoplankton in the estuarine environments utilizes carbon dioxide for photosynthesis play an important role in maintaining carbon dioxide budget of the atmosphere. The larger the world's phytoplankton community, the greater is the carbon dioxide is removal from the atmosphere. Phytoplankton forms the foundation stone of world fishery. The distribution and abundance of the commercially important fish and shellfish and their larvae are dependent on some species of the phytoplankton, forming food for majority of juveniles as well as many adult fishes.

Phytoplankton is of great economic importance in the biology of the pelagic realm, particularly in estuaries and coastal waters, since it provides the primary nutritional source. They constitute the basic source of food in the sea and the initial level of food chain. These are consumed by floating and drifting animals called zooplankton which has limited powers of swimming ability. Phytoplanktons are also consumed by larger animals such as some fishes, molluscs, and crustaceans which are herbivorous that

graze upon the floating plant life. Studies related with phytoplankton provide very useful basic information for the estimation of primary production and assessment of potential resources at higher trophic levels.

Secondary production can be defined as the generation of biomass of heterotrophic (consumer) organisms in a system and is driven by the transfer of organic material between trophic levels, and represents the quantity of new cells produced through the use of assimilated food. Secondary production is sometimes defined to only include consumption of primary producers by herbivorous consumers and commonly defined to include all biomass generation by heterotrophs. The organisms responsible for secondary production include animals, zooplankton, protists, fungi and many bacteria. Thus secondary production is a composite measure of density of an animal population, biomass, and growth over time. Secondary production converts animal abundance and biomass data into a functional measure of energy flow through an ecosystem.

Different taxa are also reliable indicators of a wide spectrum of limnological conditions such as pH, nutrient concentrations and salinity. Their number was found to be reduced due to pollution. The low densities of copepods in CBW are the sign of polluted sediments or the degradation of water quality of that area. The ecological role of an organism is largely determined by its position and significance in the food web. Some important secondary producers in estuaries are mentioned below:

Copepods are ubiquitous in marine environment. Sexes are separate and can be easily distinguished by the nature of the fifth leg. Copepods are main grazers of the phytoplankton. Their oral appendages are flattened multi lobed structures carrying long plumose setae. These appendages form an efficient filtering apparatus for filtering of diatoms. Copepods form the

food of other animals, inhabiting in the surface waters especially for shoal fishes where ever copepods are abundant. One can expect a large concentration of primary and secondary carnivorous, the seasonal variations in the abundance and distribution of copepods largely determines the distribution of pelagic fishes.

These are small crustaceans commonly called water fleas. They are ubiquitous in inland aquatic habitats, but rare in the oceans. Most are 0.2-6.0 mm (0.0079-0.24mm) in long, with a down-turned head, and a carapace covering the apparently unsegmented thorax and abdomen with a single median compound eye.

The phylum Rotifera, commonly called wheel animals are microscopic and near-microscopic pseudocoelomate animals. Most rotifers are around 0.1- 0.5 mm long. Their size can range from 50μm to over 2mm and are common in freshwater environments throughout the world with a few saltwater species. Some rotifers are free swimming and truly planktonic.

Tertiary production can be defined as the production of living material per unit area (or volume) per unit time by organisms consuming the herbivores or carnivores. Losses of marine life diversity are largely the result of the conflicting usage of the coastal habitat which hence leads to degradation of habitat. The best way to conserve biodiversity is to protect habitat diversity (Tiwari et al., 2002). The fishes caught from the aquatic environment are consumed by human being thereby reducing protein deficiency. Indiscriminate exploitation of marine food source has resulted in depletion so there should be judicious and sustainable fishing and should know the quantity of the population that can be harvested. By quantifying the biomass of plankton, fish population that will be produced can be

calculated and in turn the catchable amount per year can be predicted. In order to predict, locate and exploit the marine fishery resources, hydrobiology of marine environment can play significant role (Asha and Diwakar, 2007).

Fishes are the important tertiary producers in aquatic habitats and are significant focus of the economically important and commercial fisheries. They are important source of food and recreation and are key elements in many natural and food webs. They have an impact on the physico-chemical properties of the system, in which they occur; they affect plankton, macrophytes and other aquatic organisms and they can serve as environmental indicators. Changes in the composition of a fish assemblage often indicate a variation in pH, salinity temperature regime, solutes, flow, turbidity, dissolved oxygen, substrate composition or pollution level. The gain or loss of certain species is a common consequence of the environmental change. Because fishes are conspicuous they often are the primary indicators of the toxification of streams and lakes. Because fishes are ecologically important, there is often intense commercial and recreational interest in their study. The feeding behavior of fish is as diverse as their morphology. Their actual diet at any given time depends on the availability of the food items as well as on the presence of potentially competing fish species. It is generally agreed that fishes are herbivorous, omnivorous or carnivorous, but most of them are highly adaptable in their feeding habits. Knowledge on the food and feeding habits of fishes and their trophic relationships is essential to understand how the food influences growth, abundance, migration, reproduction. The food and feeding habits of fishes from varying habitats differ in time and space and also at different stages of growth, thereby emphasizing the need for the

study of food and feeding habits of a species in more detail. The information gathered from a qualitative study of feeding habits, on the food requirements of fishes, will be useful in ecological and aquaculture studies.

1.3 Ecological aspects of Cochin backwater system

The Cochin backwater system is a positive tropical estuary which exhibits a unique ecological complex having marine, estuarine and freshwater environments at different zones. It is the largest backwater system of Kerala state, which encompasses a large number of organisms, with its problems and opportunities. It supports rich fishery resources having several species of marine fin fishes and shell fishes and acts as a sink and transformer for the agricultural and municipal wastes discharged into it. The harbor of Cochin brings a lot of economic fortune to the city of Cochin and the backwater system provides livelihood for lot of people from fishing and paddy cum prawn farming.

The discharge of fresh water from the various rivers and drainage canals cause a dynamic condition which renders the backwaters an extremely interesting and ecologically intriguing environment. The inland extensions of the Cochin backwater system with their very many water enclaves are of utmost important from the fishery point of view and are well known for their role as nursery ground for many of the commercially important species of fishes. The major hydrological variable in the Cochin backwater is salinity (Menon et al., 2000). The salinity gradient in the Cochin back water supports diverse species of flora and fauna according to their tolerance for the saline environments. The changes in the hydrology are controlled by the seasons which play an important role in regulating the migrant fauna of the estuary.

The processes regulating the biological productivity in the Cochin backwater is very complex. This estuary is influenced by heavy rain and fresh water influx during monsoon seasons ie., south west monsoon and north east monsoon. During the peak of south west monsoon, salinity gets very low values all over the regions. High tides from the Arabian Sea contribute a regular flow of salt water, which diminishes considerably towards the head of the Cochin estuary (Madhupratap, 1987). This tropical estuarine environment exhibit multitudinal features (Quasim, 2003) which characterize freshwater and seawater mixing (Menon et al., 2000) and provide breeding ground for marine organisms (Nair et al., 1988; Sarala Devi et al., 1991; Madhu et al., 2007).

Cochin backwater system has been experiencing high levels of anthropogenic pressure during the last five decades (Menon et al., 2000). Reclamation of land for harbour and urban development, intensive exploitation of resources, discharge of untreated or partially treated sewage and industrial effluents resulted in variations in the flushing characteristics and ultimately transforming the system into a eutrophic one. There are environmental problems concerning the shrinking of the estuary and loss of its biodiversity (Gopalan et al., 1980) and in the beginning of the 19th century, the total area of CBW has shrunken from 365km^2 to 256km^2 (Gopalan et al., 1983; Balachandran et al., 2005).

1.4 Review of literature

A long-term study of documenting changes in parameters like hydrography, nutrients, chlorophyll and plankton community responses are reported in Skidaway River Estuary (Verity and Borkman, 2010). Dynamics of phytoplankton, zooplankton, and nutrients in two of the largest shallow lakes in the USA (Lake Apopka, Florida) and Europe (Lago

Trasimeno, Umbria, Italy) (Havens et al., 2009). A 30-year concurrent field observation on phytoplankton, macrozoobenthos and estuarine birds in the Dutch Wadden Sea, which has been subject to decades of nutrient enrichment (Philippart et al., 2007). Studies regarding the environmental influences on the qualitative and quantitative composition of phytoplankton and zooplankton in North African coastal lagoons were also carried out (Ramdani et al., 2009). The field of phytoplankton ecology has been enriched by the outstanding contribution of Reynolds, (2006), on phycology. The effects of grazing of fishes upon zooplankton and phytoplankton communities were investigated (Williams and Moss, 2003). More precise and diversified studies on hydrography, plankton study and fisheries sector have been reported (Cabo et al., 2003; Yahia et al., 2004; Castro et al., 2005). Huang et al., (2004) examined taxonomic composition, abundance, and spatial distribution of phytoplankton in the Pearl River estuary. Phytoplankton taxonomic composition, abundance, diurnal variability and spatial distribution were examined in the Changjiang Estuary (Gao and Song, 2005). Nozais et al., (2001), reported the annual cycle of microalgal biomass in a South African temporarily open estuary. Moreover, rates or a pathway through which exogenous nutrients are converted into algal biomass is different among estuaries (Cloern, 2001). These types of uncertainties have to be addressed for the proper protection and conservation of estuarine systems. Physico-chemical parameters like nutrient concentrations, algal chlorophyll, water transparency (Carlson, 1977; Kratzer and Brezonik, 1981) and primary production measurements (Nixon, 1995) have often been employed to assess trophic status of water. Biochemical composition of organic matter in sediments has been employed as a tool to evaluate the trophic status of coastal marine systems (Dell' Anno et al., 2002; Pusceddu et al., 2003). Interactions between the

sediment and the water column play an important role in regulating phytoplankton production and the extent of bottom water hypoxia/anoxia (Kemp and Boynton, 1992). Cabo et al., (2003) studied the effect of physico-chemical factors on phytoplankton from Parana River in Argentina and suggested that the plankton occurrence and diversity would be affected directly or indirectly by water level and seasonal climatic factors. Yahia et al., (2004) studied the spatial and temporal pattern of planktonic copepods in the bay of Tunis in SW Mediterranean Sea and found that the copepods were the dominant component of mesozooplankton. Studies by Castro et al., (2005) about rotifers in three shallow lakes in Portugal and recorded peaks in diversity and abundance during summer time which was related to temperature. Kideys et al., (2005) estimated the plankton abundance, biomass and species composition of Caspian Sea and suggested that the higher value of chlorophyll was due to the decreased grazing of phytoplankton by zooplankton. Chlorophyll a and primary production in the euphotic zone of the North-West shelf of Spanish coast has been reported (Bode et al., in 1996). Planktons have been long been used as indicators of water quality (Palmer, 1969; Stoermer and Yang, 1969). Ecological study on the feeding habits of fishes has been conducted (Whitefield and Blaber, 1978). Torreele et al., (1992) investigated the development of a functional digestive system in the African Catfish *Clarius gariepinus*. Wasidewska, (1992) studied the relationship between abiotic factors and phytoplankton in Rusalka reservoir and reported that physical factors are of greater importance for the prediction of phytoplankton biomass. Virbickas, (1998) studied the regularities of changes in the production of fish population and communities in Lithuanian Rivers. Investigations on proximate composition of biochemical components of many commercially important fishes have been published (Sinha and Pal,

1990; Das and Sahu, 2001). Eutrophication due to excess supply of nutrients from industrial and domestic activities influence coastal and estuarine waters (Barmawidjaja et al., 1995; Tsujimoto et al., 2006).

Reddy et al., (2002) reported that human activities can heavily pollute a lake while studying the eutrophic status of Hussain Sagar Lake. Systematic account of diatoms in South Indian region and described both fresh and estuarine diatoms in and around Madras, with a quite explicable taxonomic description was provided by Venkataraman, (1939). Marine planktonic diatoms of Trivandrum coast have been extensively studied (Nair, 1959). 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 Vellar estuary, East coast of India. Gopinathan, (1975b), described some new distributional records of plankton diatoms from the Indian Seas. Thresiamma and Nair, (1980) investigated the qualitative and quantitative analysis of planktonic diatoms of Vizhinjam, the southwest coast of India. Primary productivity of the exclusive economic zone of India and the factors governing phytoplankton production was investigated (Nair and Gopinathan, 1981). Sewel, (1924, 1934) has studied plankton, more especially the copepods of the Chilka Lake and the salt lakes of Calcutta. A preliminary study of the plankton of the Chilka Lake was done by Devasundaram and Roy, (1954). Jhingran, (1977) reported that all major estuarine systems are rich in fishery potential. Biological productivity and fishery potential in the coastal waters off Bombay was investigated by Varshney et al., (1982). A comparative study on zooplankton in polluted and unpolluted waters of Gujarat was made by Desai et al., (1983). The secondary production of Indian Ocean can be calculated from zooplankton biomass values (Dalal, 1986). Santra et

al., 1989, studied the seasonal fluctuations of phytoplankton in Bhagirathi-Hoogly estuary, in West Bengal. Khanna et al., (1993) studied the phytoplankton ecology of the River Ganga and reported a negative correlation of water temperature with phytoplankton and zooplankton production. The values of biological factors increases with increase in temperature have got direct effect on the biology of Sagar Lake (Agarwal et al., (1995). Waste waters from industries with high temperature lead marked ill effect on water quality, planktons, and fish fauna of the Lake (Pandey, 1995). Relation between the phytoplankton and zooplankton was established (Singh 1990; Bucka et al., 1993; Baruah et al., 1997; Khan et al 1998). Vareethiah and Haneefa, (1998) reported that phytoplankton biomass is known to control fishery potential of estuaries to a greater extent. Primary productivity and chlorophyll a of the inshore area at Tuticorin was recorded by Gopinathan et al., (1994). The chemical state of many nutrients in the water bodies are controlled by the hydrogen ion concentration (Horne and Goldman, 1994 ; Habib et al., 1997) reported that light have direct influence on phytoplankton growth and temperature acts as the limiting factor for algal development. Elskens et al., (1997) studied the contribution of nitrate to the uptake of nitrogen by phytoplankton in the ocean and reported that nitrate into the euphotic zone appears to be a major controlling factor regulating the standing stock and production of phytoplankton. From the studies about the plankton community Sanganer by Chaturvedi et al., (1999) revealed that some planktons like *Chlorella* and *Closterium* grew well in polluted waters and acts as indicators of organic pollution (Borse et al., 2003; Webber et al., 2005). Sharma (2000a, b) suggested that rotifers depict a qualitative predominance in floodplain lakes. Seasonal periodicity of plankton in Ganga river has been assessed (Khanna et al., 2000; Sath et al., 2000). Godhantaraman, (2001) reported

the abundance of plankton exhibited a clear seasonal variation and showed highest in summer and lowest in Monsoon. Bhava and Borse, (2001) reported an inverse relationship between salinity and plankton production. Gowda et al., (2001) recorded the abundance and distribution of phytoplankton in the Nethravathy estuary. Malu, (2001) reported the phytoplankton diversity on Lonar Lake. The distribution and abundance of phytoplankton from Adayar estuary has been investigated (Eswari and Ramanibai, 2002). Yalavarthy Eswari, (2002) studied the hydrobiology of red hills reservoir in North Chennai reported that phosphate act as a limiting factor for the growth of plankton. Das, (2002) studied the diversity and zooplankton population with increase in salinity. Salaskar and Yeragi, (2003) studied the seasonal fluctuation of plankton population in Powai Lake in Mumbai and reached a direct relation between dissolved oxygen and phytoplankton. Sheeba and Ramanujan, (2003) identified 38 genera of phytoplankton together with physicochemical parameters of water at monthly intervals in the estuarine environment of Ithikkara River, southern Kerala. Sharma, (2005) reported that water temperature directly influence the abundance of rotifers in the flood plain lakes of Brahmaputra basin. Roy et al., (2006) investigated the spatial variation of phytoplankton pigments along the south west coast of India. 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.

Survey of rotifer fauna was conducted in twenty reservoirs of major river systems in peninsular India during 1995-96 have been carried out (Sukumaran and Das, 2004). Many researchers have studied the

distribution, population density and biomass of the zooplankton and about the hydrography of Arabian Sea and Bay of Bengal (Jyothibabu et al., 2006; Madhu et al., 2007).

Investigations on the feeding habits of some fishes of Calicut and madras coasts were made by Venkataraman, (1960) those of Gulf of Mannar and Palk Bay by Talwar, (1962) and those of Bombay coast by Suseelan and Somasekharan, (1967). Studies were done in the food and feeding habits of some teleosts like *Psettodus erumei* (Mathew and Balakrishnan, 1976). Interspecific and intraspecific competition for food in fishes cohabiting the same location was studied by Thomas (1962), Mc Comish, (1966), Clifford, (1968). Keast and Deirdrewebb, (1966) studied mouth and body form relative to feeding ecology of fishes. Various researchers have studied the diversity of fishes in India. Ajith Kumar and Vijayan, (1987) studied the fish fauna of Keoladeo National Park, Bharatpur. Reviews of the literature on the methods of gut content analysis have been made by several workers Hynes, 1950; Pillay, 1952; Rounsefell and Everhart, 1953; Hyslop, 1980). Whole body and elemental and proximate composition of Atlantic salmon was done by Shearer et.al (1994) during its life cycle. Raju Thomas et al., (2002) have given a detailed list of freshwater fish fauna of Kerala. The studies on prevailing quality of environment form the basis for understanding impacts of a particular anthropogenic stress (Kulkarni et al., 2011).

Reports on aquatic pollution with special reference to Kuttanad region of Vembanad Lake revealed that this particular region has become a dumping yard for agricultural wastes (Padmakumar, 1987). While studying the water quality of retting zones of Vembanad lake, Bijoy Nandan et al., (1989) reported that salinity plays an important role in the distribution of

zooplankton. The effect of salinity intrusion has significant influence on the ecology of water bodies (Nair et al., 1995). Phosphorus fractionation was employed to find the bioavailability of phosphorus and its seasonal variations in the Panangad region of Cochin estuary (Renjith et al., 2011). Redox status of the Cochin estuarine system was established by using rare earths elements in sediments (Deepulal et al., 2012).

Variability in nature and composition of organic matter in the surficial sediments of mangrove and estuarine systems of Cochin were investigated (Joseph et al., 2008). The phosphorus fractions in three tropical mangrove systems of Cochin region were analysed by sequential extraction method (Joseph et al., 2011). Texture, total organic carbon, total nitrogen and stable isotopic ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta\ ^{15}N$) in surface sediments of Cochin estuary was analysed to identify major sources of organic matter (Gireeshkumar et al., 2012). Different forms of sedimentary phosphorous in the Cochin estuary and their spatial and seasonal variability, bioavailability, and the changes in the P biogeochemistry along the salinity gradient of the estuary have been assessed (Gireeshkumar et al., 2013). A close coupling between enriched levels of nutrients and the absence of *Trichodesmium* in the Cochin backwaters was established by historic and fresh time series data evidences (Martin et al., 2012).

Biological characteristics of Cochin estuary were investigated by many researchers including Kurian et al., (1975); Unnithan et al., (1977), Saraladevi, (1989) and Joy et al., (1990). Sankaranarayanan and Qasim, (1969) studied the nutrients of the Cochin estuary in relation to environmental characteristics. Zooplankton distribution along the salinity gradient in the Cochin backwaters before and after monsoon was first studied by Nair and Tranton, (1971). Gopinathan (1972), studied the qualitative and

quantitative analysis on phytoplankton of the Cochin estuary and described 120 species. Devassy and Bhattathiri, (1974) analyzed the phytoplankton ecology in the Cochin estuary. Primary production in the Vembanad Lake was assessed by Nair et al., 1975. Joseph and Nair, (1975). The general hydrography of the Cochin estuary has been investigated by several investigators (Qasim and Gopinathan, 1969; Anirudhan et al., 1987; Pylee et al., 1990). In 1975, Joseph and Pillai studied the seasonal and spatial distribution of phytoplankton in Cochin backwaters. Pillai et al., 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. Knowledge on the various aspects of the physico chemical parameters of this estuary is essential for assessing the water quality and various biogeochemical processes and also improving future guidelines on the estuarine management (Beenamma Jacob, 1993). The role of diatoms as pollution indicators has already been reported (Venkateswarulu et al., 1994). Growth constants, mean generation time and chlorophyll in relation to cell numbers and ^{14}C uptake in few unialgal cultures of selected phytoplankters isolated from Cochin estuary have been estimated (Madhu et al, 2007). Thorough study of morphology, biology and development of *Liza macrolepis* and *Mugil cunnensius* observed that early stages of both the species feed on phyto and zooplankton while the adults are mainly bottom feeders (Sunny, 1976). Species composition and distribution patterns of copepods did not change much over recurring observations which shows that the species are highly adapted to their niches (Haridas et al., 1980). Chemical condition and

physical changes are responsible for the temporal distribution of zooplankton (Madhupratap, 1987).

Large scale fish mortality has been observed on several occasions (Azis and Nair, 1981). Kurup, (1982) presented a complete systematic list of the fishes of the Vembanad Lake and their frequency of occurrence. The seasonal distribution of phytoplankton in Cochin backwaters has been reported (Jayalakshmi et al., 1986). Selvaraj and Kumaraguru (1997) noticed that higher dissolved oxygen concentration was favourable to the growth of *Microcystis aeruginosa*. A detailed review on physicochemical as well as biological aspects of CBW has been published (Menon et al., 2000).

Attempt was made to evaluate the photosynthetic pigments at the dredged and non-dredged sites in the Cochin harbour (Rasheed et al., 2000). Seasonal variation of phytoplankton abundance and productivity were studied in the surf zone of the Cochin backwaters based on cell counts, Chlorophyll a, photosynthesis and hydrographic parameters Selvaraj et al., (2003). Alkershi et al., (2003), studied the contribution of size fractions of planktonic algae to the primary organic productivity in the coastal waters off Cochin. Renjith et al., (2004) studied the primary production at selected stations in Cochin estuary and established a trimodal annual variation with peaks during April, July and November, maximum production being in November and minimum in June.

Investigations were carried out on food of some demersal fishes from the trawl grounds of Cochin (George et al., 1968). Knowledge of the food and feeding habits is important in fundamental community analysis for studies of food webs, trophodynamics resource partitioning and ecological energetic (Landenberger, 1968). A qualitative study of feeding habits together information on the food requirements of fishes will be

useful in ecological and aquaculture studies (Ramanathan et al., 1975). It is well established that the quantitative and qualitative composition of the food of a species is essential to understand many aspects concerning the fish (Gopinathan Menon and Muthaih, 1987). Extensive works were carried out on the qualitative and quantitative aspects of phytoplankton, pigments and primary productivity in the South west coast of India, mostly confined to the Cochin estuary (Gopinathan et al., 1974; Joseph and Pillai, 1975; Thangaraj 1984; Jayalakshmi et al., 1986, Selveraj, 2000, 2003; Jyothibabu et al., 2006, Madhu et al., 2007; Sanilkumar, 2009, Aneeshkumar 2009). Eutrophication and related anoxia was reported by Martin et al., (2012). Significant spatial and temporal variability of physico-chemical characteristics and productivity patterns are among the important characteristics of estuaries (Renjith et al., 2012). Pigment characterization and sedimentary biomarker pigments around Cochin estuary situated in the southwest coast of India were determined by HPLC method (Aneeshkumar, 2009). Fucoxanthin, an indicator of diatoms (Bacillariophyceae) was observed to be the most abundant carotenoid pigment in the estuary (Aneeshkumar and Sujatha, 2012)

1.5 Aim and scope of the present study

As a result of massive reclamation for the rapid urbanization and industrialization, the Cochin backwaters are facing severe ecological problems including eutrophication (Gopalan et al., 1983, Martin et al., 2012). Sixteen major and several minor industries are located on the banks of River Periyar discharge untreated or partially treated wastes containing large quantities of nutrient elements like nitrogen, phosphorous and trace metals into the estuary (Balachandran et al., 2003). Likewise, the domestic waste from the Cochin metropolitan city also creates organic pollution. All

these activities eventually lead to the changes in the population and structure of trophic webs and even affected the overall functioning of this ecosystem (Unnithan et al., 1975; Menon et al., 2000).

Several studies have been conducted in the Cochin backwaters on various physico-chemical (Sankaranarayanan and Qasim, 1969; Shyanamma and Balakrishnan, 1973) and biological characteristics (Madhupratap et al., 1975; Qasim, 2003). Environmental studies in the Cochin backwaters, revealed that seasonal fluctuations in salinity created by the monsoonal rainfall and associated run off is a major factor controlling the distribution and abundance of micro- and mesozooplankton (Madhu et al., 2007). Combined effects of hydrographic parameters and other biological features induce variations in diversity of the fauna and flora in the estuary.

In the past decades many studies have been undertaken by different researchers regarding phytoplankton composition and structure of zooplankton and fishes in different dimensions. Eventhough Cochin estuary has been subjected to intense biological study, the information available on the varying aspects of hydrography and biology has not fully described the changing biological environment. The anthropogenic stress has imposed changes in physical, chemical and biological characteristics and habitat alterations in this unique ecosystem , which demand a new approach for the quality assessment of the system, linking environmental and biological parameters.

Despite the numerous specific works that have been carried out in the Cochin estuary on physicochemical and biological characteristics, a comprehensive study covering the combined effects of hydrobiology and nutrient dynamics on trophic structure has not been attempted. An

integrated approach relating biological as wells physicochemical aspects with respect to seasons are not available for this unique backwater ecosystem. The information on the trophic structure and dynamics of Cochin backwater system would form a useful tool for further ecological assessment and will be applicable to monitor any similar tropical ecosystem. In this context, the present investigation, intends to evaluate the implications of the hydrobiology and nutrient dynamics on the trophic relationship and community structure in the Cochin backwaters.

The objectives of the present study:

- To analyze the seasonal variation in general hydrography, sediment characteristics including enrichment of nutrients from land runoff, nitrogen fractionation, phosphorous fractionation and biochemical composition of sediments in the Cochin backwater system
- To assess the spatial and seasonal variation of phytoplankton community blooming and correlation of fertility with biomass
- To study the seasonal distribution of zooplankton
- To study the trophic relationship between primary, secondary and tertiary consumers and to trace ecological indicators if any
- To assess the seasonal fish landings from the respective landing centres adjacent to sampling sites and to evaluate the damage to estuarine fishes
- To analyse and study the gut content analysis of selected fishes
- To analyse and evaluate the complexities of coastal ecosystems and the impact of hydrology on ecosystem services.

References

Agarwal, N.C., Bais,V.S., Tazeen Arasta, 1995. Comparative account of phytoplankton productivity in the Sagar lake and the military engineering lake - A statistical approach. *J. Freshwat.Biol.,* **7** (1), 27-31.

Ajithkumar,C.R.,.Vijayan, V.S., 1988. On the fish fauna of Keoladeo National Park, Bharatpur, Rajasthan. *J. Bombay Nat. Hist. Soc*. 85, 44-49.

Aksornkoae, S., N., Paphavasit, G., Wattayakorn., 1993. Mangroves of Thailand: Present status of conservation use and management. Technical Report of the Project: The Economic and Environmental Values of Mangroves Forests and Their Present State of Conservation in the South-East Asia/Pacific Region, Clough, B.F. (Ed.), PD 71/89 1(F), 83-134.

Alkershi-Akram, Menon, N.R., 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., 1998. Coastal ecosystem processes. CRC Press.

Aneeshkumar, N., 2009 Ph.D Thesis, Cochin University of Science and Technology, Kochi.

Aneeshkumar,N., Sujatha, C.H., 2012. Biomarker pigment signatures in Cochin back water system - A tropical estuary south west coast of India, *Est. Coast. Shelf Sci.*, 99, 182-190.

Anirudhan, T.S., Balchand A.N., Nair, S.M., Nambisan, P.N.K.,1987 - Distribution pattern of salinity and silicon and their interrelationship in Cochin backwaters. Proc. on National Seminar on Estuarine

Management., Kerala State Committee on Science, Technology and Environment Trivandrum, Kerala, (Abstracts) E.D. 11.

Asha, P. S., Diwakar, K., 2007. Hydrobiology of the inshore waters off Tuticorin in the Gulf of Mannar. *J. Mar. Biol. Ass. India* 49(1), 07-11.

Azis, A. P. K., Nair, N. B., 1981. Certain aspects of pollution in the aquatic ecosystems of the South west Coast of India. Proc.Seminar on Status of Environmental Studies in India: 345-356.

Badarudeen, A., Damodaran, K.T., Sajan, K., Padmalal, D., 1996. Texture and geochemistry of the sediments of a tropical mangrove ecosystem, southwest coast of India. *Environ. Geol.* 27, 164-169.

Balachandran, K. K., Laluraj, C. M., Nair M., Joseph, T., Sheeba, P., Venugopal, P., 2005. Heavy metal deposition in a flow-restricted, tropical estuary, *Est. Coast. Shelf Sci.*, 65, 361-370.

Balachandran, K.K., Thresiamma Joseph., Maheswari Nair., Sankaranarayanan. V.N., Kesavadas, V., Sheeba, P., 2003. Geochemistry of surficial sediments along the central southwest coast of India – Seasonal changes in regional distribution. *J. Coastal Res.*, 19, 664-683.

Barmawidjaja, D. M., Van Der Zwaan, G. J., Jorissen, F. J., Puskaric, S., 1995. 150 years of eutrophication in the northern Adriatic Sea, evidence from a benthic foraminiferal record. *Mar. Geol., 122*, 367-384.

Baruah, B.K., Chaudhary, M., Das, M., 1997. Plankton as index of water quality with reference to paper mill pollution, *Poll. Res.*, 16(4), 249 - 263.

Beenamma Jacob, 1993. PhD thesis, Cochin University of Science and Tecnology, Kochi, India.

Bhave,S.K., Borse, P.V., 2001. Seasonal variation in temperature, dissolved oxygen, pH and salinity and their influence on planktons in Aner river water Jalgaon, Maharashtra. *Poll.Res*. 20 (1), 79-82.

Bijoy Nandan,S, P.K.Abdul Azis and P.Natarajan, 1989. Water quality and faunal depletion in the retting zones of the black waters of Kerala, proceedings of the Kerala Science Congress, Cochin. 167-175.

Bode, R. W., Novak, M.A., Abele, L.A., 1996. Quality assurance work plan for biological stream monitoring in New York State. NYS Department of Environmental Protection; Division of Water; Bureau of Monitoring and Assessment; Stream Biomonitoring Unit; Albany, NY.

Borse, S.K., Lohar, P.S., Bhave, P.V., 2003. Hydrobiological study of algae of Aner River, Jalgaon (Maharashtra). *J. Aqua. Biol.,* 18(1),15-8.

Buckah., Roman Zurek, K. Henry., Kasza, 1993. The effect of physical and chemical parameters on the dynamics of the phyto and zooplankton development in the Goezalkowice reservoir, Southern Poland. *Acta hydrobiol.* 35(2), 133-151.

Cabo, L., Puig, A., Arreghini, S., Olguin, H.F., Seoane, R., Obertello, I., 2003. Physicochemical variables and plankton from the Lower Delta of the Paran River (Argentina) in relation to flow. Hydrological Processes. Volume: 17, Issue: 7, Publisher: Wiley Online Library, Pages: 1279-1290.

Carlson, R.E., 1977. A trophic state index for lakes. *Limnol. Oceanogr*. 22, 361-369.

Castro, B.B., Antunes, S.C., Pereira, R., Soares, A.M.V.M., Gonçalves, F., 2005. Rotifer community structure in three shallow lakes: Seasonal fluctuations and explanatory factors. *Hydrobiologia*, 543, 221-232.

Chaturvedi,R.K., Sharma, K.P., Kamayani Sharma, Bharadwaj S.M., Subhasini Sharma, 1999. Plankton community of polluted waters around Sanganer, Jaipur. *J. Env. Poll*. 6(1), 77-84.

Clawson, A.J., Garlich, J.D., Coffey, M.T., Pond, W.G., 1991. Nutritional, physiological, genetic, sex and age effects on fat-free dry matter composition of the body in avian, fish, and mammalian species: a review. *J. Anim. Sci.* 69, 3617–3644.

Clifford Ray Johnson,1968. Food of the buffalo Aculpin, enophrys bison. *Fish .Res.Bd.* Canada, 25(4): 807-812.

Cloern, J.E., 2001. Our evolving conceptual model of the coastal eutrophication problem. *Mar. Ecol. Prog. Ser.* 210, 223-253.

Dalal, S.G.Bhargava, R.M.S. Relationship between chlorophyll-a and column primary production. 1986. *Mahasagar,* vol.19, 61-63.

Das, S.K., 2002. Primary production and zooplankton biodiversity in brakish water shrimp culture pond. *J. Ecobio*. 14(4), 267 - 271

Das, S. and Sahu, B.K. 2001. Biochemical composition and calorific content of fishes and shellfishes from Rushikulya Estuary, South Orissa coast of India. *Indian. J.Fisheries*, 48, 297-302.

Day, F., 1882. The food of Herring . *Zoologist*., 3(16), 268.

Deepulal, P.M, Gireesh Kumar, T. R, Sujatha, C. H., 2012. Behaviour of REEs in a tropical estuary and adjacent continental shelf of southwest coast of India: Evidence from anomalies, *J. Earth. system,* 121(5), 1215-1227.

Dell'Anno A, Mei, M.L., Pusceddu, A., Danovaro, R., 2002. Assessing the trophic state and eutrophication of coastal marine systems-a new

approach based on the biochemical composition of sediment organic matter. *Mar. Poll. Bull.* 44, 611-622.

Desai. B, N., Gajbbiye, S, N., Vijayalakshmi. R.Nair., 1983. Comparative account on zooplankton in polluted and unpolluted estuaries of Gujarat. *Mahasagar Bull*. NIO, 16(3), 281-291.

Devassy, V. P., Bhattathiri, P. M. A., 1974. Phytoplankton ecology of the Cochin backwater. *Ind J. Mar. Sci*. 3, 46-50.

Devasundaram, M.P., Roy, J.C., 1954. A preliminary study of plankton of the Chilka Lake for the year 1950-51. Symp. Marine and fresh water plankton in the Indo-Pacific. *Indo-Pacific.Fish.Counc.Publ*., 1-7.

Elskens, M., Baeyens, W., Goeyens, L., 1997. Contribution of nitrate to the uptake of nitrogen by phytoplankton in an ocean margin environment. *Hydrobiologia.,* 353, 139-152.

Eswari, Y, N, K., Ramani Bai, R., 2002. Distribution and abundance of phytoplankton in the estuarine waters of Chennai, South east coast of India. *J.Mar.Biol.Ass.India*., 49, 205-211.

Gao , X., Song , J., 2005. Phytoplankton distributions and their relationship with the environment in the Changjiang Estuary, China. *Mar. Poll. Bull*., 50, 327-335.

George, K .C; Dayanandan, M.G., Karunakran Nair., P., 1969. Food of some demersal fishes from the trawl ground of Cochin. *Indian .J. Fish.,* 15 (1&2), 56-74.

George, K.C., Dayanandan, M.G., Nair, P.K., 1968. Food of some demersal fishes from the trawl grounds off Cochin. *India.* J. *Fish,* 15, 81-87.

Gireeshkumar, T. R., Deepulal, P. M., Chandramohanakumar, N., 2013. Phosphorous speciation in surface sediments of the Cochin estuary *Environ. Monit Assess*. 185, 2535-2552.

Gireeshkumar, T.R., Deepulal, P.M., Chandramohanakumar, N., 2012. Phosphorous speciation in surface sediments of the Cochin estuary, *Environ .Monit.Assess*.,185(3), 2535-52.

Gopinathan, C.P., 1972. Seasonal abundance of the phytoplankton in the Cochin backwaters. *J. Mar. Biol. Ass. India*. 14 (2), 568-572.

Gopinathan, C.P., Nair, P.V.R., Kesavan Nair. A.K., 1974. Studies on the phytoplankton of the Cochin Backwaters, a tropical estuary. *Indian J. Fish*, 21(2), 501-503.

Godhantaraman, N., 2001. Seasonal variations in taxonomic composition, abundance and food web relationship of microzooplankton in estuarine and mangrove waters, Parangipettai region, Southeast coast of India. *Indian J. Mar. Sci*., 30, 151-160**.**

Gopalan, U.K., Meenashikunjamma, P.P., Purushan, K.S., 1980. Fungal infection in the tiger prawn (*Penaeus monodon*) and in other crustaceans from the Cochin backwaters. *Mahasagar* 13(4), 359-365.

Gopalan, U.K., Vengayil, Doyil, T., Udaya Varma, P., Krishnan Kutty, M., 1983. The shrinking backwaters of Kerala. *J. Marine Biol.Assoc. India,* 25, 131-141.

Gopinathan C.P., Nair, P.V.R., Kesavan Nair, A.K., 1974. Studies on the phytoplankton of the Cochin Backwaters, a tropical estuary. *Indian J. Fish*, 21(2), 501-503.

Gopinathan, C, P., 1975a. Studies on the estuarine diatoms of India, Cochin Backwaters during 1971-72. *Bull. Dept. Mar. Sci.Univ.* Cochin, 7, 791-799.

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., Rodrigo, J.X., Mohamed Kasim, H., Rajagopalan, M.S., 1994. Phytoplankton pigments in relation to primary production and nutrients in the inshore waters of Tuticorin, South East coast of India. *Indian J. Mar. Sci*. 23, 209-212.

Gopinathan Menon, N., Muthaih, C., 1987. Biology of important species of catfishes. CMFRI, Bulletin. 40, 60-69.

Gowda, G., Gupta, T.R.C., Rajesh, K.M., Gowda, H., Lingadhal, C., Ramesh, A.M., 2001. Seasonal distribution of phytoplankton in Nethravathi estuary, Mangalore. *J. Mar. Biol. Ass*. India, 43, 31-40.

Habib,O..A., Tippett, R., Murphy, K.J., 1997. Seasonal changes in phytoplankton community structure in relation to physicochemical factors in loch Lomond, Scotland. *Hydrobiologia*. 350, 63-79.

Haridas, P., Gopalamenon, Madhupratapakurup, M.. 1980. Annual variations in zooplankton from a polluted coastal environment. *Mahasagar Bull.* National Institute of Oceanography., 13, 239-248.

Havens, K.E., Elia, A., Taticchi, M., Fulton, R., 2009. Zooplankton–phytoplankton relationships in shallow subtropical versus temperate lakes Apopka (Florida, USA) and Trasimeno (Umbria, Italy). *Hydrobiologia* 628, 165-175.

Hobbie, J.E. (ed.) 2000. Estuarine science: the key to progress in coastal ecological research. In: *Estuarine Science: A Synthetic Approach to Research and Practice*, Island Press, Washington, DC. pp1- 11.

Horne, A. J., Goldman, C. R., 1994. *Limnology* , Second Edition. McGraw Hill, Inc. New York.

Huang, L, W., Jian, X., Song, X., Huang, S., Liu, P., Qian, K., Yin, M., and Wu., 2004. Species diversity and distribution for phytoplankton of the Pearl River estuary during rainy and dry seasons. *Mar. Poll. Bull*. 49,

Hynes, H.B.N., 1950. The food of the freshwater stickle-backs *(Gasterosteus aculeatus* and *Pygosteus pungitius)* with a review of methods used in the studies of the food of fishes. J. *Anim. Ecol.,* 19, 36-58.

Hyslop, E. J., 1980. Stomach content analysis-a review of methods and their applications. *J. Fish. Biol*., 17: 411-429.

Iyengar, M. O. P., Venkataraman, G., 1951. The ecology and seasonal succession of the algal flora of the river Cooum at Madras with special reference to the diatomaceae. *J. Mad.Univ*., 21, 140-192.

Jayalakshmi, K.V, Kumaran, S.,Vijayan, M., 1986. Phytoplankton distribution in Cochin back waters -A seasonal study. *Mahasagar,* 19 (1), 29-37.

Jhingran, V. G. 1977. Fish and fisheries of India. 3rd Edn. Hindustan publishing Corp. Delhi.

Joseph, J., Kurup, P. G., 1987. Tidal response and circulation of the Cochin estuary. *Proc. Natl. Sem*. Estuarine Management,Trivandrum: 88-92.

Joseph, K.J., Nair, P.V.R. 1975. Growth characteristics of certain estuarine phytoplankters. *Bull.Dept.Mar.Sci.Univ*. Cochin., 7, 151-159.

Joseph, K.J., Pillai, V.K. 1975. Seasonal and spatial distribution of phytoplankters in Cochin Backwaters. *Bull.Dept.Mar.Sci.Univ.*Cochin., 7,171-180.

Joseph, M. M, Ratheesh Kumar C. S, Gireesh Kumar T.R, Renjith, K.R, Chandramohanakumar, N., 2008. Biogeochemistry of surficial sediments in the intertidal systems of a tropical environment. *Chem. and Ecol.,* 24(4), 247-258.

Joseph., M. M., Ratheesh Kumar C. S., Renjith, K. R., Gireesh Kumar T. R., Chandramohanakumar, N., 2011. Phosphorus fractions in the surface sediments of three mangrove systems of southwest coast of India. *Environ Earth Sci*. 62, 1209-1218.

Joy, C.M., Balakrishnan, K.P., Joseph, A., 1990. Effect of industrial discharges in the ecology of phytoplankton production in the river Periyar (India). *Wat. Res*., 24, 787-796.

Jyothybabu, R., Madhu, N.V.Jayalakshmi, K.V., Balachandran,K.K., Shiyas, C.A., Martin G.D., Nair,K.K.C., 2006. Impact of Freshwater influx on microzooplankton mediated food web in a tropical estuary. (Cochin backwaters-India) *Est.Coast.Shelf.Sci*., 69, 505-518.

Kawabata, Z., Magendran., A., Palanichamy, S., Venugopalan V.K., Tatsukawa, R., 1993. Phytoplankton biomass and productivity of different size fractions in the Vellar estuarine system, southeast coast of India. *Indian J. Mar. Sci.,* 22,294-296.

Keast Allen., Deidrewebb., 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake ,Opinion, Ontaria . *J. Fish. Res. Bd.*Canada ., 23 (12), 1854-1874.

Kemp, W.M., Boynton, W.R., 1992. Benthic–pelagic interactions: nutrient and oxygen dynamics. In: Smith, D.E., Leffler, M., Mackiernan, G. (Eds.), Oxygen Dynamics in the Chesapeake Bay, A Synthesis of Recent Research. Maryland Sea Grant College, Maryland, pp 149-222.

Khan, M.A., Pauwar, R.S., Mathur. A., Rekha Jetly.,1998. Studies on plankton communities and primary production in middle stretch of river ganga in context of cultural eutrophication. *J. Inland fish Soc. India* 30(1), 47-68.

Khanna, D.R., Badola, S.P., Dobriyal, A.K., 1993. Plankton ecology of the river Ganga at Chadighat, Hardwar. (Ed. Singh, H.R.). In: *Advances in Limnology.* Narendra Publlishing House. 171 - 174.

Khanna, D.R., Malik, D.S .S., Badsla, P., 2000. Impact of aquatic environmental changes in river Ganga at haridwar. *Environment issues manage*ment. National conservation publication. 6, 133-146.

Kibirige,I., Perissinotto, R., 2003. *In situ* feeding rates and grazing impact of zooplankton in a South African temporarily open estuary. *Marine Biology,* 142,357.

Kideys, A.E., Soydemir, N.Eker, E., Vladymyrov, V., Soloviev, D., Melin, F., 2005. Phytoplankton distribution in Caspian Sea during March 2001. *Hydrobiologia*. 543 (1), 159-168.

Kratzer, C.R., Brezonik, P.L., 1981. A Carlson-type trophic state index for nitrogen in Florida lakes. *Water. Res. Bull.* 17, 713-715.

Kulkarni, V. A., Naidu, V. S., Jagtap, T. G., 2011. Marine ecological habitat: A case study on projected thermal power plant around Dharamtar creek, India *J. Environ. Biol*.32, 213-219.

Kumaran, S., 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.

Kurian, C. V., Damodaran, R., Antony, A., 1975. Bottom fauna of the Vembanad Lake. *Bull. Dept. Mar. Sci. Univ*. Cochin 7, 987- 994.

Kurup, B. M. 1982. Studies on the systematic and biology of the fishes of Vembanad lake, Ph. D. Thesis, University of Cochin.

Landenberger, D.E., 1968. Studies on selective feeding in the Pacific starfish Pisaster in southern California. *Ecology* 49, 1062-1075.

Madhu, N,V., Jyothibabu, R., Maheswaran, P. A., Gerson, V. J., Gopalakrishnan, T. C., 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.

Madhu, N.V., Jyothibabu, R., Balachandran, K.K., Honey, U.K.,Martin, G.D., Vijay, J.G., 2007. Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin Backwaters-India). *Est. Coast. Shelf Sci.,* 73, 54-64.

Madhupratap, M., 1987 .Status and strategy of zooplankton of tropical Indian estuaries: A review, *Bull. Plankt. Soci. Japan.,* 34, 65-81.

Madhupratap, M., Haridas, P., 1975. Composition and variation in the abundance of zooplankton of backwaters from Cochin to Alleppey . *Indian J. Mar. Sci*., 4, 77-85.

Malu, R. A., 2001. Phytoplankton diversity in Lonar Lake. *Env. Eco,* 19(1), 244-246.

Martin, G. D., Jyothibabu, R.,. Madhu, N. V., Balachandran, K. K., Maheswari Nair., Muraleedharan, K. R., Arun, P. K. , Haridevi, C. K., Revichandran, C., 2013. Impact of eutrophication on the occurrence of Trichodesmium in the Cochin backwaters, the largest estuary along the west coast of India, *Environ. Monit. Assess.*,185, 1237-1253.

Mathew, A., Balakrishnan Nair., 1976. Food and feeding habits and breeding biology of the Indian halibut, *Psettodus erumei*(Bl.Schn). *Aquatic Biol*., 4, 643- 644.

Mc. Comish, T.S., 1966. Food habits of big mouth and small mouth buffalo in Lewis and Clarke Lake and the Missouri river. *Trans Am. Fish. Soc*. 96, 70-74.

Menon, N.N., Balchand, A.N., Menon, N.R., 2000. Hydrobiology of the Cochin Back water system, A review, *Hydrobiologia*, 430,149-183.

Merriam-Webster., 1979. Webster's New Collegiate Dictionary, G and C Merriam Co., Springfield, MA.

Nair, P.V.R., Gopinathan, C.P., 1981. Productivity of the Exclusive Economic Zone of India. *J.Mar. Biol. Ass. India*. 23(1 &2), 48-54.

Nair, K. K.C ., Tranter, T.J., 1972. Zooplankton distribution along salinity gradient in the Cochin back waters before and after the monsoon. *J.Mar. Biol. Asso. India*, 13, 203-210.

Nair, P. V. R., Joseph, K. J., Balachandran, V. K., Pillai, V. K., 1975. A study on the primary production in the Vembanad Lake. Third All India symposium on the estuarine ecology, Cochin.

Nair, P.R., 1959. The marine planktonic diatoms of Trivandrum coast. *Bull. Cent. Res.Inst.* Univ. Kerala, 7, 1-63.

Nair,K. K. C., Sankaranarayanan, V. N., Gopalakrishnan, T.C., Balasubrahmanian T., Lalithambika Devi, C.B., Aravindakshan, P.N., Krishnankutty, M., 1988. Environmental condition of Some Paddy-cum-Prawn Culture Fields of Cochin Backwaters, Southwest coast of India. *Indian J. Mar Sci.,*.17, 24-30.

Nair,S.R., Nirmala, E Jalaja T.K., Nirmala Steephen, 1995. Impact of salinity on the planktonic communities of a fresh water riverine system with reference to Beypore estuary. *Proc. Nat. Sem, Environ.* Aspects of water. Resour. Develop. Manage TVM.III 63-65.

Nixon S. W., 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia.,* 41, 199-219.

Nozais, C., Perissinotto, R., Mundree, S., 2001. Annual cycle of microalgal biomass in a South African temporarily open estuary: nutrient versus light limitation. *Mar.Ecol.Prog.Ser*., 223, 39-48.

Padmakumar, K.G., 1987. Integrated farming system to combat aquatic pollution with special reference to Kuttanad, Kerala. *Proc.Sem.Env. Poll. Cons. of nature*. TVLA.

Palmer, C, M., 1969. A Composite rating of algae tolerating Organic pollution. *J. Phycol*., 5, 78.

Pandey, K.N., Prakash, V., Sharma U.P., 1995. Assessment of primary productivity of phytoplankton and macrophytes of Kawar lake wetland (Begusarai) Bihar. *J. Freshwater Biol*., 7, 237-239.

Perissinotto, D., Iacopetti, P., Bellina, I., Doliana, R., Colombatti, A., Pettway,Z., Bronner-Fraser, M., Shinomura, T., Kimata, K., Moergelin, M., Loeftberg, J., Perris, R., 2000. Neural crest cell migration is diversely governed by

permissive and nonpermissive hyaluronan-binding proteoglycans:PG-M/versicans and aggrecan..

Philippart, C.J.M., Anadón, R., Danovaro, R., Dippner, J.W., Drinkwater, K.F., Hawkins, S.J.,Oguz, T., O'Sullivan, G., Reid, P.C., 2007. Climate change impacts on the European marine and coastal environment-ecosystem approach. Position Paper of the Marine Board of the European Science Foundation, Strasbourg, France, 82.

Pillai, V. K ., Joseph, K. J., Nair, A., Kesavan, K., 1975. Plankton production in the Vembanad Lake and adjacent waters in relation to the environmental parameters. *Bull. Dept. Mar. Sci.*, 7 (1), 137-150.

Pillay, T. V. R., 1952. A critique of the methods of study of food of fishes. *J. Zool. Soc. India,* 4(2), 185-200.

Pritchard, D.W., 1967. Observations of circulation in coastal plain estuaries. *In* Estuaries (Lauff, G.H., ed.), American Association for the Advancement of Science, Publ. 83, Washington, DC. Pp 3-5.

Pylee, A., Varma, P.U., Revichandran, C., 1990. Some aspects of circulation and mixing in the lower reaches of the Periyar estuary, west coast of India.--*Indian J. Mar. Sci*. 19, 32-35.

Qasim, S. Z., 2003. *Indian Estuaries*. Allied Publishers, New Delhi.

Qasim,S.Z., Gopinathan, C.K., 1969. Organic production in a tropical estuary. Proc. Indian. *Acad. Sci (Anim. Sci*)., B 59,51-94

Raju Thomas, K., George, M. J., Biju, C. R., 2002. Freshwater fishes of Southern Kerala with notes on the distribution of endemic and endangered species. *J. Bombay Nat. Hist. Soc.,* 99(1), 47-53.

Rama Raju, P., Udaya Varma and Abraham, P.1979 Hydrographic characteristics and tidal prism at the Cochin harbour mouth. *Indian.J.Mar.Sci.,* 8: 78-84.

Ramanathan, N., Ramaiyan,V., Natarajan, R., 1975. On the interrelationships between the morphology of the alimentary tract and food and feeding habits of the flat fishes of Port Novo. *Bull.Dept.Mar.Sci.Uni.Cochin*., 7(3), 529 -536.

Ramdani, M., Elkhiati, N., Flower, R, J., Thompson, J, R., Chouba, L., Kraiem, M, M., Ayache, F., Ahmed, M, H., 2009. Environmental influences on the qualitative and quantitative composition of phytoplankton and zooplankton in North African coastal lagoons. *Hydrobiologia*., 622, 113-131.

Rasheed, K., Balchand, A.N., Joseph, K.G., Joseph, K.J., 2000. Photosynthetic pigments in relation to dredging in Cochin harbour area. *Indian J.Mar. Sci*., 29, 57-60.

Reddy,R.C.,.Kelkar, P.S., Rao, R.R., Pande, S.P., 2002. Eutrophic status of Hussain Sagar Lake, Hyderabad. *J.Inst.Engrs.India*.83, 14-22.

Renjith, K. R., Chandramohanakumar, N., Joseph, M. M., 2011. Fractionation and bioavailability of phosphorus in a tropical estuary, Southwest India. *Environ. Monitor. Assess.*, 174, 299–312.

Renjith, K. R., Manju Mary Joseph, Prosenjit Ghosh, Habeeb Rahman, K., Ratheesh Kumar, C. S., Chandramohanakumar N., 2012 Biogeochemical. Facsimile of the organic matter quality and trophic status of a micro-tidal tropical estuary, *Environ. Earth. Sci.* DOI 10.1007/s12665-012-2159-0.

Renjith, K.R., Varma, K.K., Haridevi, C.K., Houlath, K.H., Vijayakumar., Joseph, P., 2004. Primary production and fishery potential of the

Panagad region in the Cochin estuarine system. *J. Mar. BioI. Ass. India,* 46(2), 126-132.

Reynolds, C, S., 2006. The ecology of phytoplankton. Cambridge University press.

Rounsefell, A.G and Everhart, W.H., 1953. Fishery Science: its method and applications .John Wiley and sons, New York.

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

Salaskar P.B., Yeragi S.G., 2003. Seasonal fluctuations of plankton population correlated with physico-chemical factors in Powai Lake, Mumbai, Maharastra. *J. Aquat. Biol*. 18(1), 19 -22.

Sanilkumar., 2009. PhD Thesis. Cochin University of science and Technology, Kochi, India.

Sankaranarayanan, V.N., Quasim, S.Z., 1969. Nutrients of Cochin back water in relation to environmental characteristics. *Mar. Biol*.2 (3), 236-247.

Santra, S.C., Pal, V.C., Das, T.M., Sen, S., Saha,R., Datta, S., Dastdar,P.G., 1989. Phytoplankton of Bhabirathi- Hooly estuary. An illustarte account. Indian Biol., 21(1),1-27.

Sarala Devi, K., Venugopal, P., 1989. Benthos of Cochin backwaters receiving industrial effluents. Ind. J. Mar. Sci. 18, 165-169.

Saraladevi, K., Jayalakshmi, K.V., Venugopal, P., 1991. Distribution of nutrients in Periyar river estuary. *Indian J. Mar. Sci.*, 20(4), 141-145.

Sarno, D., Zingone, A., Saggiomo, V., Carrada, G.C., 1993. Phytoplankton biomass and species composition in a Mediterranean coastal lagoon, *Hydrobiologia* 271, 27- 40.

Sath TR, Khanna D.R., Gautam Ashutosh, Chugh Tarun, Sarkar Praveen. 2000. Temporal trends of phytoplanktonic diversity in the river Ganga at Haridwar. *Himalayan J. Env. Zoo*, 14(2), 129-134.

Selvaraj, G. et al. (2000). Ecology Based Fishery Management in Thirumoorthy Reservoir. *CMFRI Bull*., 95: 42.

Selvaraj, G., Kumaraguru, A.K., 1997. Primary productivity of kalivuneer pond and thamarikulam pond in Uthamapalayam taluk. Madurai district, Tamilnadu. *Ecol.Environ .Cons*., 3(2), 75-78.

Selvaraj, G., Thomas, S.D., Khambadkar, L.R., 2003. Seasonal variation of phytoplankton and productivity in the surf zone and Backwaters at Cochin. *J. Mar. Biol. Ass. India*, 45, 9-19.

Sewell, R.B.S., 1934. A study of the fauna of the salt lakes of Calcutta. Rec. *Indian Mus*., 36, 45-121.

Sewell,R.B.S., 1924 Fauna of the Chilka Lake. Crustacea Copepoda. Mem. *Indian Mus*., 5, 771-851.

Sharma, B. K., 2000a. Synecology of Rotifers in a tropical floodplain lake of UpperAssam (NE India). *Indian J. Anim. Sci*.,70, 880-885.

Sharma, B. K., 2000b. Rotifers from some tropical floodplain lake of Upper Assam (NE India). *Tropical ecology*. 41 (2), 175-181.

Sharma, B.K., 2005. Rotifer communities of floodplain lakes of Brahmaputra basin of lower Assam (NE India) biodiversity, distribution and ecology. *Hydrobiologia.* 533, 209-221.

Shearer, K.D., Asgard, T., Andorsdottir, G., Aas, G.H., 1994. Whole body elemental and proximate composition of Atlantic salmon (Salmo salar) during the life cycle. *J. Fish Biol*.44, 785-797.

Sheeba,S., 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.

Shynamma C.S., Balakrishnan, K.P., 1973. Diurnal variation of some physic-chemical factors in Cochin backwater during southwest monsoon. *Ind. J. Mar. Sci*., 15, 391-398.

Singh, D.N., 1990. Diurnal vertical migration of plankton in M C Pherson Lake. Allahabad. *Proc.Natn.Acad.Sci.India*.6, 141-147.

Sinha, G.M., Pal, P.C., 1990. Seasonal variation in protein, lipid and carbohydrate contents of ovary, liver and body muscle in relation to gonado-somatic index and oogenesis of *Clarias batrachus* (Linn.). Impacts of Environment on Animal and Aquaculture, 45, 107-112.

Steemann Nielsen, E. 1959. Primary production in tropical marine areas *J.Mar.Biol.Ass.India*., 1, 7-12.

Stoermer, E, F., Yang, J, J., 1969. Plankton Diatom Assemblages in Lake Michigan Ann Arbor.

Sujatha, C.H, Nify Benny, Renjitha Raveendran, Fanimol, C.L., Samantha, N.K., 2009 Nutrient Dynamics in the two lakes of Kerala, *Indian J. Mar. Sci.,* 38(4),451-456.

Sukumaran, P.K., Das, A. K., 2004. Distribution and abundance of rotifers in relation to water quality of some tropical reservoirs. *Indian J. Fish*., 51 (3), 295-301.

Sunny, K. G, 1976. Studies on the Morphology, Biology and Development of the Mullets of Kerala. PhD Thesis. Thesis, Cochin University of Science and Technology, Kochi, India.

Suseelan, C., Somasekharan Nair, K.V., 1967 -69. Food and feeding habits of the demersal fishes of Bombay. *Indian .J.Fish*., 16(1-2), 56-74.

Talwar, P. K., 1962. A contribution to the biology of the halfbeak, *Hyporhamphus georgii* (Cuv. & Val.) (Hemirhamphidae) [*sic*]. *Indian J. Fish.*, 9, 168-196.

Tan, Y., Huang, L., Chen, Q., Huang, X., 2004. Seasonal variation in zooplankton composition and grazing impact on phytoplankton standing stock in the Pearl River estuary, China. *Cont. Shelf. Res*., 24, 1949-1968.

Thangaraj,G.S., 1984. Ecobiology of the marine zone of the velar estuary, Ph.D thesis, Annamalai University.

Thomas, J.D., 1962. The food and growth of the brown trout (Salmo trutta L) and eel (*Anguilla anguilla* L) in the river Telfi , West Wales *J. Anim. Ecol*., 31, 175-205.

Thresiama Mathew., Balakrishnan Nair, N., 1980. On the Planktonic diatoms of Vizhinjam coast. *Mahasagar.*, 13, 367-369.

Tiwari, M., Bjorndal, K. A., Bolten, A. B., Moumni. A., 2002. Morocco and Western Sahara: sites of an early neritic stage in the life history of loggerheads Page 9 *in* A. Mosier, A Folley, and B. Brost, compilers. Proceedings of the Twentieth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-477.

Torreele , E., Verreth ,J.A.., Spazier, J., Sluiszen, A., Vander; Rombout, J.H. W.M; Booms ,R., Segner, H ., 1992. The development of a functional

digestive system in the African cat fish *Clarius garipinus* (Burchell). *J World. Aquacult. Soc.,* 23(4), 286-298.

Toumi, Neji et al. 2005. Zooplankton Distribution in Four Ponds of Different Salinity: a Seasonal Study in the Solar Salterns of Sfax (Tunisia). *Hydrobiologia*., 534, 1-9.

Unnithan, R. V., Vijayan, M., Remani, K. N., 1975. Organic pollution in Cochin backwaters. *Indian J. Mar. Sci.,* 4, 39 - 42.

Unnithan, R. V., Vijayan, M., Radhakrishnan , E. V., Remani, K. N., 1977. Incidence of fish mortality from industrial pollution in Cochin backwaters. *Ind. J. Mar. Sci*., 6, 81-83.

Uthoff, D., 1996. From traditional use to total destruction forms and extent of economic utilization in the Southeast Asian mangroves. *Nat. Resour*. *Dev*., 43-44, 58-97.

Vareethiah, K., Haniffa, M.A., 1998. Phytoplankton indicators of coir retting pollution. *J. Env. Poll*., 5(2), 117-122.

Varshney .P.K., Vijayalakshmi, K.G., Nair ., Desai, B.N., 1982. Biological productivity and fishery potential in the coastal waters of Bombay. *J. Ind. Fish. Ass.,* Bombay; 12B, 35-43.

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

Venkataraman, G. 1960. *Indian. J. Fish.,* 7 (I & 2), 275-306.

Venkateswaralu, V., Sudhakar, G., Jyothi, B., 1994. Role of diatoms as indicators of pollution gradients. *Environ.Monit . Assess*. 33(2), 85-99.

Verity, P., Borkman, D., 2010. A decade of change in the Skidaway River Estuary. III. Plankton. *Estuar. Coast.* 33**,** 513-540.

Vibrickas,T., 1998. Regularities of changes in the production of fish populations and communities in Lithuanian rivers of different types. *Acta.Zool.litu. Hydrobiol.,* 8(4), 1-65.

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

Wasidewska, E.S., 1992. Relationship between phytoplankton and abiotic elements in a dam reservoir. *Acta hydrobiol*.34 (4), 341-356.

Webber, M. K., Roff, J. C., Chisholm L. A., Clarke, C., 1996. Zooplankton distributions and community structure in an area of the South Coast Shelf of Jamaica. *Bull Mar. Sci.,* 59, 259-270.

Whitefield, A.K., Blaber, S.J.M., 1978. Food and feeding ecology of piscivorous fishes at lake St.Lucia, Zululand. *J. Fish. Biol.,* 675-691.

Williams, A. E., Moss, B., 2003. Effects of different fish species and biomass on plankton interactions in a shallow lake. *Hydrobiol.*, 49, 331-346.

Yahiya, N.M.D., Sami Souissi., Ons daly yahia-Kefi, 2004. Spatial and temporal structure of planktonic copepoda in the bay of Tunis (southwestern Meditteranian Sea). Zoological studies, 43 (2), 366-375.

Yalavarthi Eswari., 2002. Hydrobiological studies at red hills resrvoir, north Chennai, Tamilnadu. *J.Aquatic Bio*.17 (1), 13-16.

Young, A., Britton, G., 1993. Carotenoids in Photosynthesis. Chapman & Hall, London.

Chapter 2

MATERIALS AND METHODS

Contents

2.1 Description of the study area

Vembanad Kol Wetland was included in the list of wetlands of international importance, as defined by the Ramsar Convention for the conservation and sustainable utilization of wetlands. It is a home to more than 20,000 waterfowls and serves as an ideal habitat for shrimps. Major livelihood activities of the people living on the shores of the lake include: agriculture, fishing, tourism, inland navigation, coir retting and lime shell collection. Uncontrolled mining of shells from the lakebed is also posing a threat to the ecosystem. Vembanad Lake extends from Alappuzha in the south to Azheekode in the north. This wetland system covers an area of over 2033.02 km². The lake is fed by 10 rivers flowing into it including the six major rivers of central Kerala namely: Achenkovil, Manimala,

Meenachil, Muvattupuzha, Pamba and Periyar. There are three islands located in the lake viz., Pathiramanal, Perumbalam and Pallippuram. River Periyar evacuates into the Cochin backwater system in the north and Muvattupuzha River in the central part.

Cochin backwater system situated at the tip of the northern Vembanad lake is regarded as a positive tropical estuary located between 9^{o} 14' to 10^{o} 12'N and $76^{o}10$ to 76^{o} 36'E with its northern boundary at Azheekode and southern boundary at Thannermukkom bund. The estuary has a length of 80 km and width varies from 500 to 4000m. It has been regarded as the second largest estuarine system in India, fed by six rivers with fresh water discharge of about 291,010 m^3 per year (Srinivas et al., 2003). It is permanently connected to Arabian Sea by 450 m wide channel at the bar mouth. There are three seasonal conditions prevailing in the estuary viz., pre monsoon (PRE), monsoon (MON) and post monsoon (POM). During premonsoon season (February-May), warm climate prevails over the coast, runoff is least and the estuary is predominantly marine in nature. The environment is more or less stable, well mixed and homogenous water mass is present. This estuary is under the profound influence of monsoon (June - September). It has been reported that about 71% of annual rainfall is contributed by monsoon (Jayaprakash, 2002). Hydrobiological studies (Menon et al., 2000) revealed that the high flushing during monsoon completely transforms the estuary into a freshwater habitat. Postmonsoon (October-January) is generally the stabilization period and is characterized by diminished river discharge and tides gradually gain momentum as the estuarine condition change to partially mixed type.

The rapid industrialization and the increase in population around the Cochin estuary have resulted in the discharge of a heavy load of the inorganic and organic wastes. The pollutants of greatest concern in the estuarine ecosystem are those which are persistent, such as toxic heavy metals, insecticides and pesticides. Organic materials such as domestic sewage and food processing wastes are rapidly decomposed and often enrich the elements essential for plant nutrition and productivity. Pollutants from industrial units like the Fertilizers and Chemicals Travancore Limited (FACT), Indian Rare Earths (IRE), Hindusthan News Print Factory, Hindusthan Organic Chemicals (HOCL), BPCL-Kochi refinery and Cochin Port area (handling large quantities of sulphur, crude oil and other petroleum products) find their way to this backwater system. Domestic sewage channels, coconut husk retting yards also contribute huge loads of organic matter and nutrients into the water body every year (Stephen, 1985).

2.2 Sampling and analytical methodology

Seasonal samplings of water, sediments and fish landings were carried out from the fifteen selected stations (S1 to S15) (figure 2.1) spread across Cochin backwater system. The samples were collected in five sampling campaigns that were scheduled during January 2009, April 2009, August 2009, January 2010 and April 2010, representing three seasons (premonsoon, monsoon and postmonsoon). Water samples (both surface and bottom layers) were collected using Niskin Sampler and surface sediment samples were taken using Van Veen Grab. Water samples for general hydrography and nutrient analysis was subsampled into high density polyethylene bottles, kept on ice bags transported to laboratory and analysed without delay.

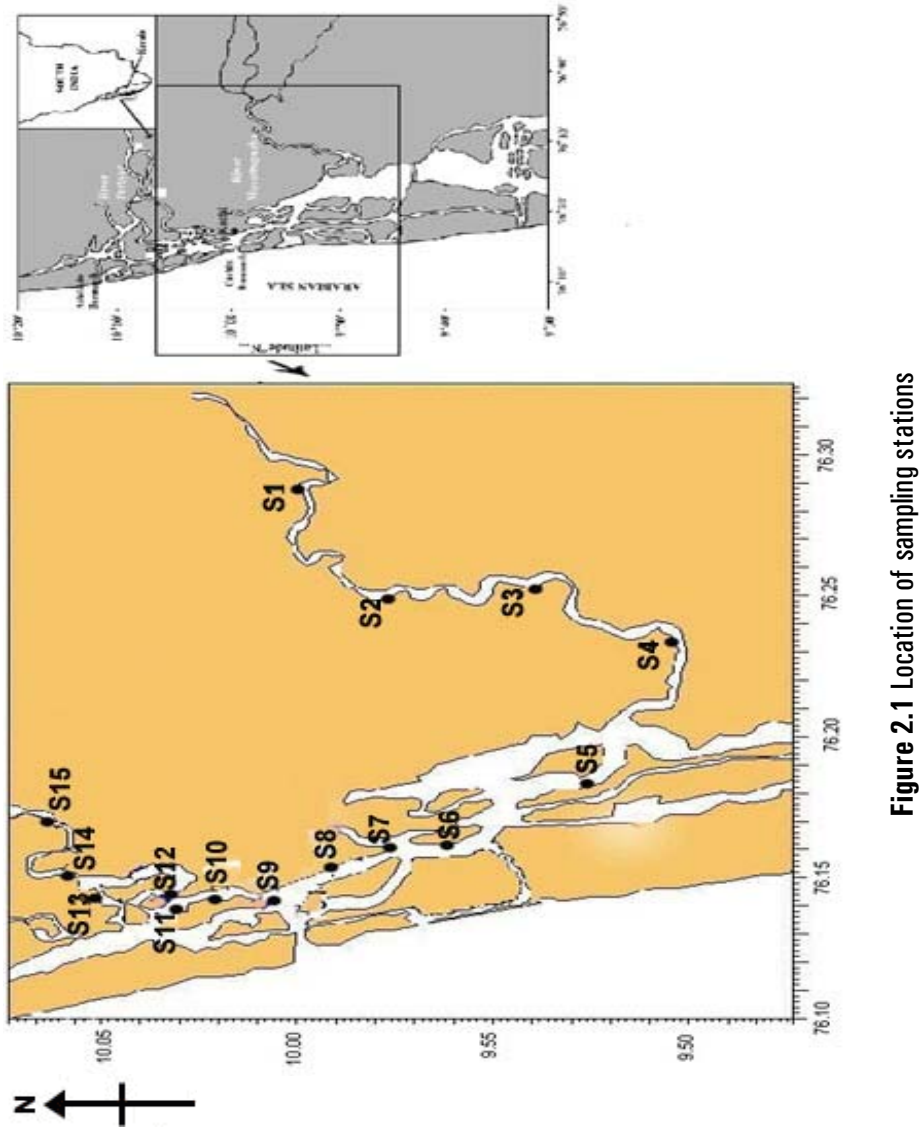


Figure 2.1 Location of sampling stations

Table 2.1 General features of sampling stations

Station Code	Place	Average Depth (m)	Latitude	Longitude	Description
S1	Karippadam	4.3	9⁰47.646'N	076⁰ 25.708'E	Thickly populated area with outflow of domestic wastes
S2	Murinjapuzha Enadi	4.4	9⁰ 47.887'N	076⁰ 24.607'E	Disposal of domestic wastes
S3	Murinjapuzha Brahmamangalam	4.9	9⁰ 48.495'N	076⁰ 24.019'E	Disposal of domestic wastes
S4	Murinjapuzha	4.6	9⁰ 49.508'N	076⁰ 23.359'E	Disposal of domestic wastes
S5	Perumbalam	3.2	9⁰ 49.793'N	076⁰ 21.430'E	Disposal of Domestic and fish processing wastes
S6	Aroor-Kumbalam	5.6	9⁰ 53.105'N	076⁰ 18.409'E	Fishing and processing unit operations
S7	Thevara Bridge	2.7	9⁰ 55.070'N	076⁰ 18.253'E	Sewage Outfall
S8	Marine Science Jetty	3.3	9⁰ 57.77'N	076⁰ 16.919'E	Sulphur Jetty input and sewage.Industrial pollution
S9	Bolgatty	2.5	9⁰ 59.213'N	076⁰ 16.084'E	Inland navigation and other tourism operations -waste disposal
S10	Mulavukad	2.2	10⁰ 01.857'N	076⁰ 15.789'E	Disposal of domestic sewages and fish wastes
S11	Chenoor	1.9	10⁰ 03.255'N	076⁰ 16.043'E	Domestic sewages out fall
S12	Cheranellur	2.1	10⁰ 03.999'N	076⁰ 16.924'E	Disposal of domestic sewage and wastes
S13	Eloor	4.4	10⁰ 05.656'N	076⁰ 17.049'E	Industrial Belt
S14	Edayar	2.5	10⁰ 05.502'N	076⁰ 17.744'E	Industrial Belt
S15	FACT-Kalamassery	2.8	10⁰ 04.993'N	076⁰ 17.906'E	Industrial Belt

2.2.1 General hydrographic parameters

Hydrographic parameters such as pH, dissolved oxygen, carbon dioxide, temperature, salinity, alkalinity, hardness, rainfall, depth and transparency were determined. Nutrients like nitrite-N, nitrate-N, ammonia-N, phosphate, silicate, iron were also estimated in the water samples.

Rainfall data were obtained from the meteorological Centre, Trivandrum (Govt. of India). Tide data was collected from Cochin Port Trust (Govt. of India). Measurement of transparency of water column was carried out with Secchi disc and extinction coefficient was calculated using the formula (Michael, 1984).

Extinction Coefficient= 1.7/depth in meters

pH measurements of water samples were made using a portable pH meter (Perkin Elmer, accuracy, ± 0. 01). Temperature was measured using a precision mercury thermometer graduated from 0-50^{o} C with accuracy of ±0.01^{o}C. Immediately after collecting the water sample in a narrow mouthed polyethylene bottle, the thermometer was introduced into the water column upto 5 cm. Salinity was estimated by Mohr- Knudsen method (Muller, 1999). Modified Winkler method was used for the estimation of dissolved oxygen (Hansen, 1999). Free CO_2 was determined with NaOH reagent and phenolphthalein indicator (Golterman et al., 1978). Alkalinity of the water samples were estimated by the method of Koroleff (Anderson et al., 1999). Five day biochemical oxygen demand test (BOD_5) employed for determination of BOD values of water samples (APHA, 1995). The dissolved oxygen in sample was determined before and after 5 days of incubation.

2.2.2 Estimation of nutrients in water column.

Nutrients (nitrite, nitrate, phosphate and silicate) were estimated spectophotometrically using standard methods.

Nitrite

NO_2^- was estimated using the standard procedure suggested by Grasshoff et al., (1999) in which the nitrite formed an azodye with

sulphanilamide and N-1 naphthyl ethylene diamine dihydrochloride. The spectrophotometric determination was done using UV-Vis spectrophotometer (Genesys 10 UV- Thermospectronic).

Nitrate

NO_3^- was reduced to NO_2^- using copper coated cadmium granules and determined as nitrite as outlined above (Grasshoff et al., 1999).

Dissolved inorganic phosphate

All methods for the determination of dissolved inorganic phosphate in water samples is based on the reaction of the ions with an acidified molybdate reagent to yield a phosphomolybdate heteropoly acid, which is then reduced to a intense blue coloured compound (Grasshoff et al., 1999). A known volume of sample was treated with mixed reagent and acidified ascorbic acid and the absorbance of the resulting blue complex was measured at 880nm using spectrophotometer.

Silicate

The determination of dissolved silicon compounds in natural waters is based on the formation of a yellow silicomolybdic acid when an acid sample is treated with a molybdate solution. This complex was reduced with ascorbic acid and absorbance was measured at 880nm (Grasshoff et al., 1999).

Iron

Water samples were preconcentrated according to Grasshoff et al., (1999); concentration of iron was estimated by Atomic absorption spectrometer (Perkin Elmer 3110).

2.2.3 General sediment characteristics

Each sample were transferred to polythene bottles using a plastic spatula and made airtight and taken to the laboratory for the further analysis under ice-cold storage conditions. Approximately, 200 g of sediment from each sample was dried in Freeze drier equipment (Beetta instruments and equipments, Chennai). Dried sediments were homogenized using a mortar and pestle, sieved through a 230 mesh sieve and used for the analysis of total organic carbon, CHNS analysis, nutrients and biochemical composition.

pH of the fresh wet sediments was measured in situ using a potable pH meter calibrated with buffer solutions. Redox potential of the fresh wet sediment was measured in situ using a portable E^h meter employing Zobell's solution for the calibration of the electrodes (Brassard, 1997).

Texture analysis of sediments

The textural characteristics of the sediments were determined by pipette analysis (Folk 1980), after removing the inorganic carbonates using 10% HCl and organic matter using H_2O_2. Sediment was wet sieved through a 63-μm sieve to collect the sand fraction. The mud fraction was divided into silt (63-4 μm) and clay (<4 μm) fractions by timed gravimetric extraction of the dispersed sediments.

Total Organic Carbon

Total organic carbon (TOC) was also determined using a CHN analyzer after removing the inorganic carbon with 1 N HCl (Tung and Tanner, 2003).

Total Organic Matter (TOM)

TOM was obtained by multiplying the Total organic carbon values with 1.724 (Nelson et al., 1996).

2.2.4 Fractionation of nitrogen in sediments

The analyses of nitrite, nitrate and ammonia were carried out by the "KCl equilibrium extraction method" (Agemian, 1997) which involves shaking of the sediment sample with a solution of KCl (2N) at room temperature for a period of one hour followed by filtration using standard filtration equipment and Whatman 42 filter paper. The filtrate containing nitrogen in the dissolved state was stored at 4^{o}C until analysis. From the filtrate the nitrite, nitrate, ammonia and were quantitatively estimated by spectrophotometric analyses as described earlier. Total nitrogen in sediments was determined by the following procedure. Sediment samples were digested in sulphuric acid in the presence of potassium sulphate and copper sulphate catalyst (Agemian, 1997). Organic compounds of nitrogen as well as free inorganic forms were thus converted to ammonium ions which were determined spectrophotometrically using indophenol blue method. Total nitrogen was estimated by CHNS analyser (Vario EL III CHNS Analyzer.).

2.2.5 Fractionation of phosphorous in sediments

The sequential extraction scheme by Golterman, (1996) using chelating agents was employed for estimating different phosphorus fractions (figure 2.2). Compared with the other methods, chelating agents allow a specific extraction of inorganic phosphorus with less destruction of organic phosphorus (Golterman, 1996). Iron bound phosphorus (Fe-IP) was extracted with buffered Ca-EDTA/dithionite and calcium bound fraction (Ca-IP) subsequently with Na-EDTA. In the next step, acid soluble organic phosphorus (ASOP) was extracted with H_2SO_4 and then alkali soluble organic

phosphorus (Alk-OP) with 2M NaOH at 90°C for 2 hours. Residual organic phosphorous (ROP) was measured after 1 hour $K_2S_2O_8$ digestion in acid medium. All the extractions were carried out under mild continuous shaking and the results are expressed on the dry weight basis. Generally, iron and calcium bound inorganic fractions and acid soluble organic fractions of phosphorous are considered to be bioavailable (Diaz-Espejo et al., 1999).

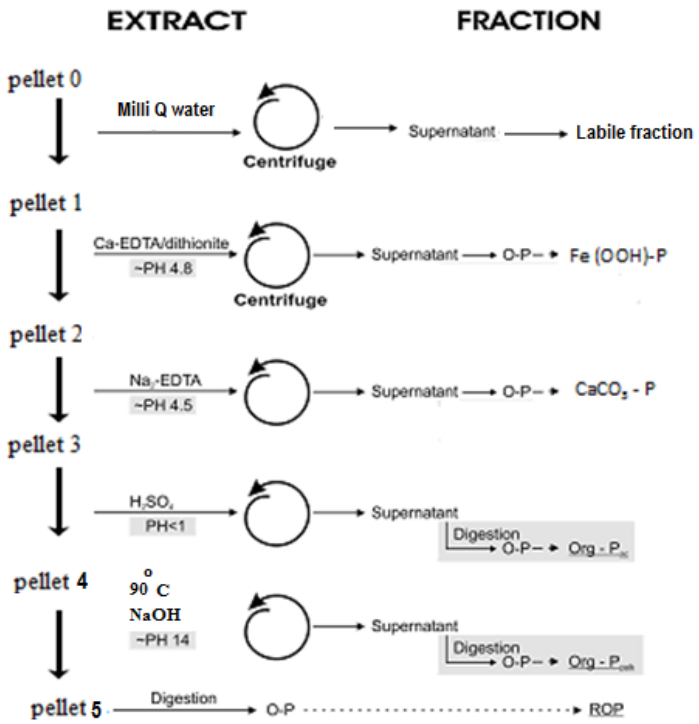


Figure 2.2 Sequential extraction scheme for phosphorus fractionation

2.2.6 Biochemical composition of sediments

Spectrophotometric methods were employed for the determination of biochemical compounds in sediments. Proteins (PRT) analyses were carried out following the procedure of Lowry et al., (1951), as modified by Rice, (1982) to account for the reactivity of phenolic compounds, with albumin as the standard. The amount of protein nitrogen was obtained by

multiplying protein with a factor of 0.16 (Mayer et al., 1986). Total carbohydrates (CHO) were analyzed according to Dubois et al., (1956), using glucose as the standard. Total lipids (LPD) were extracted according to Bligh and Dyer (1959), and estimated according to Barnes and Blackstock, (1973) using Cholesterol as the standard. All the analyses were carried out in triplicates and the average value was reported. The sum of all PRT, CHO and LPD was defined as the labile or easily assimilable organic fraction (Danovaro et al., 1993; Cividanes et al., 2002). Tannin and lignin in sediments were extracted using 0.05M NaOH at 60^{o} for 90 minutes and the estimated spectrophotometrically by the sodium tungstate-phosphomolybdic acid method (Nair et al., 1989; APHA, 1995), using tannic acid as the standard. The principle involved is the development of a blue colour on reduction of Folin phenol reagent by the aromatic hydroxyl groups present in tannins and lignins. The effects of Mg and Ca hydroxides and/or bicarbonates present in the seawater were suppressed by the addition of trisodium citrate solution (Nair et al., 1989). Chlorophyll pigments in sediments were determined spectrophotometrically after extracting with 90 % acetone according to (Lorenzen, 1967; APHA, 1995)

2.2.7 Primary Production

Plankton sampling and Enumeration

The procedure adopted in the present study was phytoplankton count based on Phytoplankton Identification Manual [Fritsch, (1935); Prescott, (1969); Santhanam et et al., (1975); Verlencar and Somshekar Desai, (2004); Mitra et al., (2006); Dona et al., (2004)]. Photographs of the identified phytoplanktons in the study area are shown in figure 2.3. Phytoplankton production and distribution were examined over a period of 15 months for phytoplankton ecology from 15 sampling stations. In order

to prevent the decay of the samples the fixation and preservation was carried out. The preserved samples are immediately stored in the high quality polyethylene bottles and neatly labeled. The labeling specifies the date, time, location of the station and type of gear used. Record was kept for cells in good or vigorous condition and those in the poor condition. Water samples were collected using Niskin sampler and 50L of water was filtered through phytoplankton net of 20µm mesh size made of bolting silk. The filtrate was preserved in 4% neutralized formaldehyde/Lugol's iodine solution. The buffered formalin was prepared by adding 30gm Borax b (Sodium tetraborate) into 1L formalin. The pH of the preserving medium was maintained at about 8.2. The preservation was done onboard immediately after collection. Quantitative analysis was done employing Sedgewick-Rafter cell. A settling and siphoning procedure was followed to concentrate samples from 250 ml to 10 ml (Utermohl, 1958). Species identification was done using a Nikon E200 light microscope. For counting phytoplankton cells and identification of genera and species, two 1ml replicates of concentrated samples were transferred into Sedge-wick-rafter cell and examined microscopically at 200x magnification; the whole slide (1000 fields) was counted for diatoms, dinoflagellates and silicoflagellates. For analyzing phytoplankton cell counts and composition, water samples from each depth were fixed in Lugol's iodine (1% w/v) and 3% formaldehyde and stored in dark until taken up for analyses. The number of phytoplankton present in all the grids was calculated. The total number of plankton present in 1 L of water sample was calculated using the formula.

$$N = (n*v*1000)/V$$

Where, N = number of phytoplankton per Litre of water filtered

n = average number of phytoplankton in 1ml of plankton sample

v = volume of plankton concentrate in 1ml

V = total volume of water filtered in Litre

Paediastrum duplex

Lyngbya sp.

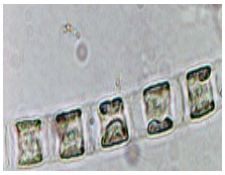
Anabaena sp.

Ceratium lineatum

Staurastrum sp.

Oscillatoria sp.

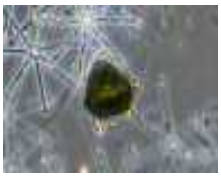
Fragillaria sp.



Ulothrix sp.

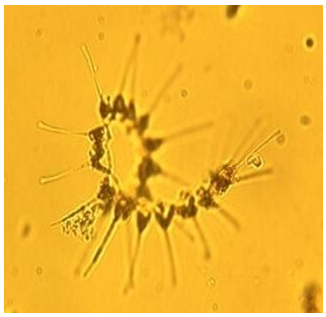
Skeletonema costatum

Stephanodiscus sp.

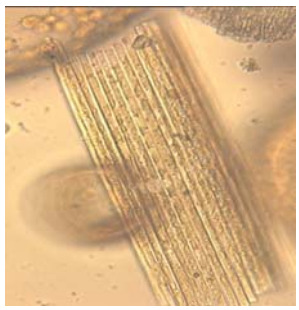


Peridinium limbatum

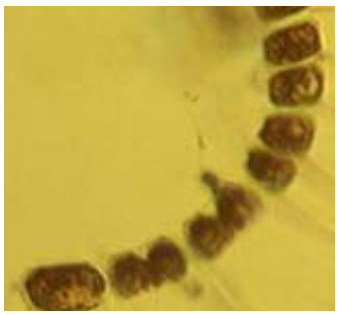
Synedra sp.



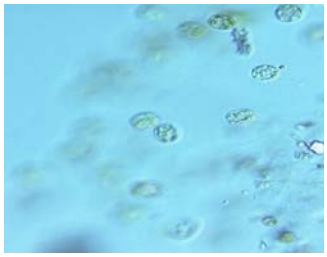
Asterionellopsis sp.



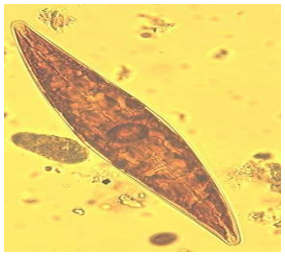
Bacillaria paxilifer



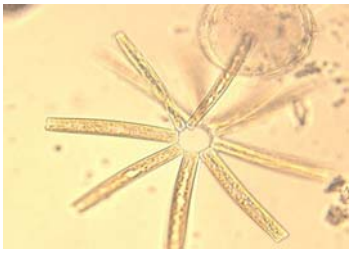
Chaetoceros sp.



Thalassiosira subtilis

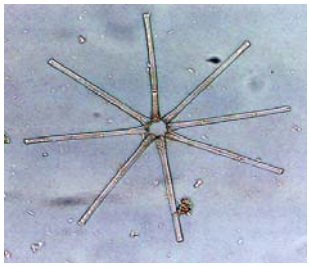


Pleurosigma sp.

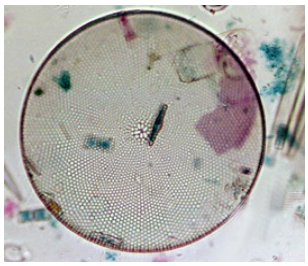


Thalassionema nitzschioides

Figure 2.3 (continued……..)



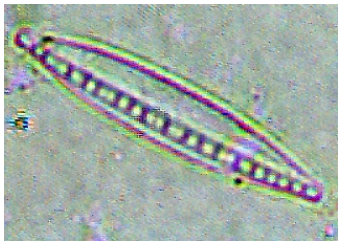
Asterionella sp.



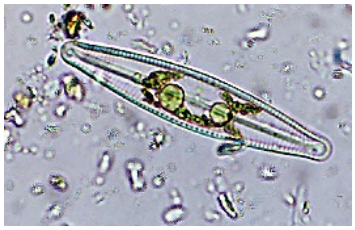
Coscinodiscus sp.

Gyrosigma sp.

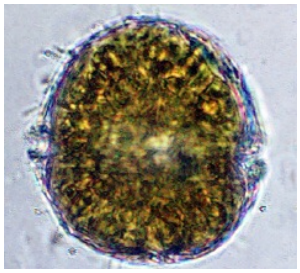
Melosira sp.



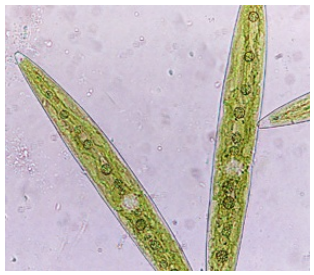
Nitzschia sp.



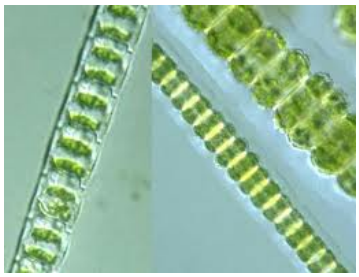
Navicula sp.



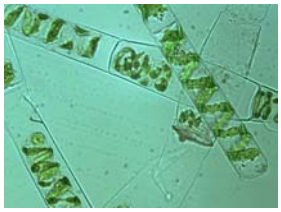
Peridinium sp.



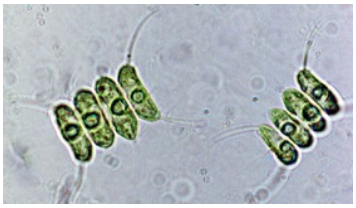
Closterium sp.



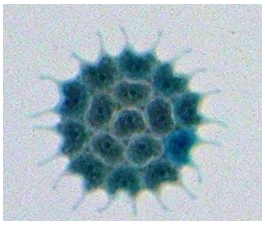
Desmidium sp.



Spirogyra sp.



Scenedesmus sp.

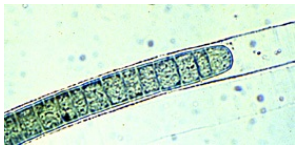


Pediastrum sp.

Anabaena sp.

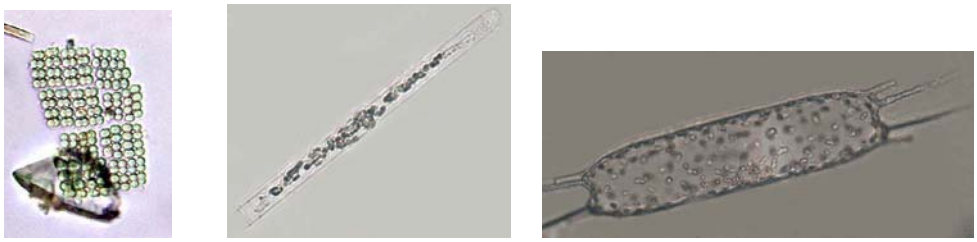
Nostoc colony

Oscillatoria sp.



Phormidium sp.

Figure 2.3 (continued……..)



Merismopedia sp. *Ceratulina* sp. *Biddulphia* sp.

Figure 2.3 Photographs of various phytoplankton species identified in the study area

Phytoplankton pigments

Determination of quantitative variation of phytoplankton pigments was done by spectrophotometric analysis (APHA, 1995). The chlorophyll a, chlorophyll b and pheophytin content of the extracts were determined by measuring optical density (APHA, 1995) using spectrophotometer. For the estimation of chlorophyll, the water sample was filtered through GF/C glass fibre filter paper, using a filtration apparatus fitted with vacuum pump. A thin bed of magnesium carbonate ($MgCO_3$) was applied to the filter paper. The filter paper containing the pigments were transferred to a clean beaker and added 5ml of 90% acetone, and the beaker was wrapped with aluminium foil, kept overnight at 4^oC in a refrigerator. The contents were macerated and made up the extract solution to 10ml .The absorbance at wave lengths of 750, 665, 645, 630 and 450 nm of the resulting acetone. Pheopigments were measured by adding 2 drops of 0.5N HCl to the same sample and measurement of absorbance were performed at wavelengths 750nm and 665 nm. For the estimation of carotenoids, the above procedure was followed and the absorbance of the pigment extract was measured at wave lengths 510 and 480nm.

Estimation of primary productivity

Light and dark bottle method (APHA, 1995) was used for the estimation of primary productivity. The "Winkler" method of determining dissolved oxygen is normally used in the 'light and dark bottle' technique for studying production rates.

2.2.8 Secondary Production

Zooplankton

The samples were taken from subsurface water using standard net having mouth area $0.07m^{2,}$,70 cm long. Maximum samples were collected at the cod end collecting tube. The sample which remained on the wall of the net was washed with water and transferred into the preservation bottles. The mesh size of 0.2mm of monofilament nylon is usually used for collecting zooplankton for taxonomic and productivity studies. In addition to the mesh size, the type, length and mouth area of the net, towing speed, time of collection and type of haul will determine the quality and quantity of zooplankton collected. The zooplankton collections can be made by horizontal, oblique and vertical hauls. In the horizontal sampling the net is towed at a slow speed usually for 10 minutes. The towing speed of the net should be such that the maximum amount of water enters through the mouth of the net for better filtration and gear used can withstand the strain. After fixation, the zooplankton are transferred and stored in airtight containers with sufficient quantity of preservative. While transferring, due care should be taken so that no part of the zooplankton sample is lost. The counting should be done under the microscope using Sedge wick rafter cell and when the specimen of a particular group is seen, a tally mark is made on the sheet. Zooplankton sampling and analysis were done following the

standard method (UNESCO, 1968; IOBC, 1969). Samples were preserved in 5% formalin (Goswami, 2004). Analysis of the zooplankton samples was done by group wise sorting. At first sub sampling was done after centrifuging the settled samples and the numerical abundance of each group in the entire 15 stations was computed and recorded.

2.2.9 Teritiary production

Fish Landing Centres

Data of fish landings of economically important food fishes adjacent to the sampling locations sited below were assessed seasonally from the following landing centres by stock assessment made through vendors.

1. Ernakulam market
2. Champakkkara, Aroor
3. Chempu
4. Vaikom
5. Vypin
6. Varappuzha Jetty
7. Perumbalam

Gut content Analysis

The study of the feeding habits of fish and other animals based upon analysis of stomach content has become a standard practice (Hyslop, 1980). The specimens for gut content analysis were obtained from the respective sites during the sampling period. The fishes were brought to the laboratory, the specimens were dissected and their stomachs were dissected and their stomachs removed and preserved in specimen bottles containing 4% formalin. In the laboratory, total weights of the stomachs and stomach

contents were determined. Some of the stomachs were used to study food composition and selection. The stomachs were dissected and the content emptied into a petridish and they were washed well in 10 ml of water. The larger invertebtates such as chironomids and oligochaets, larvae were isolated counted and weighed. The rest of the material which constituted of detritus and plankton was thoroughly mixed with 10 ml of water in a beaker. A subsample was pipette out in a Sedgewick rafter cell which carries a volume of 1ml. The food items were then enumerated under a compound microscope. The analysis was made in triplicate. The occurrence of each food item was scored and then converted to a percentage by multiplying the ratio of the number of times an item occurred to the total number of guts analyzed by a hundred. The percentage abundance of each food item was also computed by multiplying the ratio of the number of a particular item in the stomach to the total number of items in the stomach by a hundred. The plankton samples taken from different locations where fish were sampled were identified and enumerated using a compound microscope. The organisms found in the food were identified to generic level and in few cases to species level wherever possible. The percentage occurrence and abundance of each item in the samples were analyzed in a similar way.

Proximate composition of the selected fishes

All biochemical analyses were carried out on fish samples previously oven dried at 60ºC until constant weight and finely powdered with a pestle (Pulverisette2, FRITSCH).

Total Proteins

Proteins in water were hydrolysed with IN NaOH at 80°C for 30 minutes. Colour developed using Copper reagent and Folin-Ciocalteu

reagent (Lowry et al, 1951). The absorbance was then measured at 750 nm using UV - Visisble spectrophotometer.

Total Carbohydrates

Carbohydrates were estimated by the phenol-sulphuric acid method (Dubois et al., 1956). The samples were hydrolysed with IN conc. H_2S0_4 in 1: 1 ratio at 100^{o}C for 1 hour and cooled at room temperature and filtered. To l ml of the aliquots, add I ml of 5% phenol and concentrated H_2S0_4, cooled the test tube and measured absorbance at 490 nm using UV Visible spectrophotometer (Genesys 10 UV).

Total Lipids

Lipids were extracted from the sediments and particulate matter according to the method of Bligh and Dyer, 1959. To 10 ml sample, 10 ml chloroform-methanol (2: 1 v/v) mixture and 20 ml of aqueous NaCI were added in separating flask and after thorough shaking. The preparation was allowed to stand for 30 minutes from the clean biphasic layer formed, the lower phase was removed and the same quantity of chloroform was added to make up the volume. This extract was dried in a vacuum desiccator, over silica gel and added 0.5 ml concentrated H_2S0_4, boiled maintaining in a water bath at 60°C. After cooling to room temperature, 5ml vanillin reagent was added and allowed to stand for 30 minutes. The absorbance of pink color developed was measured at 520 nm using spectrophotometer.

The fishes collected were virtually of the same size and sex as variability in size stands to affect the proximate composition and the mineral elements concentration. All the samples were collected fresh and refrigerated below 40^{0}C prior use.

Moisture content

Estimation of moisture content was carried out by drying the pre-weighed wet samples at 60 °C until a constant weight was obtained. The difference in weight was calculated and expressed as percentage moisture content of the sample. Percentage was calculated by the following formula.

Moisture % = Weight of tissue-Dry weight of tissue/Wet weight of tissue ×100

The dried samples were finely powdered using mortar and pestle and stored in desiccators for further analysis.

Ash%

Ash%= Weight of dry samples/original weight of the sample taken x 100

2.2.10 Statistical Analysis

Seasonal and spatial variations in water and sediment quality parameters were examined by Two way ANOVA without replication (Microsoft Excel, 2007). Pearson correlations analysis was carried out to find out the interrelations between different parameters (SPSS 13). PRIMER was used for statistical interpretation of data. In representative stations Multi dimensional Scaling (MDS) analysis was carried out to see species clustering / specificity using Plymouth routine in Marine Environmental Research (PRIMER- Clarke and Glorey, 2001). The main goal of the MDS is to detect meaningful dimensions underlying that allow the researcher to explain the observed similarities or dissimilarities between the factors, both biological and physico chemical. MDS helps to arrange plankton species abundance at different stations in a space so as to reproduce similarities. As a result it could explain the distances in terms of dissimilarity between species occurring in different stations. Technically it uses a function minimization algorithm that evaluates different

configurations with the goal of maximizing the goodness of fit or minimizing the lack of fit. Diversity is the precise expression of how individuals of a particular community are distributed in subsets of groups. To analyze changes in plankton community due to environmental influence relating seasons following diversity indices were also used.

Species Richness (Margalef, 1968)

Species richness is the number of different species in a particular area is calculated by

$$\mathbf{D= (S-1) \log e^{N}}$$

S is the number of species and N is the total number of individuals of all the species in the sample.

Species evenness (Heips, 1974)

Species evenness is the relative abundance with which each species are represented in an area calculated by

$$\mathbf{E= e (H(S) - 1/S-1)}$$

H(S) is the species diversity in bits of information per individual and S is the number of species.

Species diversity (Shannon and Wiener, 1963)

The advantage of this index is that it takes into account the number of species and the evenness of the species. The index is increased either by having more unique species or by having greater species evenness.

$$\mathbf{H(S) = -\sum [Pi (log2\ Pi)]}$$

Pi= ni /n (proportion of the sample belonging to the i^{th} species.

References

Agemian, H., 1997. Determination of nutrients in aquatic sediments", In A. Murdoch, J. M. Azcue and P. Murdoch (eds.), *Manual of Physico-Chemical Analysis of Aquatic sediments*, New York: Lewis Publishers, 215-218.

Anderson, L. G., Turner, D. R., Wedborg, M., Dyrssen, D., 1999. Determination of alkalinity, In: *Methods of Sea Water Analyses*, Grasshoff, K., Ehrhardt, M., Kremling K. (Eds.), Verlag Chemie, Weinheim, pp 127-147.

APHA, 1995. Standard Methods for the Examination of Water and Wastewater, pp 5/47-48.

APHA, 2005. Standard Methods for the Examination of water and waste water. 21st edition. Andrew. D. Eaton, Lenore S. Clesceri, Eugine W. Rice, Arnold . E.Greenberg., (Eds) Centennial edition.

Barnes, H., Blackstock, J., 1973. Estimation of lipids in marine animals tissues: Detailed investigation of the sulphophosphovanillin method for "total" lipids. *J. Exp.Mar. Biol. Ecol.*, 12, 103-118.

Bligh, E.G. and W. Dyer, 1959. Total lipid extraction and purification. *Can. J. Biochem. Physiol*., 37, 99-110.

Brassard, P., 1997. Measurement of Eh and pH in aquatic sediments. In: Mudroch A., Azcue J.M., Mudroch P. (Eds.), Manual of physico-chemical analysis of aquatic sediments, Lewis publishers, London, pp. 47-67.

Cividanes, S., Incera, M., Lopez, J., 2002. Temporal variability in the biochemical composition of sedimentary organic matter in an intertidal flat of the Galician coast (NW Spain). *Oceanologica Acta*, 25, 1-12.

Clarke, K.R., Glorey, R.N., 2001. PRIMER (Plymouth routine in Marine Environmental Research) V5, User Mannual /Tutorial pp 90

Danovaro, R., Fabiano, M., Della Croce, N., 1993. Labile organic matter and microbial biomasses in deep-sea sediments (Eastern Mediterranean Sea). *Deep-Sea Res.*, 40, 953-965.

Diaz-Espejo, A., Serrano, L., Toja, J., 1999. Changes in sediment phosphate composition of seasonal ponds during filling. *Hydrobiologia*., 392, 21–28.

Dona, P., Somshekar, D., Verlencar, X.N., 2004. Phytoplankton Identification Manual, National Institute of Oceanography, Goa - 403 004.

Dubois, M. K., Gilles, J. K., Hamilton, P. A., Rebers, Smith, F., 1956. Colorimetric method for determination of sugars and related substances. *Anal. Chem.*, 28, 350-356.

Fabiano, M., Danovaro, R., 1994. Composition of organic matter in sediments facing a river estuary (Tyrrhenian Sea): relationships with bacteria and microphytobenthic biomass. *Hydrobiologia.,* 277, 71-84.

Folk, R.L., 1980. Petrology of Sedimentary Rocks. Hemphill Publishing, Austin, TX, 184p

Fritsch, F. E.**,** 1935. The structure and reproduction of the algae. Cambridge University Press, London.

Golterman, H. L., 1996. Fractionation of sediment phosphate with chelating compounds: A simplification, and comparison with other methods. *Hydrobiologia.*, 335, 87-95.

Golterman, H.L., Chymo, R.S., Ohnstad, M.A.M., 1978. Methods for physical and chemical analysis of fresh waters. IBP Hand book No.8. Blackwell Scientific Publications, Oxford.

Goswami S.C., 2004. Zooplankton Methodology, Collection & Identification - a field manual, National Institute of Oceanography, Dona Paula, Goa - 403 004

Grasshoff, K., Kremling, K. Ehrhardt, M., 1999. Methods of sediment Analysis. Verlag Chemie, Germany. pp 600.

Hansen, H. P., 1999. Determination of oxygen, In: Grasshoff, K., Ehrhardt, M., Kremling, K. (Eds.), *Methods of Seawater Analyses*, Verlag Chemie, Weinheim, pp 75-90.

Heips, C., 1974. A new index measuring evenness, Marine Biology Association, United Kingdom, 54, 555-557.

Hyslop, E. J., 1980. Stomach contents analysis: a review of methods and their application. *J. Fish Biol*., 17,411-429

IOBC,1969. Indian Ocean Biological Centre, Government of India.

Jayaprakash, A. A., 2002. Long term trends in rainfall, sea level and solar periodicity: A case study for forecast of Malabar sole and Oil sardine fishery. *J. Mar Biol Ass. India.*, 44, 163-175.

Lorenzen, C.J, 1967. Determination of chlorophyll and pheopigments: spectrophotometric equations. *Limnol.Oceanogr*.. 12, 343-350.

Lowry, O. H., Rosebrough, N. J., Fart, A. L., Randall, R. J., 1951. Protein measurement with Folin phenol reagent. *J. Biol. Chem.*, 193, 265-275.

Margalef, R., 1968. In: Perspectives in ecological theory .University of Chicago Press, 111.

Mayer, L. M., Schick, L. L., Setchell, W. F., 1986. Measurement of protein in nearshore marine sediments. *Mar. Ecol. Prog. Ser.*, 30, 159-165.

Menon, N. N., Balchand, A. N., Menon, N. R., 2000. Hydrobiology of the Cochin backwater system- a review. *Hydrobiologia*., 430, 149–183.

Michael. P. 1984. Ecological methods for field and laboratory investigations. Tata McGraw-Hill, pp 404.

Mitra, A., Banerjee, K, Banerjee, A., Das, S, Golui, P., Basu, S., 2006. Culture technology of freshwater prawn, *Macrobrachium rosenbergii* In: Training manual on ecofriendly and sustainable fishery. WWF-India Sundarbans landscape project.

Muller, T.J., 1999. Determination of salinity, In: Methods of Sea Water Analyses, K. Grasshoff, M. Ehrhardt, and K. Kremling, eds., Verlag Chemie,Weinheim, pp 41-74.

Nair, S. M., Balchand, A. N. Nambisan, P. N. K., 1989. On the determination and distribution of hydroxylated aromatic compounds in estuarine waters. *Toxicol. Environ. Chem.*, 23, 203-213.

Nelson, D.W., Sommers, L.E., 1996. Total carbon, organic carbon, and organic matter, In: Methods of Soil Analysis. Part 3: Chemical Methods, D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai.

Prescott, G.W., 1969. The algae - a review, Butler and Tanna, Frome and London , pp436.

Rice, D. L., 1982. The detritus nitrogen problem: New observations and perspectives from organic geochemistry. *Mar. Ecol. Prog. Series.*, 9, 153-162.

Santhanam,R., Krishnamurthy, K., Subbaraju, R.C., 1975. Quantitative phytoplankton ecology. *Bull.Dep.Mar.Sci.*, Uni.Cochin,7, 899-911.

Shannon, C.E., Wiener, W., 1963. The mathematical theory of communication, University of Illinos.

Srinivas, K., Revichandran, C., Maheswaran, P. A., Mohamed Asharaf, T. T., Murukesh, N., 2003. Propagation of tides in the Cochin estuarine system, southwest coast of India. *Indian J.Mar. Sci.*, 32(1), 14-24.

Stephen, D., 1985. Imperatives for the future development of Shrimp Culture in Cochin Backwater System (Kerala, India). Ph.D Thesis, Univ. of Hawaii.

Tomas, C.R., 1996. Identifying Marine Phytoplankton, Academic Press Limited, 857.

Tung, J. W. T., Tanner, P. A., 2003. Instrumental determination of organic carbon in marine sediments. Mar. Chem., 80, 161-170

UNESCO, 1968. Zooplankton sampling. Monographs on Oceanographic Methodology 2, 1-176.

Utermohl, H, 1958. Zur Vervokommung der quantitativen phytoplankton-method dik. Mitt.-Intern.Verein.theor.Angew. *Limnol*.9, 1-38.

Varshney, P.K., Vijayalakshmi, K.G.N., Desai, B.N., 1982. Biological productivity and fishery potential in the coastal waters of Bombay. *J. of Indian fish. Ass.,* Bombay, 12B, 35-43.

Verlencar, X.N., Somshekar Desai, 2004. Phytoplankton Identification Manual, National Institute of Oceanography, Goa, India.

Chapter 3

GENERAL HYDROGRAPHY AND SEDIMENT CHARACTERISTICS

Contents

3.1 Intoduction

Environmental factors play a major role in shaping the plankton community and consequently changes in the distribution of biological communities are related to physical and chemical characteristics of the water column. Trophic status of an aquatic ecosystem is controlled by the hydrographic and sediment characteristics and the variations in these parameters bring about drastic changes in the community structure of fauna and flora. Knowledge on the various aspects of the physico-chemical parameters of the estuary is essential for assessing the water quality and various biogeochemical processes controlling the distribution and abundance of various species of organisms. Physico chemical variables such as salinity dissolved oxygen, nutrients and major elements either individually or collectively influence the abundance and distribution of phytoplankton production which in turn affect the secondary and tertiary production.

Interactions between the sediment and the water column play an important role in regulating phytoplankton production and the extent of bottom water hypoxia/anoxia (Kemp and Boynton, 1992; Madhu et al., 2007).

3.2 Results

Water and surface sediment samples collected from the selected stations of Cochin backwaters were analysed for various physico-chemical parameters. General hydrographic variables, nutrients such as nitrate, nitrite, ammonia, phosphate, silicate and iron were determined in the water samples taken from the CBW. Data regarding rainfall and tides were also collected. Seasonal average concentration of various hydrographic parameters and their spatio-temporal variations were also determined. Characteristics of sediment like pH, Eh, texture, concentration of biochemical constituents such as total protein, total carbohydrate, total lipids, chlorophyll pigments, tannin and lignin were also estimated. Along with this, nitrogen fractionation was also done for the detailed knowledge on the concentration of nitrate, nitrite, ammonia and total nitrogen present in the sedimentary environment. Fractionation of phosphorous in sediments was carried out to evaluate the enrichment of this nutrient element in the study area.

3.2.1 General hydrographic parameters

The variations of general hydrographic parameters estimated in surface and bottom layers are furnished in tables 3.1 and 3.2 respectively.

Rainfall

Total rainfall of 367mm was recorded from January 2009 to April 2010. During POM 08, measured rainfall was 18mm and in PRE 09, it was observed to be 154mm. However MON 09 exhibited a rainfall of 180 mm. During POM 09 and in PRE 10, it was 7and 8mm respectively. Rainfall data were obtained from the meteorological Centre, Trivandrum (Govt. of India).

Tide

Tide data was collected from Cochin Port Trust (Govt. of India). At the time of collection during POM 08 high tide was observed. During PRE 09, MON 09, POM 09 and PRE 10 low tide was recorded.

Atmospheric - Temperature

Spatiotemporal variation and average value for atmospheric temperature is depicted in figure 3.1 and table 3.1. POM 08 displayed atmospheric temperature values varying from 25 to 33.2^{o}C with an average of 29.87±2.31 ^{o}C. It could be noticed that in PRE 09, values ranged between 30 and 36.16^{o}C (average: 33.28±1.98^{o}C). MON 09 recorded an average temperature of 31.14±2.33^{o}C and ranged from 26 to 34 ^{o}C. However the exhibited variation during POM 09 was from 26 to 39 ^{o}C with an average of 29.87±3.78^{o}C. The estimated average atmospheric temperature was 31.23±1.76 ^{o}C (PRE 10) and recorded variation was from 29 to 34 ^{o}C. ANOVA (table 3.1) revealed that atmospheric temperature showed significant seasonal variation ($p < 0.01$) only.

Table 3.1 General hydrographic parameters estimated in surface water

Parameter	POM 08			PRE 09			MON 09			POM 09			PRE 10			ANOVA (P value)	
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Spatial	Seasonal
Atmospheric temp. °C	25	33.2	29.87±2.32	30	36.16	33.28± 1.98	34	26	31.14±2.33	26	39	29.87±3.78	29	34	31.23±1.76	0.250	0.002
Transparency(light extinction coefficient, kem^{-1})	0.7	2.33	1.34±0.49	1	3.11	1.75±0.79	2.15	14	7.08±3.9	0.07	0.54	0.33±0.17	1.12	9.33	2.92±2.97	0.33	<<0.01
Water temp. °C	26	32	29.30±1.26	30	34.5	32.68±1.0	26	34.06	31.02±2.45	27	32	30.06±1.05	32	34	32.8±0.65	0.14	<<0.01
pH	7.4	8.1	7.65±0.19	7	8.1	7.52±0.34	7.1	7.9	7.54±0.24	6.8	8.1	7.55±0.37	6.8	8.1	7.48±0.39	0.43	0.68
Depth(m)	0.9	5	2.76±1.36	1	6	3.3±1.63	3	7	4.22±1.10	1.1	6	3.24±1.37	1	8.5	3.63±1.90	<<0.01	<<0.01
Alkalinity ($mgCaCO_3$/ L)	19.5	140	67.33±35.82	13.8	112.7	46.15±30.04	9.12	25.08	13.83±4.10	6.4	76.8	26.02±22.62	13.3	76	25.33±19.10	0.073	<<0.01
DO (mg/L)	3.74	6.34	5.3±0.7	3.59	6.18	5.07±0.66	5.24	6.76	6.00±0.50	3.32	6.69	5.4±1.1	3.96	6.95	5.49±0.99	<<0.01	<<0.01
CO_2 (mg/L)	0.44	2.64	0. 16±0. 6	0.044	2.2	1.2±0. 7	0.4	3	1.7±0. 6	0. 44	1.98	0. 98±0.04	0.44	1.32	0. 7±0. 2	0.324	<<0.01
Salinity (psu)	3.47	32	17.11±9.37	1.57	28.89	10.53±8.93	3.47	17.52	11.12±10.10	1.28	29.93	11.12±10.08	0.71	29.46	8.82±8.11	<<0.01	<<0.01
Phosphate (µmol/L)	0.1	2.55	1.20±0.62	0.029	3.062	0.55±0.79	0.08	0.65	0.36±0.17	0.03	3.06	0.55±0.79	0.01	2.02	0.32±0.53	0.01466	<<0.01
Silicate (µmol/L)	35.2	101	72.46±22.23	10.54	39.78	25.43±10.67	8.52	82.16	37.1±25.03	22.83	147.2	90.70±38.48	11.49	63.91	37.37±15.11	0.25	<<0.01
Nitrate (µmol/L)	3	47.3	13.58±12.78	2.3	27.2	10.05±6.87	6.20	290.3	30.63±70.89	1.2	15.4	8.00±4.88	0.93	30.50	9.56±8.54	0.25	0.07
Ammonia (µmol/L)	0.07	0.38	0.16±0.09	2.6	356.1	59.23±90.62	4.72	98.09	36.21±22.13	1.57	136.70	38.89±44.49	6.69	410.50	74.69±100	0.84	0.04
Nitrite (µmol/L)	0.03	1.02	0.33±0.25	0.07	1.01	0.46±0.30	0.05	0.49	0.20±0.13	0.02	0.99	0.37±0.30	0.221	0.986	0.54±0.25	0.75	0.007
Iron (mg/L)	0.01	0.34	0.10±0.08	0.005	2.02	0.46±0.53	0.052	0.188	0.11±0.04	ND	1.03	0.44±0.31	0.46	6.67	1.94±1.76	0.414	<<0.01
BOD (mg O_2/L)	0.22	6.2	2.40±1.73	0.62	5.41	3.64±1.56	0.29	4.98	2.02±1.54	0.16	6.24	2.54±1.85	0.64	5.76	4.11±1.73	<<0.01	<<0.01

Table 3.2 General hydrographic parameters estimated in bottom water

Parameters	POM 08			PRE 09		MON 09			POM 09			PRE 10			ANOVA (P value)	
Temperature °C	27	31.3	29.43±1.30	32.44	34.5	33.06±0.62	26	34	30.83±2.60	29	31	30.06±0.70	31	33	32.50±0.62	0.57	<<0.01
pH	7.4	8	7.68±0.20	7.2	8.4	7.70±0.36	7.1	7.9	7.55±0.21	6.9	8	7.59±0.33	6.7	8.2	7.42±0.44	0.13	0.1
Alkalinity (mg $CaCO_3$/ L)	22.32	145.08	85.74±33.22	11.5	165.8	49.98±26.96	6.84	36.48	13.22±7.01	6.4	70.4	24.96±19.73	9.5	74.1	29.89±21.60	0.01	<<0.01
DO(mg/L)	3.28	6.22	5.05±0.80	2.61	5.88	4.58±0.88	2.24	6.38	5.23±1.06	3.1	6.1	4.98±1.02	3.48	6.53	5.51±0.95	<<0.01	0.036
CO_2(mg/L)	0.88	2.2	1±0.4	0.04	2.0	1±0.5	0.4	3.0	2±0.6	0.2	1.98	0.8±0.4	0.4	1.3	0.06±0.2	0.84	<<0.01
Salinity (psu)	3.47	33.72	19.01±9.83	1.57	29.52	12.09±8.50	3.47	24.32	9.12±6.67	1.28	31.38	11.33±9.43	0.59	33.5	11.52±11.22	<<0.01	<<0.01
Phosphate(µm/L)	1.03	2.53	1.65±0.50	0.02	4.15	0.67±1.00	0.20	0.82	0.45±0.17	0.03	0.78	0.31±0.20	0.06	1.02	0.26±0.28	0.073	<<0.01
Silicate (µm/L)	17.45	97.08	60.64±26.84	4.22	61.45	23.88±15.11	9.516	78	38.22±22.10	23.87	118.9	76.38±41.12	3.95	65.52	39.76±16.08	0.03	<<0.01
Nitrate (µm/L)	0.53	177.4	20.96±44.20	0.88	17.4	7.81±4.96	7.5	41.89	21.04±12.55	2.3	15.6	7.96±3.88	0.79	25.6	10.59±8.50	0.395	0.19
Ammonia (µm/L)	0.02	0.96	0.19±0.22	1.57	82.73	28.38±27.19	14.97	165.2	42.29±26.38	1.34	177.70	41.31±58.80	7.48	132.80	58.62±39.66	0.84	0.042
Nitrite (µm/L)	0.01	0.59	0.26±0.21	0.11	1.09	0.53±0.32	0.07	0.55	0.21±0.13	0.11	1.09	0.53±0.32	0.22	1.26	0.75±0.33	0.72	<<0.01
Iron (mg/L)	0.05	0.69	0.19±0.18	0.063	3.136	0.72±0.90	0.04	0.47	0.20±0.12	0.10	3.54	0.84±0.90	0.35	5.18	2.11±1.53	0.07	<<0.01
BOD (mg O/L)	0.14	5.96	2.24±2.02	0.5	5.98	3.53±1.58	0.18	5.1	2.28±1.53	0.16	6.88	2.30±2.30	0.64	6.72	4.4±1.8	<<0.01	<<0.01

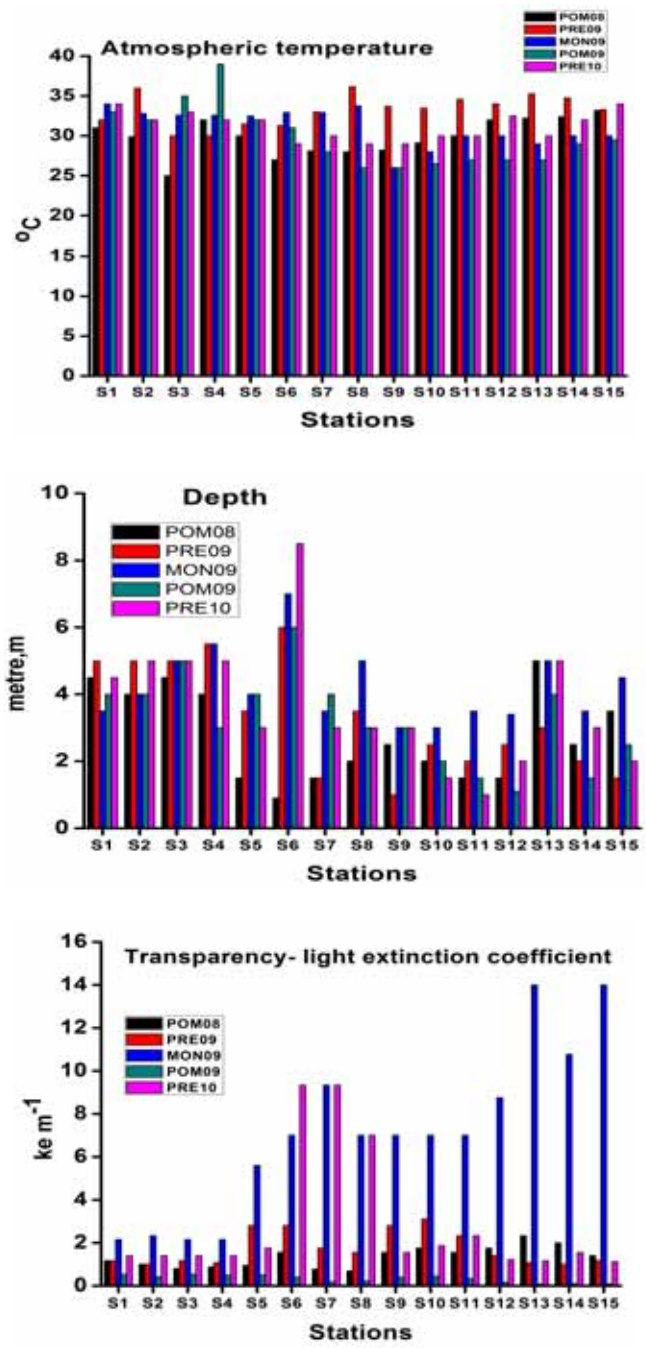


Figure 3.1 spatial and seasonal variation in atmospheric temperature, depth of stations and transparency

Depth

Figure 3.1 provides the variation in depth throughout the investigation period. Out of the 15 sampling stations, during POM 08, an average depth of 2.76±1.36m was recorded and it varied from 0.9 to 5m (table 3.1). In PRE 09, average depth was found to be 3.3±1.63m and it ranged between 1 and 6m. MON 09 exhibited an average depth of 4.22±1.1m and it ranged between 3 and 7m. Measured depth during post MON 09 ranged from 1.1 to 6m (average: 3.24±1.37m). However, PRE 10 revealed an average depth of 3.63±1.9m and it varied from 1 to 8.5m.

Transparency- light extinction coefficient

Transparency recorded an average of 1.34±0.49kem^{-1} and varied from 0.7 to 2.3kem^{-1}, during POM 08 (table 3.1). However in PRE 09, average value was found to be 1.75±0.79kem^{-1} and observed values ranged between 1 and 3.11m. MON 09 found to exhibit values varying from 2.15 to 14 kem^{-1} with an average of 7.08±3.91kem^{-1}. The observed variation in transparency during POM 09 was from 0.07 to 0.54kem^{-1} (average: 0.33±0.17kem-1). In the present investigation, PRE 10 recorded values ranging between 1.12 to 9.33 kem^{-1} with an average of 2.92±2.97kem^{-1}. ANOVA revealed that transparency exhibited only significant seasonal variation ($p<0.01$). Spatiotemporal variation in transparency is represented in figure 3.1.

pH

Spatiotemporal variation and average values of pH in surface layers of the water column is furnished in table 3.1 and figure 3.2. Measured values of pH (surface waters) during POM 08 ranged between 7.4 and 8.1 with an average of 7.65±0.19. Meanwhile, in PRE 09, the average value for this variable was found to be 7.52±0.34 and the exhibited variation was from 7 to 8.1. Observed values of pH of the surface waters during MON 09

varied from 7.1 to 7.9 (average: 7.54±0.24). During POM 09, average pH recorded was 7.55±0.37 and it varied from 6.8 to 8.1. However during PRE 10, it varied from 6.8 to 8.1 (average: 7.48±0.39).

Average values of pH and its spatiotemporal variation in bottom layers of the water column is furnished in table 3.2 and figure 3.2. During POM 08 (bottom waters), values of pH varied from 7.4 to 8 with an average of 7.68±0.20. In PRE 09, pH ranged between 7.2 and 8.4 (average: 7.7±0.36). Average value of pH was measured to be 7.55±0.21 and it ranged from 7.1 to 7.9 (MON 09). In the case of POM 09, pH of bottom layers varied from 6.9 to 8 (average: 7.59±0.33) and in PRE 10, it varied from 6.7 to 8.2 (average: 7.42±0.44).

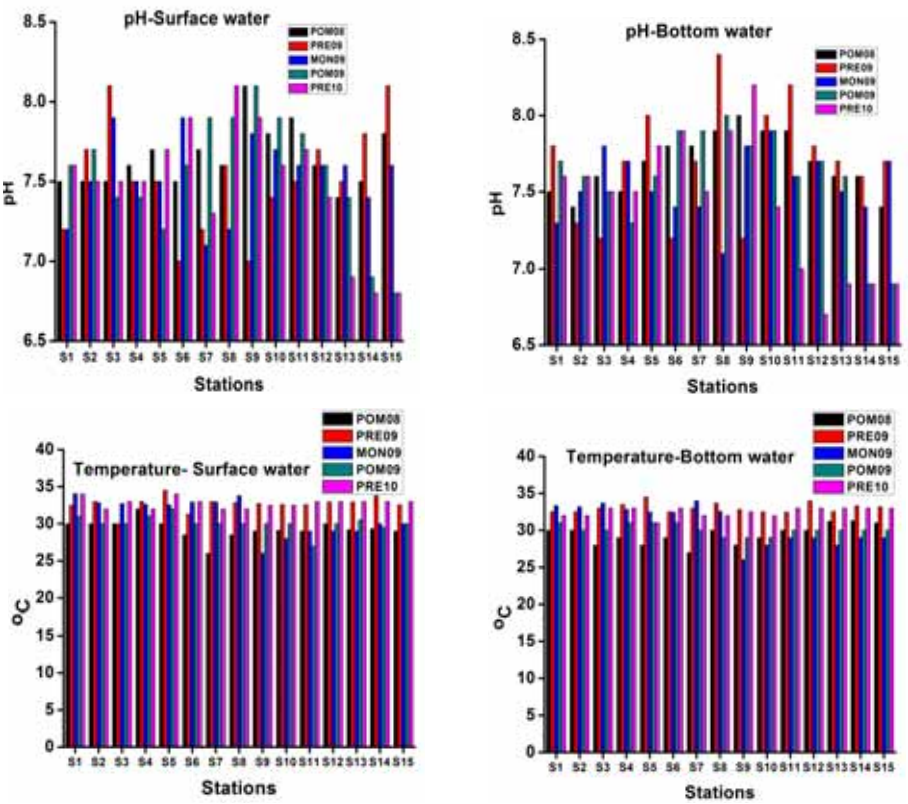


Figure 3.2 Spatial and seasonal variations in pH and temperature of water column

Water - Temperature

Seasonal variation in temperature of both surface and bottom waters is depicted in figure 3.2. Surface waters recorded values for temperature varying from 26 to 32°C (average: 29.30±1.26°C), during POM 08 (table 3.1). Meanwhile, PRE 09 exhibited an average of 32.68±1°C with values ranging between 30 and 34.5°C. The measured temperature of surface water ranged from 26 to 34.06°C with an average value of 31.02±2.44°C during MON 09. During POM 09 values for surface water temperature varied from 27 to 32°C (average: 30.06±1.04°C) and in PRE 10, it varied from 32 to 34°C (average: 32.8±0.65°C).

During POM 08, average temperature of bottom layers was 29.43±1.30°C and it varied from 27 to 31.3°C (table 3.2). In PRE 09, temperature of bottom layers ranged between 32.44 and 34.5°C with an average of 33.06±0.62°C. However the observed values of temperature in bottom waters, during MON 09, ranged from 26 to 34°C (average: 30.83±2.60°C). During POM 09, temperature of bottom waters varied from 29 to 31°C with an average of 30.06±0.70°C and in PRE 10, it varied from 31 to 33°C (average: 32.5±0.62°C).

Dissolved oxygen (DO)

During POM 08, dissolved oxygen (surface waters) varied from 3.74 to 6.34mg/L with an average of 5.3±0.7mg/L (table 3.1). In PRE 09, DO ranged between 3.59 and 6.18mg/L (average: 5.07±0.66mg/L). It recorded an average content of 6±0.5mg/L with a variation from 5.24 to 6.76mg/L during MON 09. During POM 09, it ranged from 3.32 to 6.69mg/L and recorded an average of 5.4±1.1mg/L. In the present study, PRE 10 an average concentration of 5.49±0.99mg/L and the observed DO

content found to range between 3.96 to 6.95mg/L. The seasonal average of DO content in the study area is furnished in table 3.1. The variation in concentration of DO in surface and bottom water is depicted in figure 3.3.

In bottom waters of the study area during POM 08, DO varied from 3.28 to 6.22mg/L, with an average of 5.05±0.80 mg/L (table 3.2). In PRE 09, DO exhibited an average content of 4.58±0.88mg/L and ranged from 2.61 to 5.88 mg/L. During MON 09, the value varied from 2.24 to 6.38mg/L (average: 5.23±1.06 mg/L). However, recorded DO content during POM09 ranged between 3.1 and 6.1mg/L with an average of 4.98±1.02 mg/L. The average DO content estimated during PRE 10 was observed to be 5.51±0.95mg/L, and its content during this period ranged between 3.48 and 6.53 mg/L.

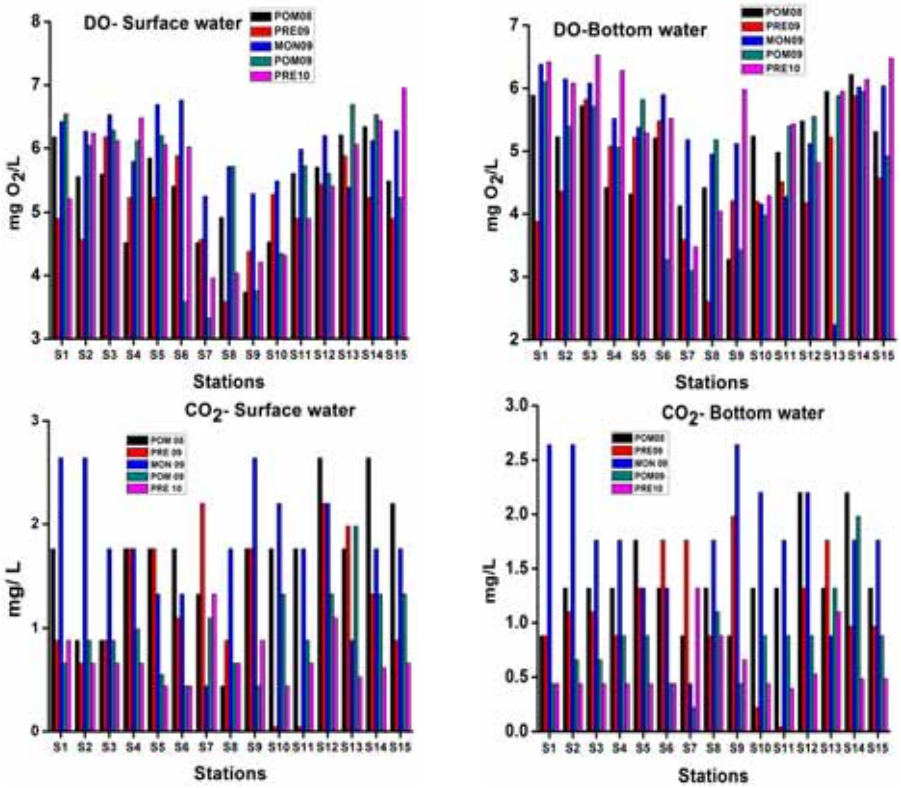


Figure 3.3 Spatial and seasonal variations in DO and CO_2 in water column

Carbon Dioxide

Spatiotemporal variation and average concentration of CO_2 in surface layers of the water column is furnished in table 3.1 and figure 3.3. Content of free carbon dioxide (surface waters) during POM 08 varied from 0.44 to 2.64mg/L with an average of 1.67±0.60mg/L. In PRE 09, CO_2 exhibited an average of 1.2±0.70 mg/L and ranged between 0.044 and 2.2 mg/L (figure 3.3). Concentration of CO_2 recorded an average of 1.7±0.6mg/L and ranged between 0.4 to 3.0mg/L, during MON 09. However, during POM 09, it ranged from 0.44 to 1.98mg/L (average: 0.98±0.04mg/L). Present study revealed that during PRE 10, the average CO_2 content was found to be 0.7±0.2mg/L and exhibited variation was from 0.44 to 1.32mg/L.

Average values of pH and its spatiotemporal variation in bottom layers of the water column is furnished in table 3.2 and figure 3.3. It was recorded that during POM 08, CO_2 (bottom waters) varied from 0.88 to 2.2mg/L (average: 1.0±0.40mg/L). In PRE 09, CO_2 recorded an average content of 1.0±0.5 mg/L and it ranged from 0.04 to 2.0mg/L. During MON 09, it found to vary from 0.4 to 3.0 mg/L with an average of 2.0±0.6mg/L. During POM 09, the average concentration was observed to be 0.8±0.4 mg/L and exhibited a variation from 0.22 to 1.98mg/L. The recorded content of CO_2 during PRE 10 ranged between 0.4 to 1.3mg/L (average: 0.06±0.2mg/L).

Biochemical oxygen demand (BOD)

Surface waters of the study area during POM 08 recorded BOD values varying from 0.22 to 6.2mg/L (figure 3.4) with an average of 2.4±1.73 mg/L (table 3.1) Meanwhile, PRE 09 recorded values ranging between 0.62 and 5.41mg/L (average: 3.64±1.56 mg/L). BOD recorded an average value of 2.02±1.54 mg/L during MON 09 and it ranged between

0.29 and 4.98mg/L. Average value BOD was estimated to be 2.54±1.85 mg/L and it ranged from 0.16 to 6.24mg/L during POM 09. During PRE 10, values of BOD ranged between 0.64 to 5.76mg/L with an average of 4.11±1.73 mg/L.

Spatiotemporal variation in BOD (bottom layers) of the water column is depicted in figure 3.4. It was found that during POM 08, BOD values in bottom waters varied from 0.14 to 5.96mg/L with an average value of 2.24±2.02mg/L (table 3.2). In PRE 09, it recorded a variation ranged between 0.5 to 5.98mg/L (average: 3.53±1.58mg/L). Meanwhile, MON 09 recorded an average BOD value of 2.28±1.53mg/L and exhibited variation from 0.18 to 5.1mg/L. The estimated average during POM 09 was 2.3±2.3mg/L, and the observed values ranged from 0.16 to 6.88g/L. PRE 10, value ranged between 0.64 to 6.72mg/L (average: 4.4±1.8mg/L). (ANOVA) displayed highly significant seasonal and spatial variation ($p<0.01$) for both surface and bottom layers.

Salinity

Seasonal and spatial variation in salinity of surface and water is furnished in figure 3.4. During POM 08, salinity in surface waters varied from 3.47 to 32 psu with an average of 17.11±9.37 psu (table 3.1). In PRE 09, exhibited an average value of 10.53±8.93psu and ranged from 1.57 to 28.89 psu. Estimated salinity during MON 09 varied from 3.47 to 17.52 psu with an average of 11.12±10.10 psu. However during POM 09, it ranged between 1.28 and 29.93 psu (average: 11.12±10.08psu). While in PRE 10, it ranged between 0.71 to 29.46 psu with an average of 8.82±8.11 psu.

During POM 08, salinity in bottom waters varied from 3.47 to 33.72 psu with an average value of 19.01±9.83psu (table 3.2). The observed average value for salinity during PRE 09, ranged from 1.57 to 29.52psu (average: 12.09±8.5 psu). Average salinity estimated during MON 09 was

found to be 9.12±6.67 psu and revealed a variation from 3.47 to 24.32psu. During POM 09, salinity ranged from 1.28 to 31.38psu and it displayed an average of 11.33±9.43psu. But during PRE 10, it ranged from 0.59 to 33.5 psu and recorded an average of 11.52±11.22psu.

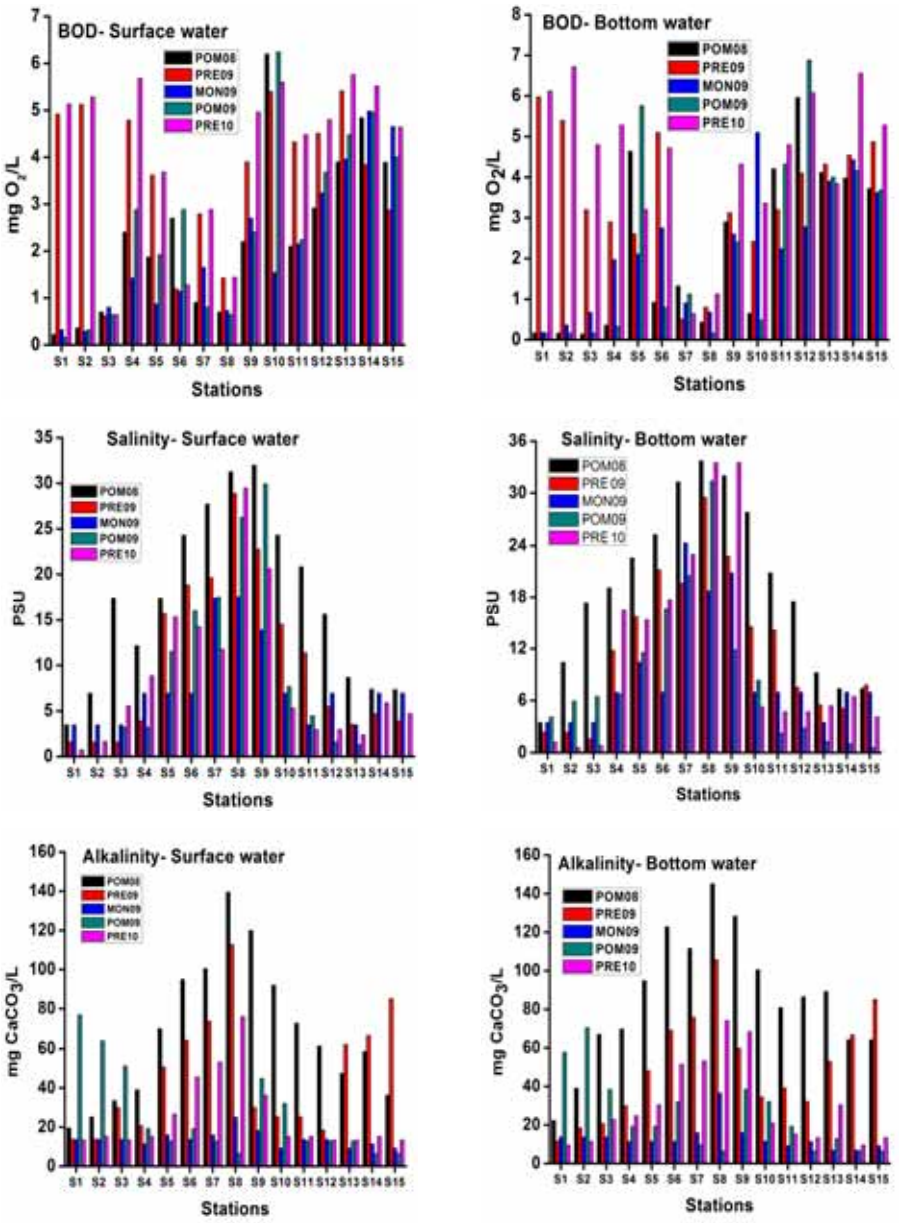


Figure 3.4 Spatial and seasonal variation in BOD, salinity and alkalinity in water column

Alkalinity

Seasonal average values for alkalinity of water samples (surface and bottom layers) is depicted in tables 3.1 and 3.2 respectively and their spatiotemporal variation is represented in figure 3.4. During POM 08 alkalinity in surface waters varied from 19.53 to 140mg$CaCO_3$/L (average: 67.33±35.82 mg$CaCO_3$/L). In PRE 09, alkalinity ranged between 13.8 to 112.7 mg$CaCO_3$/L with an average of 16.15±30.04 mg$CaCO_3$/L. The recorded average for this variable 13.83±4.08 mgCaCO3/L during MON 09 ranged between 9.12 to 25.08 mg$CaCO_3$/L. It was observed that during POM 09 value ranged from 6.4 to 76.8mg/L and the recorded average was 26.02±22.62 mg$CaCO_3$/L. Meanwhile, PRE 10 represented the minimum of 13.3 and maximum of 76mg$CaCO_3$/L (average: 25.3±19.10 mg$CaCO_3$/L).

In the present investigation, POM 08 revealed an average alkalinity value of 85.74±33.22 mg$CaCO_3$/L (bottom waters) and observed variation was from 22.32 to 145.08 mg$CaCO_3$/L. Meanwhile PRE 09 displayed an average of 49.98±26.96 mg$CaCO_3$/L and this hydrographic variable ranged between 11.5 and 105.8 mg$CaCO_3$/L. During MON 09, alkalinity ranged between 6.84 to 36.48 mg$CaCO_3$/L (average: 13.22±7.01mg$CaCO_3$/L). Alkalinity displayed an average of 24.96±19.73 mg$CaCO_3$/L during POM 09 and it ranged from 6.4 to 70.4 mg$CaCO_3$/L. Estimated value during PRE 10, ranged between 9.5 and 74.1 mg$CaCO_3$/L and displayed an average of 29.89±21.60 mg$CaCO_3$/L. Analysis of variance (ANOVA) revealed only highly significant seasonal variation ($p<0.01$) for surface waters. However, bottom waters exhibited both seasonal and spatial variation ($p<0.01$). During

MON 09, the values were lower compared to other seasons in both surface and bottom waters of the study area (figure 3.4).

3.2.2 Nutrients in water column

The spatiotemporal variation and average concentration of the estimated nutrients in surface and bottom layers of the water column is depicted in figures 3.5 and 3.6 and tables 3.1 and 3.2.

Ammonia-N

Surface water samples collected during POM 08 exhibited an ammonia content varying from 0.07 to 0.38µmol/L with an average of 0.16±0.09 µmol/L. Concentration of ammonia ranged between 2.6 and 356.1µmol/L and the estimated average concentration was found to be 59.24±90.62 µmol/L, in the PRE 09 period. The observed variation was 4.72 to 98.09µmol/L during MON 09 (average: 36.21±22.14µmol/L). Average ammonia content (POM 09) was found to be 38.89±44.49µmol/L and the observed range for this variable was from 1.57 to 136.70µmo/L. During PRE 10 value ranged between 6.69 to 410.50µmol/L (average: 74.69±100µmol/L).

During POM 08, concentration of ammonia in bottom waters varied from 0.02 to 0.96µmol/L and recorded an average of 0.19±0.22µmol/L. In PRE 09, ammonia ranged between 1.57 and 82.73µmol/L (average: 28.38±27.19µmol/L). During MON 09, concentration of ammonia recorded an average of 42.29±26.38 and it varied from 14.97 to 105.2µmol/L. During POM 09, its concentration ranged from 1.34 to 177.70µmol/L with

an average of 41.31±58.80µmol/L. While during PRE 10, concentration ranged between 7.48 and 132.80µmol/L (average: 58.62±39.66 µmol/L).

Nitrate-N

It was noticed that during POM 08 nitrate in the surface waters varied from 3 to 47.3µmol /L and recorded average of 13.58±12.78 µmol/L. In PRE 09, nitrate ranged between 2.3 to 27.2µmol/L with an average of 10.05±6.87 µmol/L. Average concentration of nitrate in surface waters of the study area, during MON 09 was found to be 30.63±70.89µmol/L and it ranged from 6.20 to 290.30µmol/L. During POM 09, value ranged from 1.2 to 15.4µmol/L and displayed an average content of 8±4.88µmol/L. While in PRE 10, concentration of nitrate varied from 0.93 to 30.50µmol/L with an average of 9.56±8.54µmol/L.

However bottom waters of the study area during POM 08 exhibited a variation nitrate concentration from 0.53 to 177.4µmol/L (average: 20.96±44.2 µmol/L). In PRE 09, nitrate ranged between 0.88 and 17.4µmol/L and recorded an average of 7.81±4.96 µmol/L. While during MON 09, its content ranged from 7.5 to 41.89 µmol/L and the estimated average was found to be 21.04±12.55 µmol/L. During POM 09,the nitrate content ranged from 2.3 to 15.6µmol/L with an average of 7.96±3.88µmol/L. Meanwhile concentration of this variable during PRE 10, ranged between 0.79 and 25.6µmol/L and displayed an average of 10.59±8.5µmol/L. Statistical analysis of variance displayed only significant spatial variation.

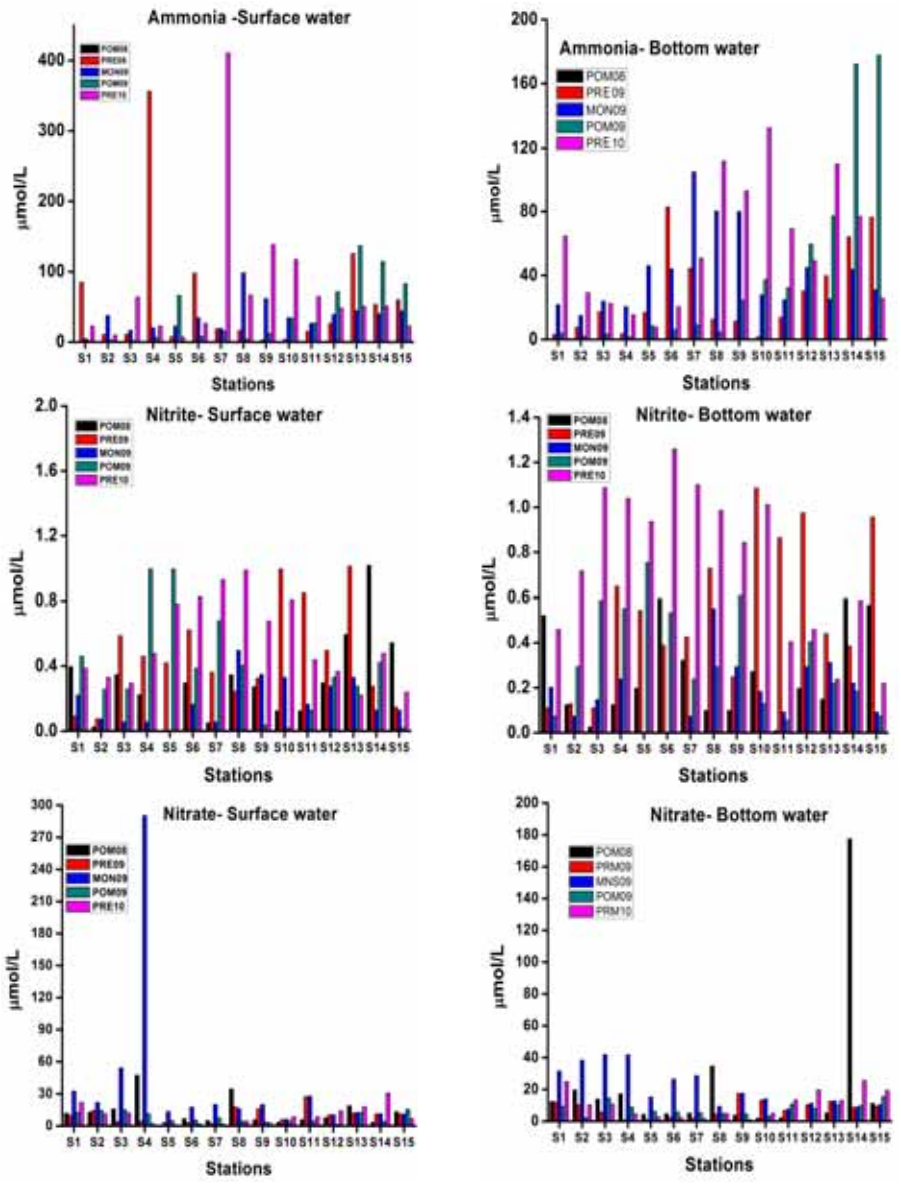


Figure 3.5 Spatial and seasonal variation in ammonia, nitrite and nitrate in water column

Nitrite

During POM 08 nitrite in the surface waters varied from 0.03 to 1.02µmol /L and the estimated average was found to be 0.33±0.25µmol/L. In PRE 09, nitrite ranged between 0.07 and 1.01µmol/L with an average

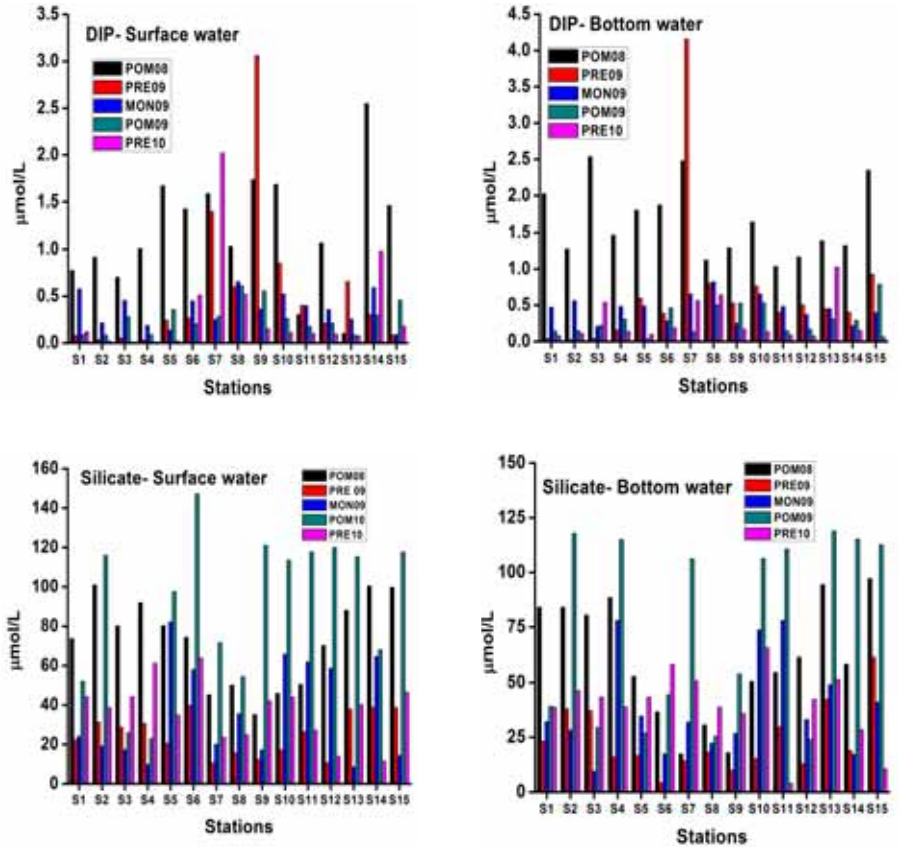
content of 0.46±0.30 µmol/L. While during MON 09, the recorded average concentration of nitrite was 0.20±0.13µmol/L and it varied from 0.05 to 0.49µmol/L. However, during POM 09, the concentration of nitrite ranged from 0.02 to 0.99µmol/L (average:0.37±0.30µmol/L). In the present investigation, concentration of nitrite during PRE 10 ranged between 0.221 and 0.986µmol/L and recorded an average of 0.54±0.25µmol/L.

While in bottom layers, the concentration of nitrite during POM 08 exhibited a variation from 0.01 to 0.59µmol/L with an average of 0.26±0.21µmol/L. PRE 09 exhibited concentration of nitrite varying from 0.11 to 1.09 µmol/L with an average of 0.53±0.32µmol/L. The estimated average concentration for this variable was found to be 0.53±0.32 µmol/L (POM 09) and it nitrite ranged from 0.11 to 1.09µmol/L. However, during MON 09 its content ranged between 0.07 and 0.55 µmol/L and revealed an average of 0.21±0.13 µmol/L. Concentration of Nitrite during PRE 10 displayed an average of 0.75±0.33 µmol/L and it ranged between 0.22 and 1.26µmol/L.

Dissolved inorganic phosphate (DIP)

Spatiotemporal variation in DIP is represented in figure 3.6. During POM 08 phosphate in the surface waters ranged between 0.10 and 2.55µmol /L and it displayed an average of 1.20±0.62µmol /L. During POM 09, it varied from 0.03 to 3.06µmol/L and exhibited an average concentration of 0.55±0.79µmol/L. The content of dissolved inorganic phosphate during MON 09 recorded an average of 0.36±0.17µmol/L and it ranged between 0.08 to 0.65µmol/L. Meanwhile, during POM 09, its content varied from 0.03 to 3.06µmol/L and the estimated average was found to be 0.55±0.79µmol/L. Average concentration of dissolved inorganic P was found to be 0.32±0.53µmol /L and it ranged between 0.01 and 2.02µmol/L (during PRE 10).

Content of inorganic phosphate during POM 08 (bottom waters) of the study area varied from 1.03 to 2.53µmol/L and recorded average of 1.65±0.50µmol/L. In PRE 09, phosphate ranged between 0.02 and 4.15µmol/L and exhibited an average concentration of 0.67±1.0µmol/L. Average concentration of phosphate during MON 09 was observed to be 0.45±0.17µmol/L and this variable ranged from 0.20 to 0.82µmol/L. While, in POM 09, the observed variation in concentration was from 0.03 to 0.78µmol/L and the estimated average was found to be 0.31±0.2 µmol /L. Concentration of DIP during PRE 10 ranged between 0.06 and 1.02µmol/L (average: 0.26±0.28µmol /L).



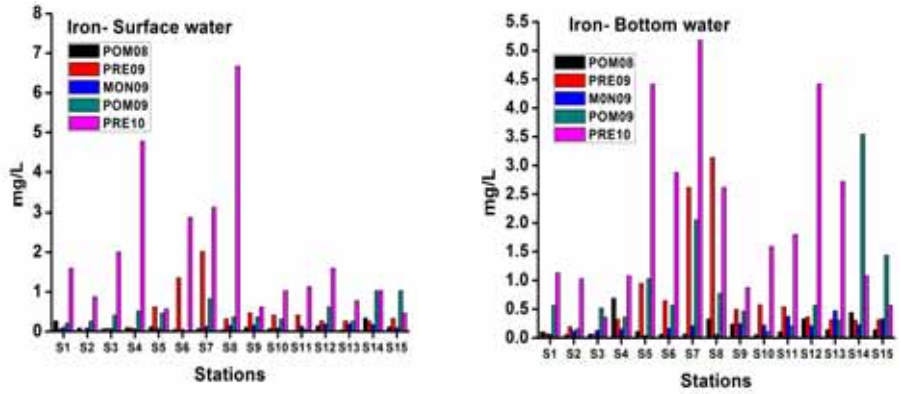


Figure 3.6 Spatial and seasonal variation in DIP, silicate and iron in water column

Silicate

Concentration of silicate (surface waters) during POM 08 ranged from 35.2 to 101µmol/L and recorded an average of 72.46±22.23µmol/L (table 3.1). It ranged between 10.54 and 39.78µmol/L, with an average of 25.43±10.67µmol/L (PRE 09). Meanwhile, during MON 09, the silicate content ranged from 8.52 to 82.16µmol/L and recorded an average of 37.1±25.03µmol/L. Average concentration of silicate during POM 09 was found to be 90.70±38.48 µmol/L and estimated concentration varied from 22.83 to 147.2µmol/L. During PRE 10, its content ranged between 11.49 to 63.91µmol/L (average: 37.37±15.11 µmol /L).

During POM 08, silicate in bottom waters varied from 17.45 to 97.08µmol/L and the estimated average was found to be 60.64±26.84 µmol/L (table 3.2). In POM 09, the concentration ranged from 4.22 to 61.45µmol/L and recorded an average of 23.88±15.11µmol/L. In the present study, during MON 09 it ranged between 9.52 and 78 µmol/L (average: 38.22±22.10µmol /L). POM 09 recorded a minimum of 23.87 and maximum of 118.9µmol/L and exhibited an average of 6.38±41.12µmol/L. Silicate concentration in bottom waters during PRE 10 varied from 3.95 to 65.52µmol/L and displayed an average of 39.76±16.08 µmol /L.

Iron

Spatiotemporal variation in concentration of iron in surface and bottom layers is furnished in figure 3.6. During POM 08, iron in the surface waters varied from 0.01 to 0.34mg/L and recorded an average 0.10±0.08mg/L (table 3.1). In PRE 09, it ranged between 0.005 and 2.02mg/L with an average of 0.46±0.53mg/L. The average concentration of dissolved Fe was 0.11±0.04mg/L and it varied from 0.052 to 0.188 mg/L, during MON 09. Exhibited variation in dissolved iron content during POM 09 was from ND to 1.03mg/L and average concentration was found to be 0.44±0.31 mg/L. During PRE 10, it ranged between 0.46 and 6.67 mg/L (average: 1.94±1.776 mg/L).

It was observed that during POM 08, iron in bottom waters varied from 0.05 to 0.69mg/L and exhibited an average of 0.19±0.18mg/L (3.2). The observed average Fe content during PRE 09 was 0.72±0.90mg/L and it ranged between 0.063 and 3.136mg/L. During MON 09, its concentration varied from 0.04 to 0.47mg/L (average: 0.20±0.12 mg/L). Meanwhile, during POM 09 its content ranged from 0.10 to 3.54 mg/L with an average of 0.84±0.90mg/L. During PRE 10, its content was found to fluctuate between 0.35 and 5.18mg/L and recorded an average of 2.11±1.53 mg/L.

3.2.3 General sediment characteristics

The average concentrations of general sedimentary parameters are furnished in table 3.3.

pH

Measured average value and seasonal variation in pH of sediments collected from the study area is depicted in figure 3.7. Values of pH during POM 08 varied from 7.3 to 7.85 (average: 7.5±0.16). PRE 09 recorded a variation from 6.98 to 8.3 with an average of 7.6± 0.37. During MON 09 it varied from 6.97 to 7.87 and recorded an average value of 7.45 ± 0.22. However, during POM 09 the observed values ranged from 6.78 to 7.88 (average: 7.52± 0.34). In the present study, PRE 10 exhibited a variation in pH from 6.65 to 8.1 (7.31 ± 0.46).

Table 3.3 General sedimentary characteristics

Parameter	POM 08			PRE 09			MON 09			POM 09			PRE 10			ANOVA (p value)	
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Spatial	Seasonal
Eh	-230	-45	-107.66	-345	-67.5	-161.5	-172.5	-33.75	-80.75	-276	-54	-129.2	-290	21	-101.8	<< 0.01	<< 0.01
pH	7.3	7.85	7.5± 0.16	6.98	8.3	7.60± 0.37	6.97	7.87	7.45± 0.22	6.78	7.88	7.52± 0.34	6.65	8.1	7.31± 0.46	0.32	0.17
Sand (%)	0.89	92.9	47.72± 33	1.68	97.88	41.65± 39	1.07	99.14	32± 33	3.74	96.38	44± 34	2.93	90	34.20± 30.53	<< 0.01	0.25
Silt (%)	2.45	53.8	26.08± 18.10	2.03	80.53	4.0± 2.7	0.24	92.59	47.82± 24.19	1.61	86.6	40± 29	9.66	77.6	43.52± 20.11	<< 0.01	0.03
Clay (%)	3.88	51.4	26.20± 16.62	0.09	41.59	17.83± 15	0.61	35.02	19± 13.49	0.64	32.26	10.9± 9.2	0.33	40.7	22.26± 12.47	<< 0.01	0.001
TOC (%)	0.88	5.13	2.58± 1.50	0.46	6.02	2.51± 1.98	0.16	6.38	2.64± 2.02	0.36	5.77	2.64± 1.83	0.61	4.98	2.37± 1.54	<< 0.01	0.98
TC (%)	0.39	6.2	3.31± 1.67	0.91	6.87	3.48± 1.93	0.42	6.97	3.62± 2.10	1.06	6.6	3.56± 1.99	0.12	6.66	4.07± 1.90	<< 0.01	0.72
TN (%)	0.1	0.38	0.21± 0.08	0.05	0.40	0.18± 0.11	0.02	0.51	0.20± 0.15	0.05	0.74	0.31± 0.18	0.12	1.07	0.38± 0.24	0.086	0.002
TS (%)	0.31	2.31	1.16± 0.65	0.26	2.08	1.11± 0.72	0.16	2.14	1.07± 0.69	0.18	2.51	1.28± 0.78	0.31	3.1	1.36± 0.80	<< 0.01	0.64
TOC/TS Ratio	0.49	9.53	3.66±2.50	1.51	8.99	3.82±2.10	2.21	6.30	3.63±1.02	1.56	6.02	3.17±1.30	0.40	8.90	3.72±2.42		
TOC/TP ratio	0.0002	0.0034	0.0008± 0.0008	0.0005	0.006	0.002± 0.0015	0.0001	0.0061	0.0026± 0.0016	0.0007	0.016	0.0040± 0.0037	0.0003	0.017	0.003± 0.003	<<0.01	<< 0.01
N/P Ratio	0.12	1.55	0.57± 0.44	0.32	2.50	0.96± 0.55	0.05	2.61	1.30± 0.67	0.29	16.88	4.5± 4.9	0.53	13.1	3.1± 3.2	0.009	<<0.01
C/N Ratio	3.29	25.3	16.4± 7.4	12.5	25.012	19.2± 3.7	11.93	25.37	19.92± 3.87	4.37	24.77	13.3± 7	1.00	23.42	12.67± 6.33	0.74	0.003

Redox potential (E^h)

Values of E^h during POM 08 varied from -230 to -45 (average: -107.66). Meanwhile PRE 09 exhibited a variation in E^h values from -345 to -67.5 (average: -161.5). In the case of MON 09, it ranged between -33.76 and -172.5 (average: -80.75). During POM 10, it varied from -276 to -54 (average: -129.2) and in PRM 10, the observed variation in E^h was from -290 to 20 (average: -101.8).

Texture

Spatiotemporal variation in sand, silt and clay in sediments of the study area is depicted in figure 3.7. In sediments, content of sand during POM 08 ranged between 0.89 and 92.9% (average: 47.72±33%) and clay varied from 3.88 to 51.4% (average: 26.20±16.62%) and silt ranged between 2.45 and 53.8% (average: 26.08±18.1%). During PRE 09, content of sand ranged from 1.68 to 97.88 % (average: 41.65±39%), clay ranged from 0.09 to 41.59% (average: 17.83±15%). In MON 09, sand exhibited a variation from 1.07 to 99.14% (average: 32.37±33 %); clay content recorded a variation from 0.61 to 35.02 % (average: 19.80±13.49%) and silt ranged from 0.24 to 92.59% (average: 47.82±24.19%). During POM 09 the estimated sand content in sediments ranged from 3.74 to 96.38 % (average: 44±34%), clay varied between 0.64 and 32.26% (average: 10.9±9.2%) and silt varied from 1.61 to 86.6% (average: 40±29%). While during PRE 10, the content of sand ranged between 2.93 to 90 % (average: 34.20±30.53%), clay recorded a variation from 0.33 to 40.7% (average: 22.26±12.47%) and silt ranged from 9.66 to 77.60% (average: 43.52±20.11%).

Total organic carbon (TOC)

During POM 08, Total Organic Carbon in sediments ranged from 0.88 to 5.13 % (figure 3.8) and recorded an average of 2.58±1.5%. In PRE 09, TOC varied from 0.46 to 6.02% with average: 2.51±1.98%. During MON 09, it ranged from 0.16 to 6.38 % and estimated average was found to be 2.64±2.02%. But during POM 09, TOC varied from 0.36 to 5.77 % (average: 2.64±1.83%). Concentration of organic carbon in sediments collected during PRE 10 exhibited a minimum of 0.61% and maximum of 4.98 % (average: 2.37±1.54%).

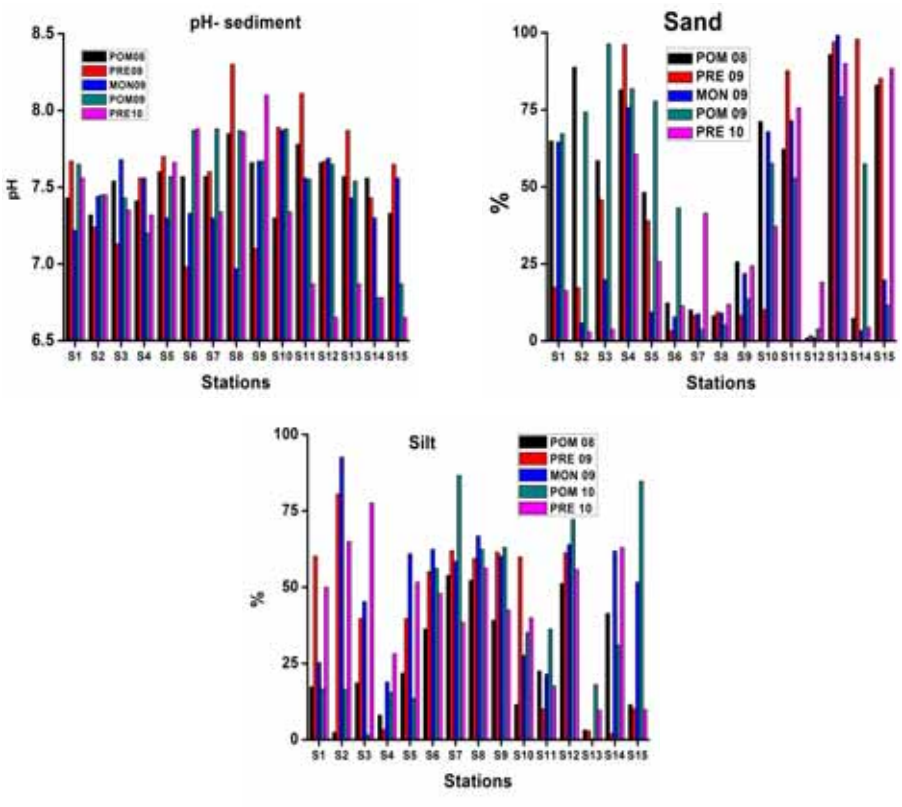


Figure 3.7 Spatial and seasonal variations in pH, sand clay and silt in sediments of the study area

Total carbon (TC)

The total carbon present in sediments during POM 08 varied from 0.39 to 6.2% with an average of 3.31±1.67% (table 3.3). In PRE 09, it varied from 0.91 to 6.87% and recorded an average content of 3.48±1.93%. While during MON 09, its concentration ranged from 0.42 to 6.97% with an average of 3.62±2.1%. During POM 09, the observed total carbon content found to vary from 1.06 to 6.6% (average: 3.56±1.99%). Average concentration of total carbon was found to be 4.07±1.9% (during PRE 10) and it ranged between 0.12 to 6.66%.

Total nitrogen (TN)

During POM 09 total nitrogen in sediments ranged from 0.10 to 0.38% (average: 0.21±0.08%). In PRE 09, it exhibited a variation from 0.05 to 0.40% and recorded average was found to be 0.18±0.11%. The recorded value of TN during MON 09, revealed a minimum of 0.02 and maximum of 0.51% (average: 0.20±0.15%). During POM 09, TN content ranged from 0.05 to 0.74 % (0.31±0.18%). In PRE 10, the concentration of TN varied from 0.12 to 1.07 % and exhibited an average content of 0.38±0.24%. Spatiotemporal variation in TN content is shown in figure 3.10.

Total sulphur (TS)

Figure 3.8 represents the spatial and seasonal variation in total sulphur in sediments. During POM 08, total sulphur content in sediments varied from 0.31 to 2.31% (average: 1.16± 0.65%). PRE 09, recorded a variation in TS content from 0.26 to 2.08% (average: 1.11±0.72%). However observed content during MON 09, it ranged from 0.16 to 2.14% with an average of 1.07±0.69%. Concentration of total sulphur during POM 09 varied from 0.18 to 2.51% and the recorded average was found to be

1.28±0.78%. PRE 10 exhibited concentrations ranging from 0.31 to 3.10% (average: 1.36±0.8%).

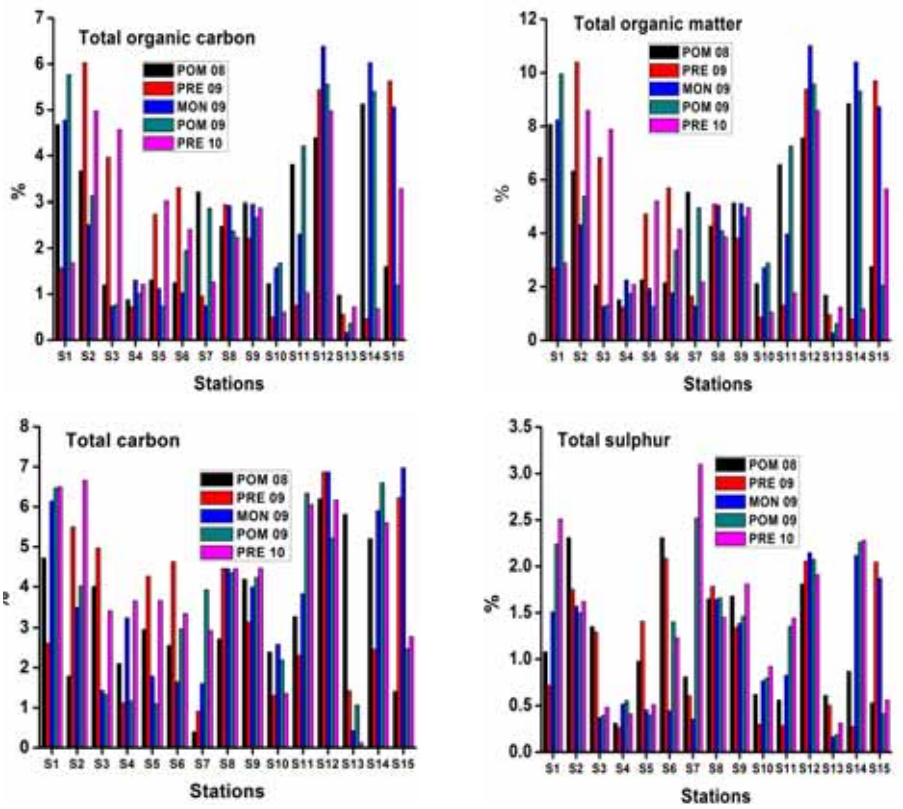


Figure 3.8 Spatial and Seasonal variations in TOC, TOM, TC, TN and TS in sediment samples

Elemental ratios

The seasonal variations of elemental ratios are depicted in figure 3.9. Present investigation recorded TOC/TS ratios ranging between 0.49 and 9.53 with an average of 3.66±2.50 (POM 08). During PRE 09, this ratio varied from 1.51 to 8.99 and recorded an average of 3.82±2.10. Average value for this ratio during MON 09 was found to be 3.63±1.02 and it varied from 2.21 to 6.30. During POM 09, TOC/TS varied from 1.56 to

6.02 (average: 3.17±1.30) and in PRE 10, it varied from 0.40 to 8.90 and estimated average value was found to be 3.72±2.42**.**

Present investigation recorded TOC/TP values (during POM 08), ranging between 0.0002 and 0.0034 (average: 0.0008±0.0008). In PRE 09, the estimated TOC/TP ratio varied from 0.0005 to 0.006 with an average of 0.002±0.0015. Observed values of TOC/TP during MON 09 varied from 0.0001 to 0.0061 and estimated an average value of 0.0026±0.0016. However during POM 09, TOC/TP varied from 0.0007 to 0.016 (average: 0.004±0.0037 and in PRE 10, it varied from 0.0003to 0.017 with an average value of 0.003±0.003.

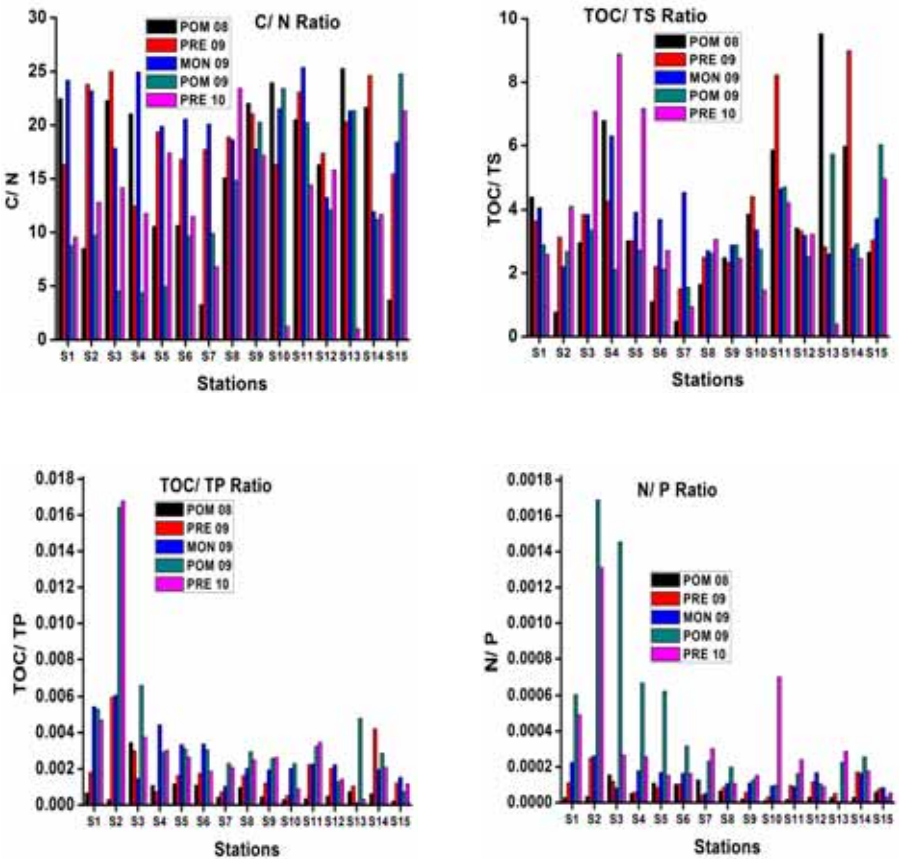


Figure 3.9 Spatial and seasonal variations in elemental ratios in sediment samples

Present study recorded N/P values during POM 08, ranging between 0.12 and 1.55 (average 0.57±0.44). In PRM 09, it varied from 0.32 to 2.50 with an average of 0.96±0.55. Observed values of N/P during MON 09 ranged from 0.05 to 2.61 and the estimated average was found to be 1.3±0.67. However, during POM 09, N/P varied from 0.29 to 16.88 (average: 4.5±4.9) and in PRM 10 it exhibited a variation from 0.53 to13.1 (average: 3.1±3.2).

3.2.4 Fractions of nitrogen in sediments

The seasonal variation of different fractions of nitrogen in sediments of the study area is depicted in figure 3.10. The average concentration various fractions of nitrogen in sediments of the study area is furnished table 3.4.

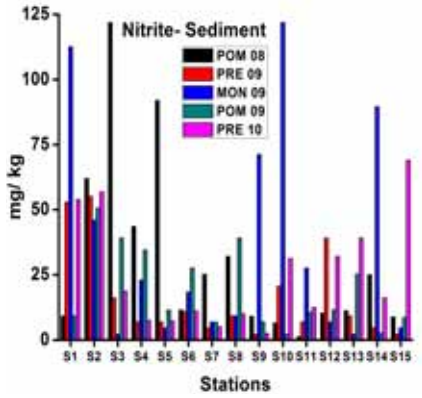
In the present study, POM 08 recorded nitrite content in sediments, ranging from 1.25 to 122mg/kg with an average of 31.32±35.14 mg/kg. The observed average concentration was found to be 16.50±17.82mg/kg during PRE 09 and it varied from 2.13 to 55.12 mg/kg. However, during MON 09, its concentration ranged between 2.25 and 121.88 mg/kg (average: 36.47±41.9mg/kg). Estimated average nitrite content in the sediments during POM 09 was 19.09±15.5mg/kg and it exhibited a variation from 2.25 to 50.63mg/kg. During PRE 10, it ranged between 2.5 and 69mg/kg and exhibited an average of 24.88±21.20mg/kg.

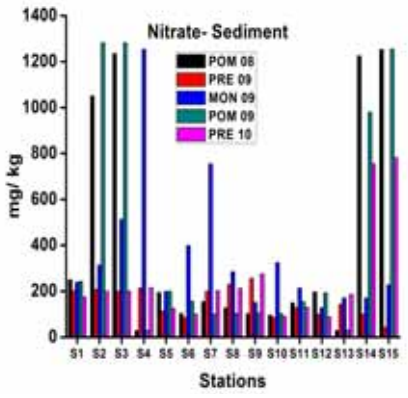
Table 3.4 Fractions of phosphorous and nitrogen in sediments

Parameter	POM 08			PRE 09			MON 09			POM 09			PRE 10			ANOVA (p value)	
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	spatial	seasonal
Lab P (mg/kg)	1.16	24.5	7.32± 6.16	5.41	191.10	57.76± 51.63	2.60	15.28	6.49± 3.56	1.18	17.34	4.80± 4.09	0.28	11.33	2.81± 2.91	0.43	<<0.01
Fe - P(mg/kg)	54.48	3479	797.04± 839.61	172	2247	788± 512	120.5	2715	743.97± 681	106.83	2720	907.95± 719	148.2	1686	878± 437	<< 0.01	0.89
Ca-P(mg/kg)	51.32	1114	325.05± 277.4	63	1193	438± 323	26.39	1359	365± 394	30.12	1472	309± 405	54.1	2727	458± 719	<< 0.01	0.57
Acd-P(mg/kg)	83.57	1611	461± 419	77.3	651.79	210± 148	16.29	302.3	156.25± 107.60	25.42	397.4	161.30± 114.68	54.16	555.4	172.34± 147.52	0.00019	<<0.01
Alik-P(mg/kg)	367.4	7155	4212± 2722	17.9	1184	494± 353	22.26	3242	479.60± 793	0.73	180.4	21.78± 44.84	25.45	449.4	154.40± 122	0.37	<<0.01
Res-P(mg/kg)	36.52	190	114.55± 47.84	27.3	270.91	114.38± 77.12	17.21	131.76	70.05± 37.06	0.21	32.69	4.77± 8.56	0.73	40.34	11.01± 12.80	0.037	<<0.01
TP(mg/kg)	944.1	12901	5918± 3694	586	5133	2104± 1175	487.3	4545.2	1822± 1225	199.88	4097	1410± 1169	396.9	4349	1677± 966	0.0011	<<0.01
Nitrite(mg/kg)	1.25	122	31.32± 35.14	2.13	55.12	16.50± 17.82	2.25	121.88	36.47± 41.90	2.25	50.63	19.09± 15.50	2.5	69	24.88± 21.20	0.39	0.27
Nitrate(mg/kg)	28.75	1253	412.98± 490	42.8	256.25	153.76± 65	128.3	1253.3	35.25± 297	28.5	1282	414.11± 498	87.5	780.8	248.8± 237	0.004	0.099
Ammonia(mg/kg)	0.75	3.63	1.96± 0.86	0.25	1.37	0.61± 0.39	0.62	3.37	1.43± 0.83	0.9	3.6	1.99± 0.89	ND	1.62	0.65± 0.52	<< 0.01	<<0.01
TN (%)	0.1	0.38	0.21± 0.08	0.05	0.40	0.18± 0.11	0.02	0.51	0.20± 0.15	0.05	0.737	0.31± 0.18	0.12	1.07	0.38± 0.24	0.086	0.002

During POM 08, nitrate in sediments ranged between 28.75 and 1253mg/kg with an average of 412.98±490mg/kg. In PRE 09, concentration of nitrate exhibited an average of 153.76±65mg/kg and it varied from 42.8 to 256.25mg/kg. During MON 09, its content ranged from 128.3 to 1253.3mg/kg (average: 356.25±297mg/kg). However, the estimated average for nitrate during POM 09 was 414.11±498mg/kg and the observed concentration varied from 28.5 to 1282/kg. During PRE 10, it ranged from 87.5 to 780.8mg/kg with an average of 248.8±217mg/kg.

POM 08 recorded an ammonia content ranging between 0.75 and 3.63 with an average of 1.96±0.86mg/kg. However, in PRE 09, the observed concentration varied from 0.25 to 1.37mg/kg (average: 0.61±0.39 mg/kg). During MON 09, it ranged from 0.62 to 3.37 mg/kg and recorded an average of 1.43±0.83mg/kg. POM 09 exhibited ammonia content ranging between 0.9 and 3.6 mg/kg (average: 1.99±0.89 mg/kg). Average ammonia content in sediments was estimated to be 0.65±0.52 mg/kg (during PRE 10), and it ranged from ND to 1.62mg/kg.





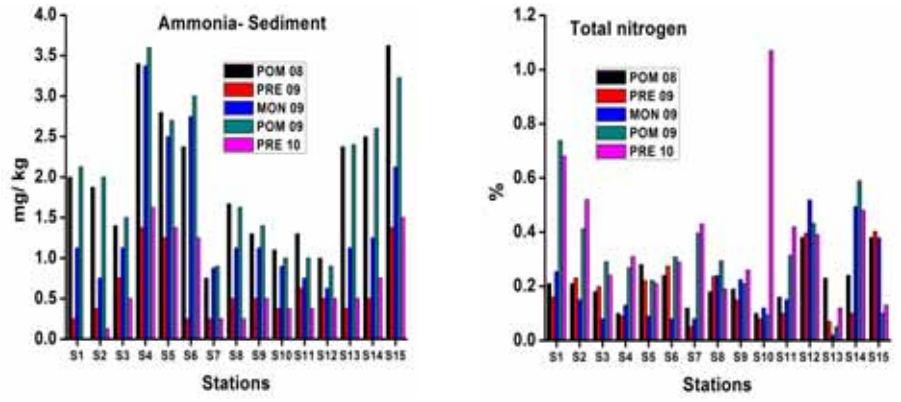


Figure 3.10 Seasonal variations in different fractions of nitrogen in sediment samples

3.2.5 Fractions of phosphorus in sediments

The seasonal and spatial variation in concentration of various fractions of phosphorous in estuarine sediments is shown in table 3.4 and figure 3.11. During POM 08, the labile P ranged between 1.16 and 24.5 mg/kg with an average of 7.32±6.16mg/kg. The Iron bound P varied from 54.48 to 3479 mg/kg and the estimated average was found to be 797.04 ± 839.61mg/kg. The calcium bound P varied from 51.32 to 1114mg/kg (average: 325.05±277.4mg/kg). The ASOP varied from 83.57 to 1611 mg/kg (average: 461±419mg/kg). The Alk-OP varied from 367.4 to 7155 mg/kg and recorded an average content of 4212±2722mg/kg. Res-P varied from 36.52 to 190 mg/kg with an average of 114.55±47.84 mg/kg. TP ranged between 944.1 to 12901 mg/kg (average: 5918± 3694mg/kg).

In the present investigation, labile P ranged between 5.41 and 191.10mg/kg with an average of 57.76 ± 51.63mg/kg (during PRE 09). The Iron bound P varied from 172 to 2247mg/kg (average: 788±512mg/kg). The Calcium bound P varied from 63 to 1193mg/kg (average: 438±323mg/kg). The ASOP varied from 77.3 to 651.79mg/kg (average: 210±148mg/kg). The Alk-OP varied from 17.9 to 1184mg/kg and estimated average concentration was 494 ± 353mg/kg. The Res-P varied from 27.3

to 270mg/kg with an average content of 114.38±77.12mg/kg. TP ranged between 586 to 5133 mg/kg and recorded an average concentration of 2104± 1175mg/kg.

It was found that during MON 09, the labile P ranged between 2.60 and 15.28mg/kg (average: 6.49±3.56mg/kg). The iron bound P varied from 120.5 to 2715 mg/kg (743.97± 681mg/kg) The Calcium bound P varied from 26.39 to 1359 mg/kg (average: 365±394mg/kg). The ASOP varied from 16.29 to 302.3mg/kg (average: 156.25±107.6mg/kg). The Alk-OP varied from 22.26 to 3242mg/kg (average: 479.60 ±793mg/kg). Res-P varied from 17.21 to 131.76mg/kg (average: 70.05± 37.06mg/kg). TP ranged between 487.3 to 4545.2mg/kg (average: 1822±1225mg/kg).

The concentration of labile P during the period POM 09 ranged between 1.18 and 17.34mg/kg (average: 4.80± 4.09 mg/kg). The iron bound P varied from 106.83 to 2720mg/kg (average: 907.95±719 mg/kg) The Calcium bound phosphorous varied from 30.12 to 1472mg/kg (average: 309 ± 405 mg/kg). The content of ASOP varied from 25.42 to 397.4mg/kg (average: 161.30±114.68mg/kg). The Alk-OP varied from 0.73 to 180.4mg/kg (average: 21.78±44.84mg/kg). The Res-P varied from 0.21 to 32.69mg/kg (average: 4.77± 8.56mg/kg). Total P ranged between 199.88 and 4097 mg/kg (average: 1410±1169mg/kg).

During the period PRE 10, the labile P ranged between 0.28 to 11.33mg/kg (average: 2.81± 2.91mg/kg). The iron bound P varied from 148.2 to 1686mg/kg (878± 437mg/kg). The Calcium bound P varied from 54.1 to 2727 mg/kg (average: 458± 719mg/kg). The ASOP varied from 54.16 to 555.4mg/kg (average: 172.34± 147.52mg/kg). The Alk-OP varied from 25.45 to 449.4mg/kg (average: 154.40± 122mg/kg). The Res-P varied from 0.73 to 40.34mg/kg (average: 11.01± 12.80mg/kg). TP ranged between 396.9 to 4349mg/kg (average: 1677± 966 mg/kg).

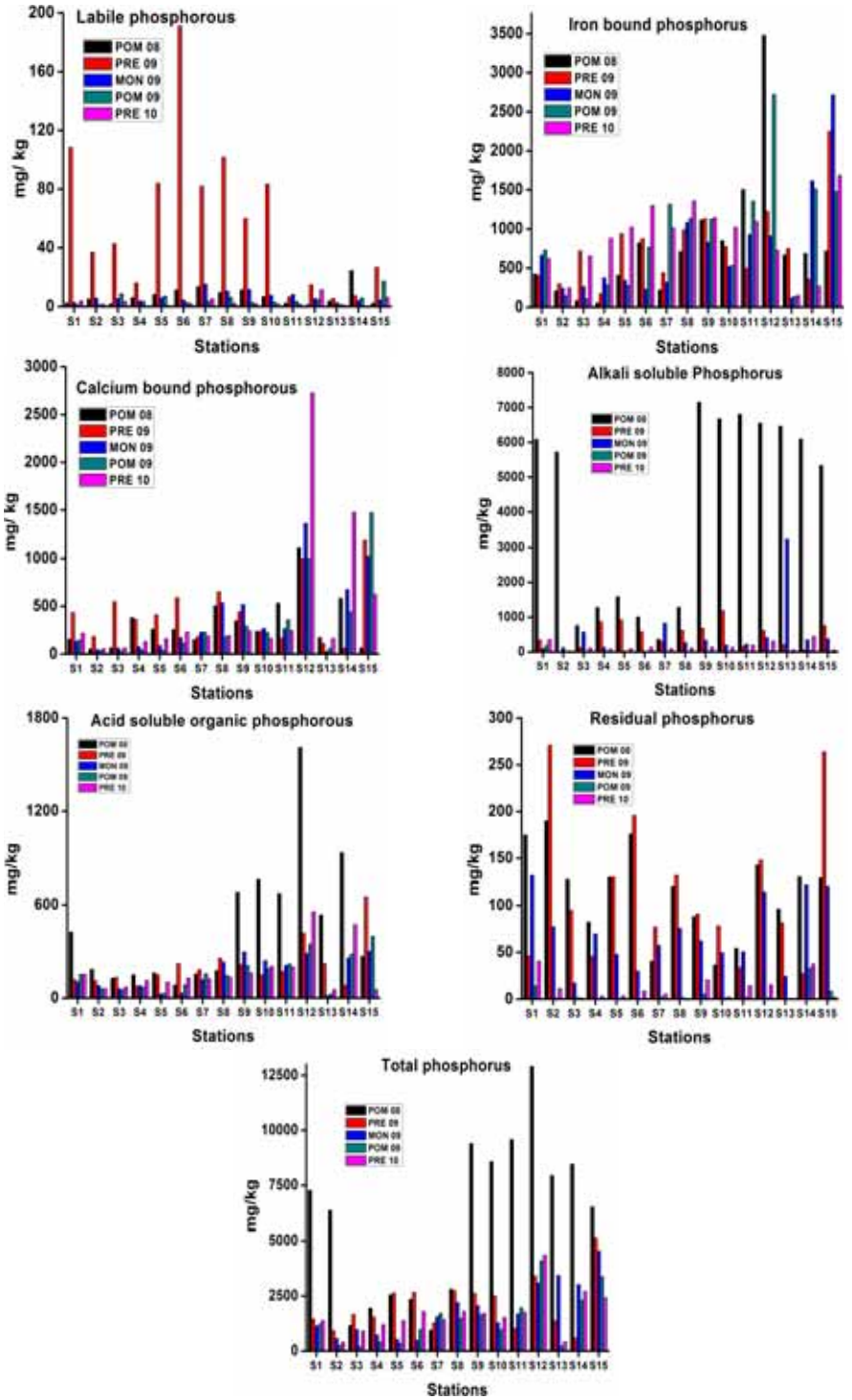


Figure 3.11 Seasonal variations in different fractions of phosphorus in sediment samples

3.2.6 Biochemical composition of sediments

Spatiotemporal variation and average concentration of various biochemical components estimated in the sediments of the study area are depicted in figure 3.12 and table 3.5.

Total protein (PRT)

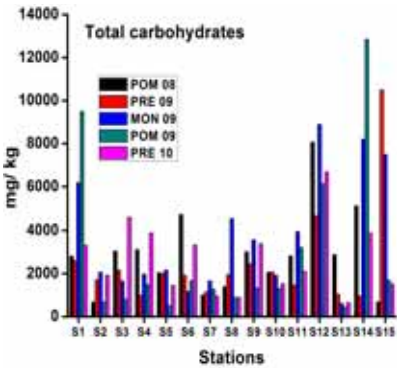
It was found that during POM 08, total protein content in sediments ranged from 352.6 to 6884 mg/kg and recorded an average of 2508±1533mg/kg. However during PRE 09, it varied from 111 to 12782 mg/kg (average: 2072±3313mg/kg).The concentration of PRT during MON 09 showed minimum 156.5 and maximum 7256 mg/kg and exhibited an average content of 1337±1884mg/kg. During POM 09, it varied from 195.11 to 19420mg/kg (average: 3166±5860 mg/kg). The recorded value during PRE10 ranged from 130.9 to 14000mg/kg (average: 2604±4039 mg/kg). The seasonal variation of proteins in sediments was graphically represented in figure 3.12.

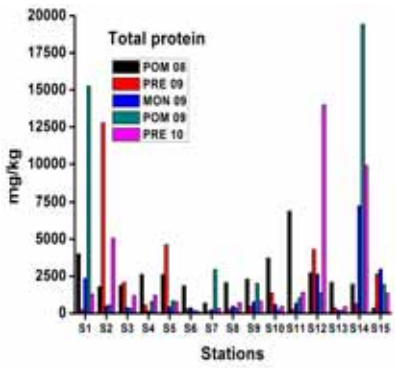
Total carbohydrates (CHO)

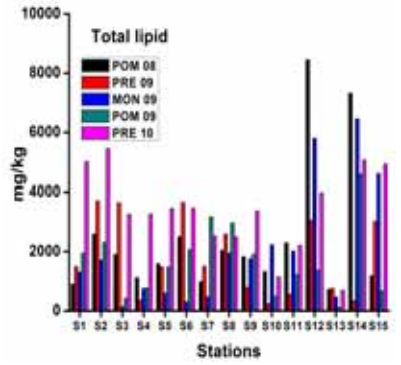
The seasonal variation of total carbohydrates (CHO) in the sediments is depicted in figure 3.12. During POM 08, concentration of carbohydrate in sediments ranged from 673.6 to 8072mg/kg and the estimated average content was found to be 2901±1936mg/kg. The CHO in sediments during PRE 09, varied from 943to 10491mg/kg and recorded average concentration was 2510±2393mg/kg. During MON 2009, its content ranged from 618.6 to 8887mg/kg (average: 3736 ±2725mg/kg). While during POM 09, value varied from 434.19 to 12840 mg/kg with an average of 2913 ±3690mg/kg. The concentration of CHO ranged between 657.3 and 6680mg/kg (average: 2671 ±1677mg/kg) during PRE 10.

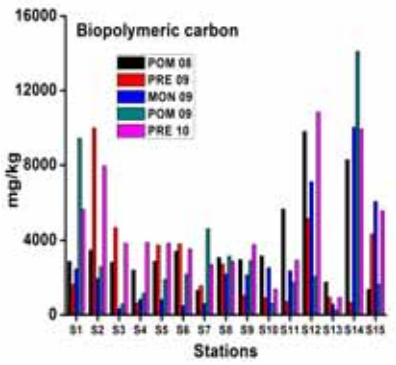
Table 3.5 Biochemical composition of sediments

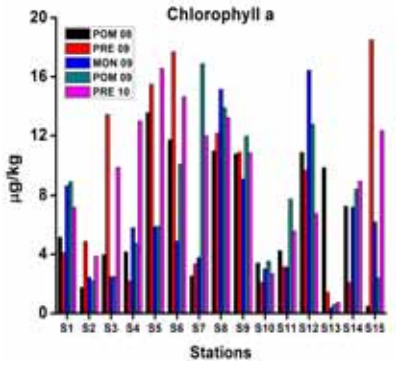
Parameter	POM 08			PRE 09			MON 09			POM 09			PRE 10			ANOVA (p value)	
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	spatial	seasonal
C/N	3.29	25.3	16.4± 7.4	12.5	25.012	19.2± 3.7	11.93	25.37	19.92± 3.87	4.37	24.77	13.3± 7	1.00	23.42	12.67± 6.33	0.74	0.003
CHO (mg/kg)	673.6	8072	2901± 1936	943	10491	2510± 2393	618.6	8887	3736± 2725	434.19	12840	2913± 3690	657.3	6680	2671± 1677	<< 0.01	0.53
PRT (mg/kg)	352.6	6884	2508± 1533	111	12782	2072± 3313	156.5	7256	1337± 1884	195.11	19420	3166± 5860	130.9	14000	2604± 4039	0.03	0.65
LPD (mg/kg)	724.3	8451	2451± 2291	240	3711	1814± 1332	132.1	6456	2037± 2004	115.29	4587	1699± 1213	688.7	5450	3355± 1407	<< 0.01	0.012
Chl a (µg/kg)	0.46	13.6	6.7± 4.2	1.42	18.49	8.0±6.1	0.36	16.43	6.2± 4.5	0.59	16.89	7.4± 4.9	0.74	16.54	9.1± 4.6	<< 0.01	<< 0.01
Chl b(µg/kg)	0.69	7.07	3.8± 2.1	0.87	11.73	4.1±2.9	0.24	7.00	2.7± 1.9	0.75	7.39	3.6± 2.0	0.54	15.83	4.7± 3.4	0.002	0.17
Chl c(µg/kg)	0.66	8.4	4.4± 2.2	1.03	14.59	4.86±3.47	0.23	6.91	3.15± 1.83	0.88	7.09	4.01± 1.93	0.51	26.19	5.91± 5.86	0.025	0.17
Tanin & Lignin(mg/kg)	7.18	2215	659± 714	126	4898	1303±1409	113.5	3957.4	1503± 1443	244.81	4193	1202±1185	453.81	6706	2229± 1794	<<0.01	0.002
LPD/CHO	0.25	3.85	1.02± 0.89	0.12	2.16	0.86±0.65	0.08	1.16	0.51± 0.28	0.20	3.42	1.21± 1.21	0.59	3.28	1.58± 0.92	<< 0.01	0.001
PRT/CHO	0.34	2.66	1.09± 0.74	0.09	7.46	1.0± 1.87	0.07	0.88	0.28± 0.19	0.11	2.33	0.88± 0.69	0.04	2.63	0.85± 0.85	0.03	0.16
LOM (mg/kg)	2215	19262	7861±4426	1916	18205	6396±5222	1268	21910	7111±6272	746	36847	7779±1014	1792	24661	8631±6092	<< 0.01	0.82
TOM %	1.52	8.84	4.46±2.56	.80	10.39	4.34±3.43	0.28	11.01	4.56±3.49	0.62	9.95	4.56±3.17	1.05	8.59	4.09±2.67	<< 0.01	0.98

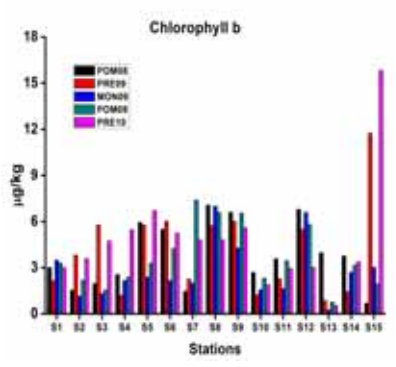

Total carbohydrates
POM 08
PRE 09
MON 09
POM 09
PRE 10
mg/ kg
Stations

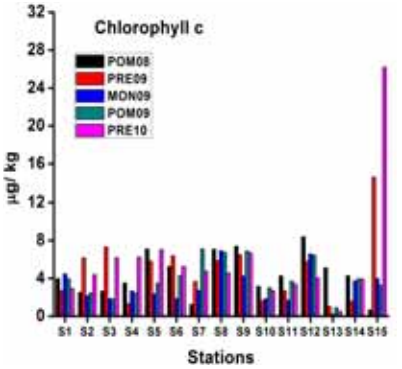

Total protein
POM 08
PRE 09
MON 09
POM 09
PRE 10
mg/kg
Stations

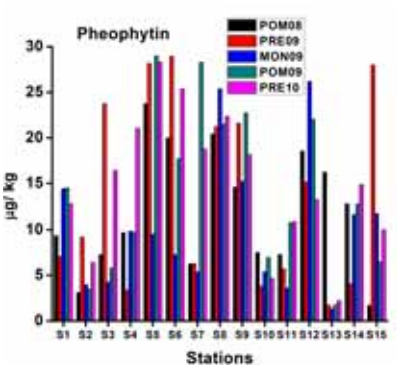

Total lipid
POM 08
PRE 09
MON 09
POM 09
PRE 10
mg/kg
Stations


Biopolymeric carbon
POM 08
PRE 09
MON 09
POM 09
PRE 10
mg/kg
Stations


Chlorophyll a
POM 08
PRE 09
MON 09
POM 09
PRE 10
µg/kg
Stations


Chlorophyll b
µg/kg
Stations


Chlorophyll c
POM08
PRE09
MON09
POM09
PRE10
µg/ kg
Stations


Pheophytin
POM08
PRE09
MON09
POM09
PRE10
µg/ kg
Stations

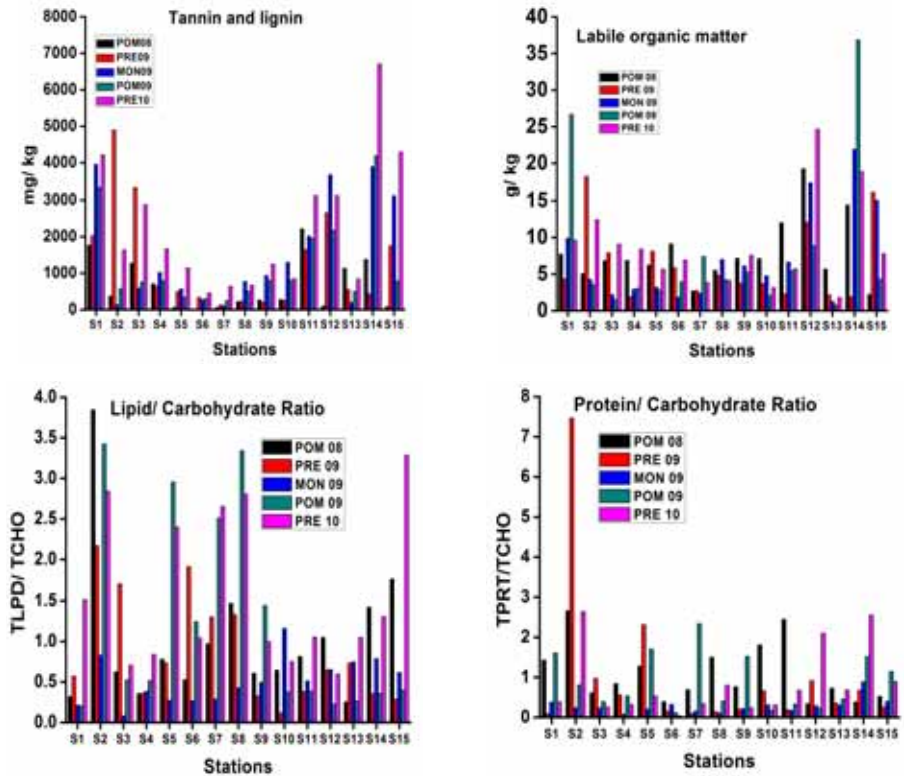


Figure 3.12 Spatial and seasonal variation of biochemical components and sediments

Total lipids (LPD)

During POM 08, lipid in sediments ranged from 724.3 to 8451 mg/kg with an average of 2451±2291mg/kg. In PRE 09, lipid content varied from 240 to 3711mg/kg and recorded an average content of 1814 ±1332mg/kg. While during MON 09, it was observed that the concentration ranged from 132.1 to 6456 mg/kg and the estimated average content was 2037±2004mg/kg. However, POM 09 revealed a minimum of 115.29 and maximum of 4587mg/kg with an average of 1699±1213 mg/kg. The content of lipid in sediments during PRE10 exhibited values between 688.7 and 5450mg/kg (average: 3355±1407mg/kg).

Total organic matter (TOM)

During POM 08, total organic matter in sediments ranged from 1.52 to 8.84 % and recorded an average content of 4.46±2.56%. In PRE 09, TOM varied from 0.80 to 10.39% and recorded average was 4.34±3.43%. The concentration of TOM during MON 09 ranged from 0.28 to 11.01 % and estimated average was found to be 4.56±3.49%. While in POM 09, value varied from 0.62 to 9.95 % and the observed average content was 4.56±3.17%. The concentration of TOM during PRE 10, ranged between 1.05 and 8.59% (average: 4.09±2.67%). Spatiotemporal variation in TOM content is furnished in figure 3.8.

Labile organic matter (LOM)

In the present study, POM 08 recorded LOM content ranging from 2215 to 19262mg/kg and recorded an average content of 7861±4426mg/kg (table 3.5). In PRE 09, LOM varied from 1916 to 18205mg/kg and recorded average was 6396±5222mg/kg. The concentration of LOM during MON 09 ranged from 1268 to 21910 mg/kg and estimated average was found to be 7111±6272mg/kg. While in POM 09, its content varied from 746 to 36847 mg/kg and estimated average was 7779±1014mg/kg. The content of LOM during PRE 10, ranged between 1792 and 2466 mg/kg (average: 8631±6092mg/kg).

Lipid/Carbohydrate ratio

During POM 08, lipid/carbohydrate ratio in sediments ranged from 0.25 to 3.85 and the recorded average was 1.02±0.89. Meanwhile during PRE09, lipid/carbohydrate proportion varied from 0.12 to 2.16 (average: 0.86±0.65). But during MON 09 the estimated ratio ranged from 0.08 to 1.16 with an average of 0.51±0.28. However POM 09 recorded a minimum

of 0.20 and maximum of 3.42 (average: 1.21±1.21). In the case of PRE 10, the ratio ranged from 0.59 to 3.28 and exhibited an average of 1.58±0.92.

Protein/ Carbohydrate ratio

Spatiotemporal variation of PRT/CHO ratio is depicted in figure 3.12. During POM 09, PRT/TCHO ratio in sediments ranged from 0.34 to 2.66 and recorded an average value of 1.09±0.74. In PRE 09, PRT/CHO varied from 0.09 to 7.46 and estimated average was found to be 1±1.87. MON 09 exhibited PRT/CHO ratio ranging from 0.07 to 0.88 with an average of 0.28±0.19. While during POM 09, its value ranged 0.11 to 2.33 and estimated average value was 0.88±0.69. PRE 10 showed a variation from 0.04 to 2.63 (average: 0.85±0.85).

Chlorophyll a

The estimated concentration of chlorophyll a during POM 08 ranged from 0.46 to 13.6 µg/kg with an average of 6.7 ±4.2µg/kg (table 3.5). In PRE 09, it recorded a variation from 1.42 to 18.49 µg/kg and recorded an average content of 8 ±6.1µg/kg. While during MON 09, it was observed that the content of chl a ranged between 0.36 and 16.43µg/kg and the estimated average content was found to be 6.2±4.5µg/kg. However, POM 09 revealed a minimum of 0.59 µg/kg and maximum of 16.89 µg/kg with an average of 7.4±4.9 µg/kg. The content of chl a in sediments during PRE 10 exhibited values between 0.74 and 16.54µg/kg (average: 9.1±4.6µg/kg).

Chlorophyll b

POM 08 exhibited chlorophyll b content ranging from 0.69 to 7.07 µg/kg with an average of 3.8 ±2.1µg/kg. In PRE 09, it varied from 0.87 to 11.73µg/kg and recorded an average content of 4.1±2.9µg/kg. While during

MON 09, it was observed that the concentration ranged from 0.24 to 7.0µg/kg and the estimated average content was 2.7±1.9µg/kg. However, POM 09 revealed a minimum of 0.75 and maximum of 7.39 with an average of 3.6±2.0µg/kg. The content of chl b in sediments during PRE10 exhibited values between 0.54 and 15.83µg/kg (average: 4.7±3.4µg/kg).

Chlorophyll c

Chlorophyll c exhibited concentration ranging from 0.66 to 8.4 µg/kg with an average of 4.4±2.2µg/kg during POM 08. In PRE 09, it varied from 1.03 to14.59 µg/kg and recorded an average content of 4.86±3.47µg/kg. While during MON 09, it was observed that the concentration ranged from 0.23 to 6.91µg/kg and the estimated average content was 3.15±1.83µg/kg. However, POM 09 recorded a minimum chl c content of 0.88 µg/kg and a maximum of 7.09µg/kg with an average of 4.01±1.93 µg/kg. The content of chl c in sediments during PRE10 exhibited values between 0.51 and 26.19µg/kg (average: 5.91±5.86µg/kg).

Tannin and Lignin

Spatiotemporal varion in concentration of tannin and lignin in sediments is represented in figure (3.12). In the present investigation, POM 08 exhibited tannin and lignin content ranging between 7.18 and 2215 mg/kg with an average of 659±714mg/kg (table 3.5). In PRE 09, it varied from 126 to 4898mg/kg and recorded an average content of 1303±1409mg/kg. While during MON 09, it was observed that the concentration ranged from 113.5 to 3957mg/kg and the estimated average content was 1503±1443mg/kg. However, POM 09 revealed a minimum of 244.81 mg/kg and maximum of 4193 mg/kg with an average of 1202±1185mg/kg. Concentration of tannin and lignin in sediments during

PRE10 exhibited values between 453.81 and 6706mg/kg (average: 2229±1794mg/kg).

Discussion

Rainfall is the most important cyclic phenomenon in tropical countries as it brings important changes in the hydrographical characteristics of the marine and estuarine environments. During the present study, the maximum rainfall was recorded during south west monsoon. In the present study, the peak values of rainfall were recorded during MON 09. The rainfall in India is largely influenced by two monsoons viz., southwest monsoon on the west coast, northern and northeastern India and by the northeast monsoon on the southeast coast (Perumal, 1993).

Generally, temperature of surface waters is influenced by the intensity of incident solar radiation, evaporation, freshwater influx and cooling and mix up with ebb and flow from adjoining neritic waters. The surface and bottom water temperature (average) during post monsoon was lower because of strong land sea breeze and underwater currents and the recorded high value during premonsoon could be attributed to higher insolation rate of solar radiation (Karuppasamy and Perumal, 2000; Senthilkumar et al., 2002; Santhanam and Perumal, 2003). In the present investigation, there was no spatial variation ($p>0.05$) observed in temperature which could be due to the lack of viable intensity of prevailing streams and the resulting mixing of water (Reddi et al., 1993). Statistical analysis (ANOVA) showed that there is no spatial variation and therefore be concluded that stations are almost similar temperature, but with high seasonal variation ($p<0.01$). Present study recorded the minimum temperature at S9 (MON 09) and maximum at S5 (PRE 09).

The tidal mixing and estuarine circulation are crucial factors influencing the hydrographic status of an estuary which in turn affect the nutrient distribution and productivity. Cochin backwater system is characterized by an ox-bow shape, running parallel to Arabian Sea (Soman, 1997). Due to its peculiar topography, the circulation patterns in the northern and southern arms of the CBW are found to be different (Ramamirtham and Muthusamy, 1986).The higher freshwater flow during summer monsoon suppresses the tidal characteristics and increases stratification in the lower estuary (Qasim and Gopinathan, 1969). Tides at Cochin estuarine system are of a mixed semi-diurnal type, with the maximum spring tide range of about 1m (Srinivas, 1999), resulting in incomplete flushing. Hydrobiological studies of the estuary (Menon *et al*., 2000) showed that the high flushing during monsoon completely transforms the estuary into a freshwater habitat.

Wide fluctuations in the values of transparency (figure 3.4) might be due to discharge of water due to floating sediments carried by the river from catchment areas. Dredging operations to maintain the average depth of ship channel, Cochin harbour area, Cochin Shipyard and Vallarpadom Container Terminal region, generates huge loads of suspended sediments which affect the transparency of water column. It is evident that heavy rainfall and intense cloud cover prevailing in the monsoon season reduces solar insolation and the high input of suspended sediments makes the estuary more turbid (Renjith et al., 2012). However, during the post-monsoon period, the excess nutrients carried to the estuarine system through the land runoff, increased solar radiation and reduction in turbidity result in the development of an ideal environment for high primary production. In the present investigation, the estimated light attenuation

coefficient was higher during MON 09, a similar observation reported by Madhu et al., 2009 and thereby the light limitation significantly reduces the primary production during this particular season. Generally, higher attenuation values are expected in the monsoon months especially during flood conditions due to likely increase in turbidity of the water and low intensity of solar radiation due to the intense mixing of water having heavy loads of suspended particulate matter (Sarala Devi, 1989). Low values of extinction coefficients were recorded during premonsoon months, which indicated a higher transparency.

Significant spatial and temporal variability of physico-chemical characteristics and productivity patterns are among the important characteristics of estuaries (Renjith et al., 2012). Physico-chemical parameters like nutrient concentrations, algal chlorophyll, water transparency (Carlson, 1977; Kratzer and Brezonik, 1981) and primary production measurements (Nixon, 1995) have often been employed to assess trophic status of water.

In the present investigation, the values of pH in both surface and bottom waters remained slightly alkaline at all the stations. Recorded pH during POM 10 was maximum at S9 (surface water), but in maximum was recorded at S8 (bottom water) during PRE 09. Generally, fluctuations in pH values during different seasons of the year is attributed to factors like removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of seawater by freshwater influx, low primary productivity, reduction of salinity and temperature and decomposition of organic materials (Karuppasamy and Perumal, 2000; Rajasegar, 2003). Higher values for pH were recorded during summer seasons, which might be due to the influence of seawater ingression, increased photosynthetic activity

(Subramanian and Mahadevan, 1999). The statistical analysis also revealed that salinity showed highly significant negative correlation with rainfall. In the present study, pH (bottom layers) showed highly significant positive correlation with salinity and alkalinity which might be attributed to the fact that rise in pH values associated with increasing salinity and alkalinity, is a general phenomenon observed in aquatic systems.

The maximum DO content was recorded at FACT- Kalamassery (S15) (surface) and at Murinjapuzha –Brahmamangalam(S3) (bottom) during PRE 10. Statistical analysis (ANOVA) showed that there is much seasonal and spatial variation in DO (both surface and bottom layers). It is well known that the temperature and salinity affect the dissolution of oxygen (Vijayakumar et al., 2000). In the present investigation, higher content for dissolved oxygen was recorded during monsoon, which could be due to the cumulative effect of higher wind velocity joined with heavy rainfall and the resultant freshwater mixing (Das et al., 1997). Mitra et al., (1990) mainly attributed seasonal variation of DO to freshwater flow and terrigenous impact of sediments. Further, significant inverse relationship between rainfall and nutrients indicated that freshwater flow constituted the main source of the nutrients in the estuary. In surface waters, the negative correlation of DO with salinity implied the general fact that solubility of oxygen decreases with increase in salinity.

Phytoplankton photosynthesis drives many biogeochemical and ecological processes in lakes, estuaries, and the ocean. Dynamic changes in pH, trace metal speciation, and concentrations of dissolved gases (oxygen and carbon dioxide), inorganic nutrients (nitrate, phosphate, silicate), and organic compounds (amino acids, organosulfur compounds) are all closely associated with fluctuations in phytoplankton photosynthesis. Trophic

linkages also exist, between the phytoplankton as primary producers and populations of consumer organisms including bacteria, zooplankton, benthic invertebrates, and fish.

Biochemical oxygen demand depends on temperature, extent of biochemical activities, concentration of organic matter and such other related factors. Maximum value of BOD was observed in pre monsoon period due to the restricted flow of oxygenated water from upper reaches of the contributing river (Renjith et al., 2012). The higher biological production coupled with sinking of organic matter also leads to a high oxygen demand in the water column (Martin et al., 2010). Rapid industrialisation and urbanization in the around Cochin area has resulted in a daily discharge of about 104 million litres of untreated effluents and 260 m^3 of raw sewage into the backwater system (Qasim 2003; Balachandran et al., 2005). Waste disposal from aquaculture fields and agricultural fields have worsened the organic pollution in this unique aquatic system. The combined effects of all these factors might be contributed to the increased BOD levels in the study area.

Both surface and bottom waters exhibited spatial and seasonal variation ($p < 0.01$) for salinity. In the present investigation, no vertical stratification was observed and fresh water conditions were prevalent during the monsoon season. However, stratification was observed during the post-monsoon season. Higher values for salinity noticed during post monsoon season (figure 3.4) could be due to increased rate of evaporation and the neritic water dominance. The salinity acts as a limiting factor in the distribution of living organisms, and its variation caused by dilution and evaporation is most likely to influence the fauna in the intertidal zone (Gibson, 1982). Generally, changes in the salinity in the brackish water

habitats like backwaters might be due to the influx of freshwater from land run off, caused by monsoon or by tidal variations. In the study area, POM 08 recorded higher values which could be attributed due to the higher tidal inflow of saline water. During the monsoon season, the rainfall and the freshwater inflow from the land in turn moderately reduced the salinity (Govindasamy et al., 2000; Gowda et al., 2001; Rajasegar, 2003; Qasim, 2003). It was observed that during the present investigation, salinity displayed highly significant negative correlation with DO indicating the fact that higher salinity inhibits the dissolution of atmospheric oxygen.

Analysis of variance was carried out to compare the free CO_2 in the surface and bottom water which revealed no significant difference among the stations. In the present investigation concentration of CO_2 found to exhibit highly significant seasonal variation ($p<0.01$). Estuaries have been regarded as a significant source of CO_2 to the atmosphere (Frankignoulle et al., 1998). This CO_2 is produced in high concentrations in estuarine regions which were known to be heterotrophic systems, where organic carbon transported by rivers is partly mineralized (Gattuso et al., 1998).

Nutrient levels are important determinants of biodiversity, influencing the processes of competition and community structure in the water bodies. In the pelagic waters, concentration levels of inorganic nutrients such as nitrate, phosphate and silicate in the water dictate population growth of planktonic primary producers. Rates or pathways through which exogenous nutrients are converted into algal biomass is different among estuaries (Cloern, 2001). Eutrophication caused by excess supply of nutrients from industrial and domestic activities can influence coastal and estuarine waters (Barmawidjaja et al., 1995; Tsujimoto et al., 2006). Increased input of nutrient to the CBW is not only from the rivers

but also contributed by increased industrial and domestic activities (Jyothibabu et al., 2006). Monsoon rain, after the dry summer period (January to May) washes the adjacent land area and drain nutrient enriched waters to CBW, making the system highly productive (Qasim,2003; Madhu et al., 2007).

Nutrients are generally considered to be the limiting factors for phytoplankton productivity. The nutrient content of estuaries is determined by their concentration in the riverine and coastal water sources. Generally nitrate, nitrite, phosphate and silicate are regarded as essential nutrients for plankton growth which affects the survival and population fluctuation of other fauna and flora in the food chain (Pramodbabu, 2007). The changes and seasonal cycles of these nutrients control most of the biological activities in estuarine systems. The nitrogen as nitrate and phosphorus as phosphate greatly augment the primary productivity and both are essential for the survival of primary producers, yet they subsist in very small concentration in the surrounding medium. Very low concentration of silicon present in the water can limit phytoplankton production due to the suppression of metabolic activities of the cell. Silicon represents a vital nutrient for the skeletal growth of diatoms (Pramodbabu, 2007).

In the present investigation, average values of ammonia was found to be higher during premonsoon season (figure 3.5) and this may be partly due to the death and subsequent decomposition of phytoplankton and also might be the excretion of ammonia by planktonic organisms (Segar and Hariharan, 1989; Ananthan, 1994; Rajasegar, 1998). Some stations exhibited higher values that may be due to industrial effluents and terrestrial input. Ammonia displayed a non-uniform distribution throughout

the entire study period which indicated an exogenic input in the estuary (Renjith et al., 2011; Renjith et al., 2012).

The recorded maximum for nitrate content (37.63µmol/L) during monsoon season (figure 3.5) could be mainly due to the organic materials received from the catchment area during ebb tide and similar results were also recorded by Das et al., 1997. Besides, the increased nitrate level was due to fresh water inflow, organic decomposition and terrestrial run-off during the monsoon season and previous literature by Karuppasamy and Perumal, (2000) supports these facts. Another possible way of nitrates entry is through oxidation of ammonia form of nitrogen to nitrite formation (Rajasegar, 2003). The minimum concentration of (8µmol/L) was recorded during post monsoon period may be due to its utilization by phytoplankton as evidenced by high photosynthetic activity apart from the neritic water dominance, which contained negligible amount of nitrate (Rajashree Gouda and Panigrahy, 1995; Das et al., 1997; Govindasamy et al., 2000). In the present investigation, the increased in nitrate content observed during the monsoon season, higher content in the low saline stations and the significant negative correlation with salinity, indicated the riverine input (Renjith et al., 2012). Moreover, nitrate in water column showed highly significant positive correlation with DO which inferred the fact that oxygenated condition favoured the formation of nitrate.

During the present investigation the nitrite content was lower during monsoon season (figure 3.5). Nitrite exhibited its maximum at S14 (POM 08) and S6 (PRE 10) in surface and bottom waters respectively. Average nitrite content in surface and bottom water was also found to be higher during the pre monsoon and which could be attributed due to the variation in phytoplankton, excretion and oxidation of ammonia and reduction of

nitrite (Kannan and Kannan, 1996). The lower contents of nitrite during the premonsoon season were due to less freshwater input, higher salinity, pH and also uptake by phytoplankton. The similar situation has already been reported (Edwards and Ayyakannu, 1991; Mathevan, 1994). Highly significant seasonal variation (p value<0.01) was recorded for this parameter in the case both surface and bottom waters.

Both surface and bottom waters exhibited lower content for phosphorous during PRE 10 (Figure 3.14), which could be attributed to the limited flow of freshwater, high salinity and utilization of phosphate by phytoplankton (Senthilkumar, et al., 2002; Rajasegar, 2003). PRE 09 exhibited higher phosphate concentration due to high rainfall and freshwater inflow compared to PRE 10. The addition of super phosphates applied in the agricultural fields as fertilizers and alkyl phosphates used in households as detergents can be other sources of inorganic phosphates during the season (Das et al., 1997; Senthil Kumar et al., 2002). Analysis of variance applied to test the significance of difference between stations showed that phosphate concentration differ spatially in surface waters ($p<0.05$) compared to bottom waters ($p>0.05$). The variation may be due to the processes like adsorption and desorption of phosphates and buffering action of sediment under varying environmental conditions (Rajasegar, 2003). The higher phosphate content in the water column could be attributed to regeneration and release of total phosphorus from sediment into the water column by turbulence mixing (Chandran and Ramamoorthy, 1984). Phosphate exhibited highly significant seasonal variation ($p<0.01$). In the present study, dissolved inorganic phosphate displayed significant positive correlation with salinity indicating the internal loading (Renjith et al., 2012).

The distribution pattern of salinity and silicate and their interrelationship in Cochin backwater system was investigated by (Anirudhan et al., 1987) and pointed out the fact that construction of Thanneermukkom bund had led to the stagnation of water resulting in the large changes in the hydrography. In the present study, both surface and bottom waters exhibited higher silicate content during POM 08 and POM 10 (Figure 3.15). The maximum content was recorded at Aroor-Kumbalam (S6) (surface) during POM 09 and Eloor (S13) (bottom) during POM 09. Highly significant seasonal ($p<0.01$) variation was noticed for silicate in the surface waters of the study area. However, in bottom waters, the significant spatial ($p<0.05$) and seasonal ($p<0.01$) variations were observed. Silicate exhibited significant negative correlation with salinity, suggesting its input through land runoff (Renjith et al., 2012).

Primary production can be limited by Fe availability in coastal environments (Kirchman et al., 2000; Bruland et al., 2001). Dissolved Fe in aquatic systems can exist in two different oxidation states [Fe (II) and Fe (III)]. The Fe (III) is the thermodynamically stable form in oxygenated waters and has a very low solubility in high saline water (Liu and Millero, 2002). Fe (III) becomes rapidly hydrolyzed into various Fe(III) oxyhydroxides. The low solubility of Fe oxyhydroxides and the tendency to form colloids which can contribute to the scarcity of directly bioavailable Fe species in the marine environment (Wen et al., 1999). Dissolved Fe (III) occurs for a major part as complexes (Fe (III)) with strong organic ligands (Waite, 2001). The majority of dissolved Fe in river water exists as small colloid particles (Wen et al., 1999). Flocculation of these colloids, upon mixing of fresh river water with seawater during estuarine mixing, causes a massive removal of the freshly formed particulate Fe (Sholkovitz, 1978).

Riverine dissolved iron, comprises mostly colloidal iron oxy-hydroxides closely associated with natural organic matter (Nowostawska, 2008). Organic complexation is an important factor in the biogeochemistry of Fe in estuarine waters, as it maintains iron in the dissolved phase at high salinities beyond the flocculation zone. The dissolved phase will be flushed from the estuary while the non-organically complexed fraction tends to aggregate and adsorb to particles, thereby exhibiting longer residence time (Morris et al., 1986). Organically complexed iron of estuarine systems can act as a source of dissolved iron for coastal waters (Powell and Wilson-Finelli, 2003).

Texture analysis of sediments revealed that during MON 09, most of the stations exhibited the dominance of mud (silt + clay) except S13. During POM 10 majority of the stations exhibited muddy-sand /silty-sand character, but S3 and S4 displayed sandy nature. Almost all the stations showed the dominance of mud, while S2, S4, S13 and S14 exhibited sandy nature during POM 09. Sand dominated sediments were observed at S3, S4, S5, S11, S13, S14, and S15 during PRE 09. The occurrence of mud as the major grain size fraction at S6, S7, S8, S9, S10 and S12 could also be noticed. The stations S1, S2, S6, S8, S12 and S14 were muddy in nature and others were dominated by sand during PRE 10. Determination of textural components in aquatic sediments is an essential requirement for the better understanding of fluvial process. The content of textural components and their relative proportions have a strong bearing in the physico-chemical characteristics of aquatic environments. It is an important abiotic measure determining the living condition / environment of aquatic flora and fauna.

A large part of the carbon flux between terrestrial and marine systems is mediated by estuaries (Holligan and Reiners, 1992). Terrestrial

carbon enters the estuary mainly through freshwater tidal reaches. Significant fraction of the particulate and dissolved organic matter becomes associated with sediment particles to form large macro-aggregates called estuarine flocs (Eisma, 1993). The high sinking rates due to the specific hydrodynamic conditions of estuaries, these flocs accumulate in turbidity maxima situated in the upstream estuarine reaches (Largier, 1993). Because of the increased residence time of particles in the turbidity maxima, most of the terrestrial organic matter entering the estuary is respired in the freshwater tidal to brackish estuarine zones (Frankignoulle et al., 1998). Inspite of the higher productivity, the transfer coefficient from primary to secondary level in the Cochin backwater system is only 7% and the excess organic matter may be transported to the coastal waters or sink within the estuary (Madhupradhap et al., 1980; Jyothibabu et al., 2006).

Higher concentration for organic carbon reported at Cheranellur (S12) during MON 09 (figure 3.7) could be attributed to anthropogenic input of organic matter derived from land runoff. Lower contents for TOC recorded at Eloor (S13) might be attributed to the dilution effects associated with high river discharge from River Periyar. Analysis of variance (ANOVA) revealed highly significant spatial variation ($p<0.01$). Organic carbon constitutes an integral part of aquatic sediments. The increased attention in the determination of organic carbon in the sediments of various aquatic environments is due to its significance in assessing the biological, chemical and geological process operating in these environments. Organic carbon in sediments may be derived from autochthonus or allochthonus processes. Sedimentation followed by diagenetic decomposition of organic carbon can alter the Eh-pH conditions of aquatic environments. Further, the organic carbon in the form of organic matter provides the main energy

source for the heterotrophic organisms living in aquatic environments. The organic carbon distribution in an aquatic environment is controlled mainly by the textural attributes of sediments. An understanding of the distribution of organic carbon and its bearing on the physico-chemical and biological parameters is very much essential for assessing the extent of nutrient input and/or pollution load in aquatic systems. In the present investigation, the strong association (table 3.6) between organic matter with clay and silt speculated to be a result of sorption of organic matter to mineral surfaces. The fact that much of organic matter is not easily removed from the mineral matrix has major ramifications for the role of sorptive preservation of organic matter in sedimentary environments. One reason for such stability is that organic matter may be lodged in small mesopore-sized spaces which are too small for access by microbial enzymes (Mayer, 1994).

Total organic carbon/ total sulphur (TOC/ TS) ratio provides a qualitative indication of the redox status of the environment of deposition, when TS concentrations are high (Raiswell et al., 1987). TOC/ TS ratios > 5 are considered as oxic sediment with oxygenated bottom water, TOC/ TS = 1.5-5 indicates sediments deposited under periodic anoxia and TOC/ TS < 1.5 represents anoxic sediment with anoxic water. The average TOC/ TS values in the study region can be included in the second category (periodic anoxia) suggesting that the sediments undergo sulphate reduction below an oxygenated water column (Hedges and Keil, 1995).

Stoichiometric ratios of nutrients are utilized to determine the origin and transformation of organic matter (Yamamuro, 2000). According to Redfield, (1958), C/ P ratio for algal material is 7. Hecky et al., (1993) indicated that wide range of C/ P and N/ P ratios in aquatic sediments can still be considered to follow Redfield ratio (C/ P= 28 to 56 and N/ P=4 to

9). The lower values for this ratio indicated enrichment of phosphorous in sediments of the estuarine system. The observed N/P ratio in estuarine sediments revealed considerable variations among stations. The lower N/P ratios also suggest that there might be higher benthic nitrogen recycling, and denitrification, and the benthic release of nitrogen could play a role in sustaining the productivity of the system (Renjith et al., 2010). The C/P ratio recorded maximum in the seasons POM 09 and PRE 10 at same station S2, due to the higher organic carbon content derived from domestic sewage. The N/P recorded maximum at S2 (POM 09).

Anthropogenic activities like industrialization, urbanization and agricultural runoff have resulted in tremendous ecological stress on aquatic ecosystems. Most of estuarine sediments around the world possess increased levels of nutrients, and other ecologically harmful chemical compounds. The problem is further complicated by the fact that most of these pollutants tend to adhere on suspended organic and inorganic particles which ultimately deposited in aquatic sediments. These contaminants may continuously released from the sediments by diffusion or resuspension. Sediment is the source of nutrient for macrophytes (Jin et al., 2006). Release from the sediment-water interface has been suggested as the main pathway for nutrient recycling (Sanchez-Carrillo et al., 2006). Nitrogen occurs in sediments in various forms like nitrate, nitrite and ammonia and a range of organic nitrogen compounds, like amino acids, urea and humic substances. Nitrate is the most stable form of nitrogen under oxic conditions.

In the present investigation, concentration of ammonia was much lower in sediments, and could be explained by that the processes like denitrification and nitrogen fixation can determine available nutrient ratios (Mc Carthy et al.,

2007). Its maximum content was recorded at S15 (POM 08).Besides, dissimilatory nitrate reduction to ammonium is also important, relative to denitrification. The anoxic conditions are more favourable for maintaining high NH_3/NH_4^+ levels, mainly because the conversion of NH_4^+ to nitrate by nitrification remains low because of the lack of dissolved oxygen under these conditions. Nitrification coupled with denitrification converts biologically available N forms (NH^{4+} and NO_3^-) to molecular nitrogen gas and may reduce effects of excessive N inputs and eutrophication. Release of ammonium from sediments was reported during periods of hypoxia and anoxia (Berman et al., 1999). The fluxes of ammonia from benthic recycling and from the river discharge could be of the same order of magnitude in monsoon as well as non monsoon seasons (Padma, 2005).

Nitrate for coupled denitrification derives from organic matter mineralization to NH_4^+ followed by nitrification. Dissimilatory nitrate reduction to ammonium is an alternative pathway for nitrate in sediments (An and Gardner, 2002). The relative partitioning between nitrate reduction pathways is also regarded as an important mechanism, since denitrification removes fixed N from the system while dissimilatory nitrate reduction returns it as bioavailable ammonium. The higher nitrogen and phosphorus concentrations of sedimentary nitrate-N in the present study pointed to higher rate of nitrification and less denitrification. Nitrification, the conversion of ammonia (NH_3) to nitrate (NO_3^-) via nitrite (NO_2^-), is essential to the function of the nitrogen cycle in aquatic environments (Urakawa et al., 2006). The very low concentrations of nitrite-N in the sediment revealed the fact that the nitrite-nitrogen is intermediate in oxidation state between ammonia and nitrate, and as such it can appear as a transient species in both the oxidation of ammonia and the reduction of

nitrate. Mixing with sea water was found to exert a negligible effect on the concentration of nitrite-N in the sediment. Being very low values, it could be assumed that the nitrite-N is more or less uniformly distributed in the sediments of the study area and thus it ruled out any conditions for the existence of anoxic basins in any of the sampling sites.

Analysis of variance revealed that only spatial variation was highly significant ($p<0.01$) in the case of nitrate. In the present study, NO_3^- was higher during POM 08 and POM 09 and recorded lower concentration during PRE 09 and PRE 10. The higher nitrate-N concentrations are related to more intense mixing of the super lying water column due to rain, land run off and high river discharges. The higher values were particularly important where there was influence on sediment from agriculture, industries and waste water and also physical degradation of the land area. The lower values in the sediments could be attributed to the sandy nature of the sediments. The enriched levels of nitrogen compounds in the backwaters could be attributed to the discharge of industrial, domestic, and agricultural wastes (Saraladevi et al., 1991; Qasim, 2003).

Fractionation is the method used to characterize phosphorus in aquatic sediments and it separates phosphorus into different forms based on solubility and reactivity against various reagents. Sequential chemical extraction techniques have been a useful tool to examine these processes (Ruttenberg, 1992; Jensen and Thamdrup, 1993), since the analysis of total sediment phosphorus does not represent an accurate measurement of phosphorus exchangeability and bioavailability for algal growth. In the present study, fractionation was employed to quantify different fractions of phosphorus in the estuarine sediments in order to assess the processes leading to the fractional distribution of phosphorus, its bioavailability and influence on the trophic

status. Bioavailability and cycling of phosphorus in estuaries depend upon phosphorus fractionation (Andrieux-Loyer and Aminot, 2001). Conditions like salinity, pH or redox potential present in estuarine systems determines the relative importance of each fraction of P (Lebo, 1991; Paludan and Morris, 1999). Phosphorous in sediments can be found in association with iron, aluminium and calcium oxides or adsorbed on the mineral surface and organic materials. In order to eliminate the disadvantages such as uncertainity in the bioavailable and the nonspecific nature of the extraction solutions, an extraction scheme using chelating agents was developed by Golterman, (1996). This procedure is useful for the extraction of inorganic phosphorus pools with lesser modifications of the organic pool.

Iron-bound IP fraction was found to be the main phosphorous pool in the estuary, and exhibited a seasonal maximum accounting for 28.66% (S6, POM 08), 48.83% (S14, PRE 09) 60.62% (S5, MON 09), 74.80% (S7, POM 09) and 69.37% (S4, PRE 10) of the total phosphorus. Iron- and calcium-bound inorganic fractions and acid soluble organic fractions of phosphorus are generally considered to be bioavailable (Diaz-Espejo et al., 1999). Contribution of bioavailable fraction to total P was in the range: 29.45±14.77% (POM 08); 68.27±13.4% (PRE 09); 70.68±23.8% (MON 09); 97.24±3.85±3.85% (POM 09); 89.50±6.19% (PRE 10). Present study revealed that the bulk of the total phosphorus is bioavailable; the estuarine sediments have the potential to act as source of phosphorus to the overlying waters (Joseph et al., 2010). The Fe bound P exhibited highly significant positive correlation with clay, silt, TOC, TN, TS, chlorophyll pigments and negative correlation with sand pointed towards influence of granulometry and diagenetic processes controlling its distribution. The variations in concentration of different P fractions are depicted in figure 3.23.

Correlation analysis confirmed the significant interrelations among the bioavailable fractions. In estuarine sediments, the calcium bound phosphorous exhibited significant positive correlation (table 3.6) with total carbon, organic carbon and acid soluble organic phosphorous. The Ca bound P exhibited significant positive correlation with clay, silt, TOC, TS, Chl b and significant negative correlation with sand inferred the fact that texture and granulometry influences the distribution of calcium bound phosphate. Significant positive correlation with sulphur, the redox indicator also suggested that there is preferential accumulation of Ca-IP when the system is highly reducing.

Fe-IP displayed highly significant positive correlations with other two bioavailable fractions (Ca-IP and ASOP) and Ca-IP exhibited highly significant positive correlations with ASOP. The P-fractions available for biological uptake are all well correlated indicating a common biogeochemical balance. In the present investigation the acid soluble P exhibited significant high positive correlation with clay and TOC, since the components in this fraction are organic and clay provides adsorption sites for these organic compounds.

The main inorganic forms of P are the fraction associated with Al, Fe and Mn oxides and hydroxides. Phosphorus and iron are usually strongly associated in sediments, P being adsorbed onto iron compounds with the formation of iron phosphate complexes. The amount of FeOOH is therefore one of the factors controlling P release from sediment. Fe-IP, which is exchangeable between the particulate and dissolved phases through sorption processes, was the major fraction in estuarine sediments

(majority of the stations). Salinity plays a role in the seasonal variations of P fractions as it controls the flocculation and sedimentation mechanisms in estuarine environments, changing the availability of elements (Kautsky, 1998). During the monsoon season, when the system changes to a freshwater condition, Ca-IP is found to be lower. It might be due to the lower availability of solid calcium carbonates, which is governed by salinity and pH (Huanxin et al., 1994; Zwolsman, 1994). In estuarine sediments, Ca-IP, referring to the fraction that is fixed in sediments and may be lost into deep sediments through the burial process, which exhibited significant positive correlation with total carbon, organic carbon and total nitrogen (table 3.6). The observed variation for Ca-IP concentration was from 0.38% (S10, POM 08) to 37.91%. Carbonate-adsorbed P has been identified as an important and potentially dominant phase of P in shallow-water tropical carbonate-rich sediments, due to the high adsorption capacity of carbonates (Millero et al., 2001). In the present investigation, the higher concentration of calcium-bound P in the estuarine sediments might be interpreted by the favourable accumulation of calcium carbonate under higher salinity and pH conditions (Huanxin et al., 1994). The increase in Ca-IP at some stations estuary (pre and post-monsoon) might be due to increase in salinity. Similar trend is reported in marine sediments presumably by the accumulation of calcium under high salinity, which favours apatite formation (Ryden et al., 1997). Silva and Mozeto, (1997) also suggested that phosphorus combine with calcium under high salinity and this process acts as a principal mechanism for retention of phosphorous.

The maximum contribution of ASOP to total P during each season was found to be 16.3% (S7, POM 08), 16.56% (S11, PRE09), 18.84 % (S10 MON 09), 26.17% (S3, POM09) and 17.48% (S14, PRE10). Acid soluble organic phosphorous varied from 0.47% (S13, MON 09) to 26.17% (S3, POM 09). ASOP includes apatite bound phosphate and biochemical components such as nucleic acids, lipids and sugars that bound to phosphate (De Groot, 1990). ASOP had highly significant positive correlation with total sulphur in mangrove sediments indicated that highly reducing environment is favourable for retention of ASOP in sediments similar to Ca-IP.

The concentration of Alk-OP contributed its maximum towards total phosphorous pool at S13 (94.46%; MON 09). Alk-OP generally constitutes humic phosphate and phytate phosphate (Golterman, 2001). Phosphorus associated with humic acids has been considered either to be an integral part of humic acids or as a phosphate metal/organic matter complex (Stevens and Stewart, 1982). During the study, the alk-P exhibited significant negative correlation with silt, pointed towards the allochthonous origin of this fraction.

Residual organic-P was the smallest fraction estimated in sediments collected from estuarine stations. The RP varied from 0.01% (S14, PRE10; S12, POM 08) to 94.46% (S13, MON 09). Total phosphorus content in the estuarine sediments varied from 199.88 mg/Kg (S3, POM 10) to 12900.59 mg/kg (S12, POM 08). Organic phosphorus is a complex fraction, the exact nature of which is not precisely known (Reitzel et al., 2007). As a result of diagenetic reorganization of phosphorus within sediments, organic

phosphorus concentrations usually decrease with time as it is ultimately transformed to authigenic phosphorus during diagenesis (Ruttenberg and Berner, 1993; Andersen et al., 2001). The lower content of this fraction in sediments of estuarine stations might be attributed to diagenesis. In the present study, strong positive correlation of residual phosphorous with sulphur (table 3.6) confirmed the occurrence of diagenic processes. Degradation of organic P compounds also releases phosphate (PO_4-P), making it available to bacteria and algae. As a result of the diagenetic reorganization of P within sediments, organic phosphorous concentrations usually decrease with time as it is ultimately transformed to bioavailable forms. Bacteria are generally considered to be the catalysts that accelerate the solubilization of P (Gatcher and Meyer, 1993) and the processes of anoxic mineralization of phytate (Golterman et al., 1998) could release organic P buried during monsoon season. Generally, organic bound phosphorus accounted for 6 to 19% of total in coastal sediments (Hirata, 1985). Also organic phosphorus mineralization is high under anaerobic condition than aerobic conditions (Bridgam et al., 1998). Highly negative redox potential of sediments of the study area resulted in higher mineralization and subsequently lower concentration of organic phosphorus. Res-P exhibited correlation of residual P with TOC and total sulphur pointed towards diagenesis since sulphur is the redox indicator.

Table 3.6 Correlation matrix for various Phosphoros fractions

	EH	pH	SAND	CLAY	SILT	TOC	CHN N	CHN S	CHLO A	CHLO B	CHLO C	PHEO	LABILE "P"	T FE P	T CA P	Acid P	Alk P	RESD P	T PHOSP
EH	1.00	-0.22	0.19	-0.13	-0.19	0.09	0.21	0.03	-0.22	-0.36 (**)	-0.33 (**)	-0.19	-0.31 (**)	-0.20	-0.08	-0.10	0.00	0.09	-0.07
pH	-0.22	1.00	-0.10	0.17	0.04	-0.05	-0.13	-0.02	0.10	0.00	-0.13	0.14	0.02	0.08	-0.28 (*)	0.02	0.06	0.03	0.02
SAND	0.19	-0.10	1.00	-0.78 (**)	-0.93 (**)	-0.33 (**)	-0.18	-0.42 (**)	-0.40 (**)	-0.24 (*)	-0.13	-0.39 (**)	-0.26 (*)	-0.28 (*)	-0.33 (**)	-0.16	0.16	-0.09	-0.03
CLAY	-0.13	0.17	-0.78 (**)	1.00	0.49 (**)	0.25 (*)	0.20	0.38 (**)	0.39 (**)	0.25 (*)	0.12	0.38 (**)	0.24 (*)	0.26 (*)	0.26 (*)	0.31 (**)	0.13	0.22	0.25 (*)
SILT	-0.19	0.04	-0.93 (**)	0.49 (**)	1.00	0.31 (**)	0.13	0.36 (**)	0.33 (**)	0.20	0.11	0.32 (**)	0.23 (*)	0.24 (*)	0.30 (**)	0.03	-0.29 (*)	0.00	-0.11
TOC	0.09	-0.05	-0.33 (**)	0.25 (*)	0.31 (**)	**1.00**	**0.40 (**)**	0.57 (**)	0.40 (**)	0.40 (**)	0.38 (**)	0.33 (**)	0.01	0.48 (**)	0.42 (**)	0.34 (**)	0.08	0.38 (**)	0.30 (**)
CHN N	0.21	-0.13	-0.18	0.20	0.13	**0.40 (**)**	**1.00**	0.59 (**)	0.26 (*)	0.16	0.11	0.24 (*)	-0.15	0.31 (**)	0.22	0.14	-0.11	-0.03	0.04
CHN S	0.03	-0.02	-0.42 (**)	0.38 (**)	0.36 (**)	0.57 (**)	0.59 (**)	1.00	0.53 (**)	0.39 (**)	0.26 (*)	0.48 (**)	0.06	0.40 (**)	0.35 (**)	0.20	-0.06	0.31 (**)	0.14
CHLO A	-0.22	0.10	-0.40 (**)	0.39 (**)	0.33 (**)	0.40 (**)	0.26 (*)	0.53 (**)	1.00	0.83 (**)	0.66 (**)	0.94 (**)	0.20	0.49 (**)	0.28 (*)	0.15	-0.11	0.19	0.11
CHLO B	-0.36 (**)	0.00	-0.24 (*)	0.25 (*)	0.20	0.40 (**)	0.16	0.39 (**)	0.83 (**)	1.00	0.95 (**)	0.71 (**)	0.10	0.54 (**)	0.29 (**)	0.22	-0.02	0.19	0.20
CHLO C	-0.33 (**)	-0.13	-0.13	0.12	0.11	0.38 (**)	0.11	0.26 (*)	0.66 (**)	0.95 (**)	1.00	0.52 (**)	0.08	0.49 (**)	0.28 (*)	0.19	-0.01	0.18	0.20
PHEO	-0.19	0.14	-0.39 (**)	0.38 (**)	0.32 (**)	0.33 (**)	0.24 (*)	0.48 (**)	0.94 (**)	0.71 (**)	0.52 (**)	1.00	0.21	0.42 (**)	0.25 (*)	0.13	-0.12	0.16	0.07
LABILE "P"	-o.31 (**)	0.02	-0.26 (*)	0.24 (*)	0.23 (*)	0.01	-0.15	0.06	0.20	0.10	0.08	0.21	1.00	-0.02	0.11	-0.02	-0.06	0.36 (**)	-0.02
T FE P	-0.20	0.08	-0.28 (*)	0.26 (*)	0.24 (*)	0.48 (**)	0.31 (**)	0.40 (**)	0.49 (**)	0.54 (**)	0.49 (**)	0.42 (**)	-0.02	1.00	0.46 (**)	0.57 (**)	0.13	0.12	0.49 (**)
T CA P	-0.08	-0.28 (*)	-0.33 (**)	0.26 (*)	0.30 (**)	0.42 (**)	0.22	0.35 (**)	0.28 (*)	0.29 (**)	0.28 (*)	0.25 (*)	0.11	0.46 (**)	1.00	0.50 (**)	0.01	0.17	0.35 (**)
Acid P	-0.10	0.02	-0.16	0.31 (**)	0.03	0.34 (**)	0.14	0.20	0.15	0.22	0.19	0.13	-0.02	0.57 (**)	0.50 (**)	1.00	0.67 (**)	0.32 (**)	0.87 (**)
Alk P	0.00	0.06	0.16	0.13	-0.29 (*)	0.08	-0.11	-0.06	-0.11	-0.02	-0.01	-0.12	-0.06	0.13	0.01	0.67 (**)	1.00	0.35 (**)	0.90 (**)
RESD P	0.09	0.03	-0.09	0.22	0.00	0.38 (**)	-0.03	0.31 (**)	0.19	0.19	0.18	0.16	0.36 (**)	0.12	0.17	0.32 (**)	0.35 (**)	1.00	0.40 (**)
T PHOSP	-0.07	0.02	-0.03	0.25 (*)	-0.11	0.30 (**)	0.04	0.14	0.11	0.20	0.20	0.07	-0.02	0.49 (**)	0.35 (**)	0.87 (**)	0.90 (**)	0.40 (**)	1.00

* Significant at 0.05 level, ** Significant at 0.01 level

The assessment of the quantity and quality of organic matter, whether labile or refractory, is a prerequisite for explaining diagenetic processes. Biochemical composition of sedimentary organic matter has been used to gather information on the origin and parameters controlling the diagenetic fate of organic matter (Colombo et al., 1996). Organic matter in marine sediments is composed of labile and refractory compounds, whose relative importance of changes as a function of a complex array of processes, including degradation, heterotrophic utilization, transformation, accumulation and export (Viollier et al., 2003). The labile fraction of organic matter consists of simple molecules or biopolymers; which includes carbohydrates, lipids and proteins, which are assumed to represent the fraction of organic matter more readily available to benthic consumers (Fabiano et al., 1995; Dell'Anno et al., 2002). The labile portion of organic matter could be suitable to assess the trophic status of coastal marine systems (Dell'Anno et al., 2002; Pusceddu et al., 2003). Refractory organic compounds like humic and fulvic acids, structural carbohydrates and black carbon constitute most of the sedimentary organic matter and are usually accumulated in marine sedimentary environments (Middelburg et al., 1999; Zegouagh et al., 1999).

The autochthonous production or external inputs of rapidly sinking particles allows the accumulation of organic matter, which have suffered a continuous process of degradation of labile compounds in the water column as well as after sedimentation (Colombo et al., 1996) resulting in preferential loss of more labile compounds (Neal et al., 1986; Wakeham and Lee, 1989). Environmental and biological factors like water column depth, rate of sedimentation, DO content, primary productivity and bioturbation have immense influence on quantity and quality of the bulk

organic matter in sediments (Danovaro et al., 1999; Fiordelmondo and Pusceddu, 2004). Estimation of the labile fraction of organic matter is crucial in assessing food quality and quantity in benthic ecological studies (Incera et al., 2003). There is no universally accepted methodology to evaluate the labile fraction of sedimentary organic matter is available, concentrations of some specific compounds have been used to estimate the nutritional value of the sediment (Buchanan and Longbottom, 1970). The nutritional quality of sediments is generally evaluated with the help of biochemical indices like concentration of protein, carbohydrate, lipids, protein/carbohydrate ratio and lipid/carbohydrate ratio (Dell'Anno et al., 2000; Dell'Anno et al., 2002).

The biochemical composition of sedimentary organic matter in the study region showed a dominance of lipids followed by proteins and carbohydrates. The higher concentrations of sedimentary lipids, proteins and carbohydrates recorded in the study area. The total lipid recorded its maximum at S12 (POM 08), protein and carbohydrate content was maximum at S14 (POM 09) which could be related to the morphodynamic, hydrological and physicochemical characteristics. ANOVA results revealed highly significant spatial and seasonal variation for lipids ($p<0.01$). The seasonal average contribution of labile organic matter (LOM) to total organic matter (TOM) in the sediments was: 22.19±13.14% (POM 08); 17.37±8.2% (PRE 09); 17.10±8.3% (MON 09); 15.28±8.9% (POM 09); 30±19.41% (PRE 10). Present investigation revealed the fact that irrespective of the higher content of total organic matter, the contribution of labile organic matter towards total organic matter was low, comparable with previous reports (Joseph et al., 2008; Renjith et al., 2012). Hence the

sediments of the study area comprised of large amount of refractory material (uncharacterised material).

Sedimentary protein concentrations reflect the productivity of marine ecosystems and it appears to be a good descriptor of the trophic status of the benthic systems at different spatial scales (Danovaro et al., 1999, 2000; Dell' Anno et al., 2002). Like proteins, lipids also indicate the productivity of the system (Gremare et al., 1997). Carbohydrates are polyhydroxyllated compounds, ranging in size from 5-6 carbon sugars to large biopolymers (starch, cellulose), and their concentration is found to be much higher in vascular plants compared to algae (Cowie and Hedges, 1984). The dominance of lipids and protein over carbohydrates indicated the nutritive value as the freshness of the labile organic matter in the sediments of the study region.

The most abundant nitrogen containing substances in organic matter like proteins and peptides, have been regarded as part of the labile fraction in the environment, although recent studies have shown that proteinaceous material can resist microbial degradation in sedimentary environments and consequently a portion of the nitrogen is incorporated into biologically refractory organic material and removed from the active nitrogen pool (Nguyen and Harvey, 2001; Joseph et al., 2008). The occurrence of higher fractions of labile nitrogen point towards the high nutritional quality of the sediments in the study area.

In the present study, the maximum concentration of protein was found in sediments collected during POM 09. The study revealed that the organic matter is mostly of terrestrial origin and make profound influence in the biogeochemical processes. The high turnover of protein and other organics such as lipids and carbohydrates in the sediments could be due to

the decomposition of organic matter in phytoplankton and in domestic waste water. The wastes from fish peeling and processing units are dumped into the water bodies and these animal tissues undergo decomposition and liberate proteins which are adsorbed onto the sediments. A decrease in the concentration of proteins during monsoon may be due to the preferential utilization of protein by the benthic organisms and biological activity (Bhosle and Dhople, 1988). Clayey silt and silty clay sediments were capable of adsorbing more organics than the sandy ones. Generally, in estuarine sediments a predominance of silty clay or clayey silt nature during pre and post monsoon and reason for lower protein in sediments during MON 09 could be due to the input of sandy sediments from land run off. ANOVA revealed only significant spatial variation ($p<0.05$) for protein.

Lipids, the main class of organic matter in algal material (Sun et al., 2002), are well suited for source characterization of organic matter on account of the fact that they are less labile than carbohydrates and proteins and are thus often used as biomarkers to determine the sources (Volkman, 2003) and to assess the degradation of organic matter (Wakeham, 1995). Due to the presence of chlorophyll, which is a very efficient photosensitizer (Foote, 1976; Knox and Dodge, 1985), visible-light induced photosensitized processes act intensively during the senescence of phytoplanktonic cells.

Biochemical components in sediments generally undergo mineralization process in the following order: LPD >PRT >TN>TOC>CHO (Colombo et al., 1996). The application of PRT/CHO and LPD/CHO as indicators of the status of biochemical degradation processes is well established (Galois et al., 2000). PRT/CHO was found to

be maximum at S2 during PRE 09 and minimum at S6 during PRE 10. Protein to carbohydrate ratio (PRT/CHO) is used as an index to determine the origin of material present in sediments and to distinguish between the presence of fresh materials and age of sedimentary organic matter (Danovaro et al., 1993; Cividanes et al., 2002). Dominance of carbohydrates and lower PRT/CHO ratio (< 1) is a typical feature of detrital heterotrophic environments (Danovaro, 1996). PRT/ CHO ratio can also be used for classifying benthic trophic status which in turn reflects patterns of nutrient enrichment (Dell' Anno et al., 2002). In the present investigation, the estimated PRT/ CHO ratios having values <1 indicated the presence of aged or less degradable organic matter (refractory organic matter). The higher PRT/ CHO ratios in some stations of the study indicated living organic matter or "newly-generated" detritus (Danovaro et al., 1993) because proteins are more readily used by bacteria compared to carbohydrates (Williams and Carlucci, 1976; Newell and Field, 1983) and revealed the role of proteins as potentially limiting factor for the benthic consumers (Fabiano et al., 1995).

In the present investigation, maximum value for LPD/ CHO ratio was found in sediments collected from S2 during POM 08 and the minimum at S3 during MON 09. The lower values of this ratio might be attributed to the higher concentration of carbohydrates derived from allochthonous sources. The lipid content and lipid to carbohydrate ratio (LPD/ CHO) have been used as good indices to describe the food quality of the organic contents in the sediments (Fabiano and Pusceddu, 1998; Grémare et al., 2002). Furthermore, lipid concentrations have been associated with the most labile fraction of sedimentary organics and it is

considered as the best descriptor for meiofauna abundance (Cartes et al., 2002; Grémare et al., 2002).

Biochemical composition of organic matter in sediments have widely been employed as a tool to evaluate the trophic status of coastal marine systems (Dell' Anno et al., 2002; Pusceddu et al., 2003; Renjith et al., 2012). Trophic status of an aquatic system can be evaluated on the basis of both PRT and CHO trophic thresholds: hypertrophic (PRT >4.0 mg/g, CHO >7.0 mg/g, PRT/CHO >1), eutrophic (PRT = 1.5-4.0 mg/g, CHO = 5.0-7.0 mg/g, PRT/CHO <1) and meso-oligotrophic (PRT <1.5 mg/g, CHO <5.0 mg/g, PRT/CHO <1). The present investigation revealed that the trophic state of the study area can be included under meso-oligotrophic (Dell'Anno et al., 2002; Renjith et al., 2012).

Stoichiometric ratios of nutrients are utilised to determine the origin and transformation of organic matter based on the generalization that organic matter derived from marine plankton has atomic C/N ratios between 4 and 10 while higher plants have C/N ratios of 20 and above (Prahl et al., 1994; Jennerjahn and Ittekkot, 1997; Yamamuro, 2000). However the selective degradation of the different minerals in sediments can affect the C/N ratios of organic matter (Muller, 1997). In shallow coastal ecosystems, most of the organic carbon and nitrogen produced by microphytobenthos and macroalgae rather than phytoplankton (Lucas et al., 2000). Organic matter should have a C/N ratio lower than 17 for the nutritional use to invertebrates (Russel-Hunter, 1970). The C/N ratios estimated for sediments of this study area were comparable with estuaries and other similar aquatic environments (Verma and Subramanian, 2002; Joseph et al., 2012; Renjith et al., 2012). The seasonal average values of C/N (table 3.5) indicated a mixed origin of organic matter ie.

Autochthonous as well as terrestrial input. Considering the system as a whole, during PRE 09 and MON 09 showed values more than 17. Organic matter should have a C/N ratio lower than 17 have nutritional use to invertebrates (Russel-Hunter, 1970). However, the selective degradation of the different minerals in sediments can affect the C/N ratios of organic matter (Muller, 1997).

It has already been established that chlorophyll a and other phytoplankton pigments are effective indicators of fresh phytoplankton inputs to sediments (Sun et al., 1991; Josefson and Conley, 1997). The higher chlorophyll content in the sediments of the study area pointed towards the higher primary production, settling of the pigments to sediment and their preservation due to anoxic conditions. In the absence of effective number of grazers, the organic matter synthesised by primary producers are not transferred to higher tropic level leading to the settling of the excess chlorophyll to the sediment (Jyothibabu et al., 2006).

The tannins and lignins are high molecular weight polycyclic aromatic compounds widely distributed in the plant kingdom (Schnitzer and Khan, 1972; Finar, 1976; Field and Lettinga, 1987). Lignin is regarded as a nitrogen-free co-polymer of phenyl propenyl alcohols and widely occur in vascular plants. Because of the exclusive association with higher plants, lignin is usually considered as a specific tracer of terrestrial plant remains. Tannins occur in plant leaves, roots, wood, bark, fruits and buds (Kraus et al., 2003), and are estimated to be the fourth most abundant compound types produced by vascular plant tissue after cellulose, hemicellulose and lignin (Hernes and Hedges, 2000). The quantification of tannin and lignin (phenolic compounds) in sediments provide information on the input of land-derived organic detritus in marine systems. The

estimation of tannin and lignin content in sediments has been used to determine the relationship between allochthonous and autochthonous origin of organic matter in aquatic systems. The present investigation recorded the occurrence of higher concentration of tannin and lignin in the sediments which could be attributed to the input of terrestrial higher plant debris associated with land runoff.

3.3 Conclusion

Values of pH in both surface and bottom waters remained slightly alkaline at all the stations. Higher values for pH might be due to the influence of seawater ingression or increased photosynthetic activity. Wide fluctuations in the values of transparency might be due to discharge of water due to floating sediments carried by the river from catchment areas as well as dredging operations in Cochin estuary. Higher content for dissolved oxygen was recorded during monsoon, which could be due to the cumulative effect of higher wind velocity joined with heavy rainfall and the resultant freshwater mixing. The combined effects of higher biological production coupled with sinking of organic matter, discharge of untreated effluents, wastes from aquaculture fields and agricultural fields into the backwater system have contributed to the increased BOD levels in the study area. In the present investigation, no vertical stratification for salinity was observed and fresh water conditions were prevalent during the monsoon and the estimated higher values during post monsoon season could be due to increased rate of evaporation and sea water ingression. Among nutrients, ammonia displayed a non-uniform distribution throughout the entire study period which indicated an exogenic input in the estuary. The increased nitrate level was due to fresh water inflow, organic decomposition and terrestrial run-off during the monsoon season.

The lower contents of nitrite during the premonsoon season were due to less freshwater input, higher salinity, higher pH and also uptake by phytoplankton. The higher phosphate content in the water column could be attributed to regeneration and release of total phosphorus from sediment into the water column by turbulence mixing. Silicate exhibited significant negative correlation with salinity, suggesting its input through land runoff.

Texture analysis provided an insight into the grain size of the sediments in the study area. Higher concentration for organic carbon reported at some stations could be attributed to the settling of the terrigenous organic matter derived from land runoff and the minimum during monsoon could be attributed to the dilution effects associated with high river discharge associated with heavy rain. The average TOC/ TS values indicated the periodic anoxia nature of the system where, the sediments undergo sulphate reduction below an oxygenated water column. Fractionation of nitrogen and phosphorous in sediments were carried out to evaluate their various forms and enrichment character. The lower values for C/P and N/P ratio indicated enrichment of phosphorous in sediments of estuarine system. Phosphorus fractions were analyzed to quantify different fractions of phosphorus in the estuarine sediments in order to assess the processes leading to the fractional distribution of phosphorus its bioavailablity and influence on trophic status. Iron-bound IP fraction was found to be the main phosphorous pool in the estuary.

Biochemical composition of sedimentary organic matter in the study region showed a dominance of lipids followed by proteins and carbohydrates. Sedimentary protein concentrations reflect the productivity of marine ecosystems and it appears to be a good descriptor of the trophic status of the benthic systems. Lipids in sediments also indicate the

productivity of the system (Gremare et al., 1997). The dominance of lipids and protein over carbohydrates indicated the nutritive value as the freshness of the labile organic matter in the sediments of the study region. PRT/CHO and LPD/CHO ratios were useful to evaluate the quality and quantity of organic matter in the estuarine sediments. Estimated PRT/ CHO ratios having values <1 indicated the presence of aged or less degradable organic matter (refractory organic matter). Lower values of LPD/CHO ratio might be attributed to the higher concentration of carbohydrates derived from allochthonous sources. The present investigation revealed that the trophic state of the study area can be included under meso-oligotrophic (Dell'Anno et al., 2002; Renjith et al., 2012). The higher chlorophyll content in the sediments of the study area pointed towards the higher primary production, settling of the pigments to sediment and their preservation due to anoxic conditions. The average values of C/N indicated a mixed origin of organic matter ie., autochthonous as well as terrestrial input. The higher tannin and lignin content in the estuarine sediments could be attributed to the input of terrestrial higher plant debris associated with land runoff.

References

An, S., Gardner, W. S., 2002. Dissimilatory nitrate reduction to ammonium (DNRA) as a nitrogen link, versus denitrification as a sink in a shallow estuary (Laguna Madre/ Baffin Bay, Texas). *Mar. Ecol. Prog. Ser*. 237: 41–50.

Ananthan, G., 1994. Plankton ecology and heavy metal studies in the marine environments of Pondicherry, India, Ph.D. Thesis, Annamalai University, India, 125.

Anderson, L. D., Delaney, M. L., Faul, K. L., 2001. Carbon to phosphorus ratios in sediments: implications for nutrient cycling. *Glob.Biogeochem. Cycles*, 15, 65-79.

Andrieux-Loyer, F., Aminot, A., 2001. Phosphorus forms releated to sediment grain size and geochemical characteristics in French coastal areas, *Est. Coast. Shelf Sci.*, 52, 617-629.

Anirudhan, T.S., Balchand, A.N., Nair, S.M., Nambisan, P.N.K., 1987. Distribution pattern of salinity and silicon and their interrelationship in Cochin backwaters. Proc. on National Seminar on Estuarine Management., Kerala State Committee on Science, Technology and Environment Trivandrum, Kerala, (Abstracts) E.D. 11.

Balachandran, K.K., Lalu Raj, C.M., Nair, M., Joseph, T., Sheeba, P., Venugopal, P., 2005. Heavy metal accumulation in a flow restricted, tropical estuary. *Est. Coast. Shelf Sci.*, 65, 361-370.

Barmawidjaja, D. M., Van Der Zwaan, G. J., Jorissen, F. J., Puskaric, S., 1995. 150 years of eutrophication in the northern Adriatic Sea, evidence from a benthic foraminiferal record. *Mar. Geol., 122*, 367-384.

Berman, T., Bechemin, C., Maestrini, S. Y., 1999. Release of ammonium and urea from dissolved organic nitrogen in aquatic ecosystems. *Aqu. Microb. Ecol.,* 16, 295-302.

Bhosle N.B., Dhople V.M., 1988 distribution of some biochemical compounds in the sediments of Bay of Bengal. *Chem. Geol.,* 67, 341-352.

Bridgham, S. D., Updegraff, K., Pastor, J., 1998. Carbon, nitrogen, and phosphorus mineralization in northern wetlands. *Ecology*, 79, 1545-1561.

Bruland, K. W., Rue, E. L., and Smith, G. J., 2001: Iron and macronutrients in California coastal upwelling regimes: Implications for diatom blooms, Limnol. Oceanogr., 46, 1661–1674,

Buchanan, J.S., Longbottom, M.R., 1970. The determination of organic matter in marine muds: the effect of the presence of coal and the routine determination of proteins. *J. Exper. Mar. Biol. Ecol.,* 5, 158-169.

Carlson, R.E., 1977. A trophic state index for lakes. *Limnol Oceanogr.,* 22, 361-369

Cartes, J. E., Gremare, A., Maynou, F., Villora-Moreno, S., Dinet, A., 2002. Bathymetric changes in the distributions of particulate organic matter and associated fauna along a deep-sea transect down the Catalan sea slope (Northwestern Mediterranean), *Prog. Ocean.*, 53, 29-56.

Chandran, R., Ramamoorthy, K., 1984. Hydrobiological studies in the gradient zone of the Vellar estuary-Nutrients. *Mahasagar Bull. Natl. Inst. Oceanogr.,* 17, 133-140.

Cividanes, S., Incera, M., Lo'pez, J., 2002. Temporal variability in the biochemical composition of sedimentary organic matter in an intertidal flat of the Galician coast (NW Spain), *Oceanolog. Acta* 25, 1-12.

Cloern, J.E., 2001. Our evolving conceptual model of the coastal eutrophication problem. *Mar. Ecol .Prog Ser* ., 210, 223-253

Colombo, J. C., Silverberg, N., Gearing, J. N., 1996. Biogeochemistry of organic matter in the Laurentian Trough, II. Bulk composition of the sediments and relative reactivity of major components during early diagenesis. *Mar. Chem.*, 51, 295-314.

Colombo, J.C., Silverberg, N., Gearing, J.N., 1996. Biogeochemistry oforganic matter in the Laurentian Trough, II. Bulk composition of the sediments and relative reactivity of major components during early diagenesis. *Mar. Chem.*, 51, 295-314.

Cowie, G. L., Hedges, J. I., 1984. Carbohydrate sources in a coastal marine environment. *Geochimica et Cosmochimica Acta*, 48, 2075-2087.

Danovaro, R., Fabiano, M., Della Croce N., 1993. Labile organic matter and microbial biomasses in deep-sea sediments (Eastern Mediterranean Sea). *Deep-Sea Res.* 40, 953-965.

Danovaro, R., 1996. Detritus-bacteria- meofauna interactions in a seagrass bed (Posidonia oceanica) of the NW Mediterranean. *Mar. Biol.*, 127, 1-13.

Danovaro, R., Marrale, D., Della Croce, N., Parodi, P., Fabiano, M., 1999. Biochemical composition of sedimentary organic matter and bacterial distribution in the Aegean Sea: trophic state and pelagic–benthic coupling. *Jour. Sea Res.*, 42, 117-129.

Danovaro, R., Marrale, D., Dell'Anno, A., Della Croce, N., Tselepides, A., Fabiano, M., 2000. Bacterial response to sea seasonal changes in labile organic matter composition on the continental shelf and bathyal sediments of the Cretan Sea. *Prog. Ocean.*, 46, 345-366.

Das, J., Das, S.N., Sahoo, R.K., 1997. Semidiurnal variation of some physicochemical parameters in the Mahanadi estuary, East coast of India. *Ind. J. Mar. Sci.*, 26, 323-326.

De Groot, C. J., 1990. Some remarks on the presence of organic phosphates in sediments. *Hydrobiologia*, 207, 303-309.

Dell'Anno, A., Fabiano, M., Mei, M. L., Danovaro, R., 2000. Enzymatically hydrolysed protein and carbohydrate pools in deep-sea sediments:

estimates of the bioavailable fraction and methodological considerations. *Mar. Ecol. Progr. Ser.*, 196, 15-23.

Dell'Anno, A., Mei, M. L., Pusceddu, A., Danovaro, R., 2002. Assessing the trophic state and eutrophication of coastal marine systems. A new approach based on the biochemical composition of sediment organic matter. *Mar. Poll. Bull.*, 44, 611-622.

Diaz-Espejo, A., Serrano, L., Toja, J., 1999. Changes in sediment phosphate composition of seasonal ponds during filling. *Hydrobiologia, 392*, 21-28.

Edward, P.J.K., Ayyakannu, K., 1991. Temporal variation in annual production of *Tellina nobilis* and *Tellina cuspis* in a tropical estuarine environment. *Mahasagar.*24 (1), 22-29.

Eisma, D., 1993. Suspended matter in the aquatic environment. Springer-Verlag.

Fabiano, M., Danovaro, R., 1994. Composition of organic matter in sediments facing a river estuary (Tyrrhenian Sea): relationships with bacteria and microphytobenthic biomass. *Hydrobiologia*, 277, 71-84.

Fabiano, M., Danovaro, R., Fraschetti, S., 1995. A three-year time series of elemental and biochemical composition of organic matter in subtidal sandy sediments of the Ligurian Sea (North-Western Mediterranean). *Cont. Shelf. Res.*, 15, 1453-1469.

Fabiano, M., Pusceddu, A., 1998.Total hydrolizable particulate organic matter (carbohydrates, proteins, and lipids) at a coastal station in Terra Nova Bay (Ross Sea, Antarctica), *Polar Biol*. 19 , pp. 125–132.

Field, J. A., Lettinga, G., 1987. The methanogenic toxicity and anaerobic degradability of hydrolysable tannin. *Wat. Res.*, 21, 367-374.

Finar, I. L., 1976. Organic Chemistry, Volume 1. Longman, Singapore

Fiordelmondo, C., Pusceddu, A., 2004. Short-term response of benthic bacteria and nanoflagellates to sediment resuspension: an experimental study. *Chem. Ecol.,* 20: 107-121.

Foote, C.S., 1976. Photosensitized oxidation and singlet oxygen: consequences in biological systems. In: Pryor, W.A. (Ed.), Free Radicals in Biology. Academic Press, New York, pp. 85-133.

Frankignoulle M., Abril, G., Borges A., Bourge, I., Canon C., Delille, B., Libert E., Théate J.M., 1998. Carbon dioxide emission from European estuaries, *Science,* 282, 434-436.

Galois, R., Blanchard, G., Seguignes, M., Huet, V., Joassard, L., 2000. Spatial distribution of sediment particulate organic matter on two estuarine mudflats: a comparison between Marennes-Oléron Bay (France) and the Humber estuary. *Cont. Shelf Res.,* 20, 1199-1217.

Gatcher, R., Meyer, J. S., 1993. The role of microorganisms in mobilization and fixation of phosphorus in sediments. *Hydrobiologia, 253*, 103-121.

Gattuso, J.P., Frankignoulle M., Wollast R., 1998. Carbon and carbonate metabolism in coastal aquatic ecosystems, *Annu. Rev. Ecol. Syst*. 29, 405-434.

Golterman, H. L., 1996. Fractionation of sediment phosphate with chelating compounds: A simplification, and comparison with other methods. *Hydrobiologia*, 335, 87-95.

Golterman, H. L., 2001. Phosphate release from anoxic sediments or 'What did Mortimer really write? *Hydrobiologia, 450*, 99-106.

Golterman, H. L., Paing, J., Serrano, L., Gomez, E. 1998. Presence of and phosphate release from polyphosphates or phytate phosphate in lake sediments. *Hydrobiologia, 364*, 99-104.

Gouda, R., Panigrahy, R.C., 1995. Seasonal distribution and behaviour of nitrate and phosphate in Rushikulya estuary, east coast of India. *Ind.J. Mar. Sci.,* 24, 233-235 .

Govindasamy, C., Kannan, L., Jayapaul Azariah, 2000. Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel Coast, India. *J. Environ. Biol*., 21, 1-7.

Gowda, G., Gupta, T.R.C., Rajesh, K.M., Gowda, H., Lingadhal, C., Ramesh, A.M., 2001. Seasonal distribution of phytoplankton in Nethravathi estuary, Mangalore. *J. Mar. Biol. Ass. India*, 43, 31-40 .

Gremare, J. M., Amouroux, F., Charles, A., Dinet, C., Riaux-Gobin, J., Baudart, L., Medernach, J. Y., Bodiou, G., Vétion, Colomines, J. C., 1997. Temporal changes in the biochemical composition and nutritional value of the particulate organic matter available to surface deposit-feeders: A two year study. *Mar. Ecol. Prog. Ser.*, 150. 195-206.

Grémare, L., Medernach, F., deBovée, J., Amoroux, M., Vétion, G., Albert, P., 2002.Relationships between sedimentary organics and benthic meiofauna on the continental shelf and the upper slope of the Gulf of Lions (NW Mediterranean. *Mar. Ecol. Prog.* Ser. 234 , 85–94.

Hecky, R. E., Campbell, P., Hendzel, L. J., 1993. The stoichiometry of carbon, nitrogen and phosphorus in particulate matter of lakes and oceans. *Limnol. Ocean.*, 38, 709 -724

Hedges, J. I., Keil, R. G., 1995. Sedimentary organic matter preservation: An assessment and speculative hypothesis. *Mari. Chem., 49*, 81-115.

Hernes, P. J., Hedges, J. I., 2000. Determination of condensed tannin monomers in environmental samples by capillary gas chromatography of acid depolymerization extracts. *Anal. Chem.* 72, 5115-5124.

Hirata, S., 1985. Phosphorus and metals bound to organic matter in coastal sediments-an investigation of complexes of P, Cu, Zn, Fe, Mn, Ni, Co and Ti by inductively coupled plasma-atomic emission Spectrometry with sephadex gel chromatography. *Mar. Chem.*, 16, 23-46.

Holligan, P.M., Reiners,W.A., 1992. Predicting the responses of the coastal zone to global change. In: Woodward, F.I. (Ed.), Global Climate Change. Academic Press, London, pp 212-255.

Huanxin, W., Presley, B. J., Armstrong, D., 1994. Distribution of sedimentary phosphorus in Gulf of Mexico estuaries. *Mar. Environ. Res.,* 37, 375-392.

Incera, M., Cividanes, S. P., Lopez, J., Costas, R.C., 2003. Role of hydrodynamic conditions on quantity and biochemical composition of sediment organic matter in sandy intertidal sediments (NW Atlantic coast, Iberian Peninsula). *Hydrobiologia.*, 497, 39-51.

Jennerjahn, T. C., Ittekkot, V., 1997. Organic matter in sediments in the mangrove areas and adjacent continental margins of Brazil: 1. Amino acids and hexosamine, *Oceanol. Acta*, 20, 359-369.

Jensen, H. S., Thamdrup, B., 1993. Iron-bound phosphorus in marine sediments as measured by bicarbonate-dithionite extraction. *Hydrobiologia*, 253, 47-59.

Jin, X., Jiang, X., Yao, Y., Li, L., Wu F.C., 2006. Effects of light and oxygen on the uptake and distribution of phosphorus at the sediment–water interface. *Sci. Tot. Environ.,* 357, 231- 236.

Josefson, A.B., Conley, D.J., 1997. Benthic response to a pelagic front. *Mar. Ecol. Prog. Ser.,* 147, 49-62.

Joseph, M. M., Ratheesh Kumar, C.S., Gireeshkumar, T.R., Renjith, K. R., Chandramohanakumar, N., 2008. Biogeochemistry of surficial sediments in the intertidal systems of a tropical environment, *Chem. Ecol.,* 24, 247- 258.

Joseph M.M., Ratheesh Kumar C. S., Renjith, K. R., Gireeshkumar, T. R., Chandramohanakumar, N., 2010. Phosphorus fractions in the surface sediments of three mangrove systems of southwest coast of India. *Environ. Earth Sci*., 62(6), 1209-1218.

Joseph, M. M., Renjith, K. R., Ratheesh Kumar, C. S., Chandramohanakumar, N., 2012. Assessment of Organic Matter Sources in the Tropical Mangrove Ecosystems of Cochin, Southwest India, *Environ. Forensics*., 13 (3), 262-271

Jyothybabu, R.,.Madhu , N.V., Jayalakshmi , K.V., Balachandran , K.K., Shiyas , C.A., Martin, G.D ., Nair , K.K.C., 2006. Impact of Freshwater influx on microzooplankton mediated foodweb in a tropical estuary.(Cochin backwaters-India) *Est.Coast.Shelf.Sci*., 69, 505-518.

Kannan, R., Kannan, L., 1996. Physico-chemical characteristics of sea weed beds of the Palk Bay, Southeast coast of India. *Ind. J. M ar. Sci*., 25, 358-362.

Karuppasamy, P.K., Perumal, P., 2000. Biodiversity of zooplankton at Pichavaram mangroves, South India. *Adv. Biosci*., 19, 23-32.

Kautsky, L., 1998. Monitoring eutrophication and pollution in estuarine environments-focusing on the use of benthic communities. *Pur. Appl. Chem.,* 70, 2313-2318.

Kemp, W. M., Boynton, W. R., 1992. Benthic-pelagic interactions: Nutrient and oxygen dynamics, In: D. E. Smith, M. Leffler, and G. Mackiernan [eds.], Oxygen dynamics in the Chesapeake Bay. Mary land Sea Grant Publication. pp 149-221.

Kirchman, D.L., Meon, B., Cottrell, M.T., Hutchins, D.A., Weeks, D., Bruland, K.W., 2000. Carbon versus iron limitation of bacterial growth in the California upwelling regime. *Limnol. Oceanogr*. 45, 1681-1688.

Knox, J.P., Dodge, A.D., 1985. Singlet oxygen and plants. *Phytochem.* 24, 889–896.

Kratzer, C.R., Brezonik, P.L., 1981. A Carlson-type trophic state index for nitrogen in Florida lakes. *Wat. Res. Bull.,* 17, 713-715

Kraus, T. E. C., Yu ,Z., Preston, C. M, Dahlgren, R .A., Zasoski, R. J. Z., 2003. Linking chemical reactivity and protein precipitation to structural characteristics of foliar tannins. *J. Chem. Ecol.,* 29, 703-730.

Largier, J.L., 1993. Estuarine fronts: how important are they? Estuaries 16,1-11.

Lebo, M. E., 1991. Particle-bound phosphorus along an urbanized coastal plain estuary. *Mar. Chem.*, 34, 225-246.

Liu X., Millero F. J., 2002. The solubility of iron in seawater. *Mar. Chem.,* 77, 43–54.

Lucas, C.H., Widdows, J., Brinsley, .M.D., Salkeld, P.N., Herman, P.M.J., 2000. Benthic-pelagic exchange of microalga at a tidal flat. 1. Pigment analysis, *Mar. Ecol. Prog. Ser.*, 19, 59-73.

Madhu. N.V., Jyothibabu, R., Balachandran, K.K., Honey, U.K., Martin, G.D., Vijay, J. G., Shiyas, C. A., Gupta, G.V.M., Achuthankutty, C.T.. 2007. Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin Backwaters - India). *Est. Coast. Shelf Sci.*, 73, 54-64.

Madhupratap, M., Devassy, V. P., Nair, S. R. S., Rao, T. S. S., 1980. Incidence of swarming of pelagic tunicates associated with phytoplankton bloom in the Bay of Bengal, *Indian J. Mar. Sci.* 9, 69-71.

Martin, G. D., Muraleedharan, K. R., Vijay, J. G., Rejomon, G., Madhu, N. V., Shivaprasad, A., 2010. Formation of anoxia and denitrification in the bottom waters of a tropical estuary, southwest coast of India. Biogeosciences Discussions, 7, 1751–1782.

Mathevan, P.M., 1994. Hydro biological investigation on the intertidal diatoms of the Cuddalore Uppanar estuary India. Ph.D. Thesis, Annamalai University, India, 159.

McCarthy, M. J., Lavrentyev, P. J., Yang, L., Zhang, L., Chen, Y., Qin, B., Gardner, W. S., 2007. Nitrogen dynamics and microbial food web structure during a summer cyanobacterial bloom in a subtropical, shallow, well-mixed, eutrophic lake (Lake Taihu, China). *Hydrobiologia,* 581, 195-207

Menon, N. N., Balchand, A. N., Menon, N. R., 2000. Hydrobiology of the Cochin backwater system-A review. *Hydrobiologia, 430*, 149-183.

Meyers, P.A., 1994. Preservation of elemental and isotopic source. Identification of sedimentary organic matter. *Chem. Geol.*, 144, 289-302.

Middleburg, J.J., Nieuwenhuize, J., Can Breuge, P., 1999. Black carbon in marine sediments. *Mar. Chem*. 65, 245–252.

Millero, F., Huang, F., Zhu, X., Liu, X., Zhang, J., 2001. Adsorption and desorption of phosphate on calcite and aragonite in seawater. *Aqu.Geochem., 7*, 33-56.

Mitra, A., Patra, K.C., Panigrahy, R.C., 1990. Seasonal variations of some hydrographical parameters in a tidal creek opening into the Bay of Bengal. *Mahasagar-Bull. Nat. Inst. Oceanogr*., 23,55-62.

Morris, A.W., Bale, A.J., Howland, R.J.M., Millward, G.E., Ackroyd, D.R., Loring, D.H., Rantala, R.T.T., 1986. Sediment mobility and its contribution to trace-metal cycling and retention in a macrotidal estuary. *Water Sci. Technol*. 18 (4–5), 111 – 119.

Muller, P.J., 1997. C/N ratios in Pacific deep sea sediments: Effect of inorganic ammonium and organic nitrogen compound sorbed by clays, *Geochim. Cosmochim. Acta* 41, 765-776.

Neal, A. C., Prahl, F. G., Eglinton, G., O'Hara, S. C. M., Corner, E. D. S., 1986. Lipid changes during planktonic feeding sequence involving unicellular algae, *Elminius naupki* and adult Calanus. *Indian. J. Mar. Biol. Ass. United Kingdom*, 66, 1-13.

Newell, R.C., Field, J.G., 1983. The contribution of bacteria and detritus to carbon and nitrogen flow in a benthic community, *Mar. Biol. Lett*. 4, 23–36.

Nguyen, R., Harvey, H. R., 2001. Preservation of protein in marine systems: Hydrophobic and other noncovalent associations as major stabilizing forces. *Geochim. Cosmochim. Acta*, 65, 1467-1480.

Nixon, S.W., 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia* 41,199 -219.

Nowostawska, U., Kim, J. P., Hunter, K. A., 2008. Aggregation of riverine colloidal iron in estuaries: A new kinetic study using stopped-flow mixing, *Mar. Chem*., 110, 205–210.

Padma, 2005. PhD thesis. Cochin University of Science and Technology, Kochi, India.

Paludan, C., Morris, J. T., 1999. Distribution and speciation of phosphorus along salinity gradient in intertidal marsh sediments. *Biogeochem.,* 45,197-221.

Perumal, P., 1993.The influence of meteorological phenomena on the ecosystems of a tropical region, southeast coast of India. A case study. *Ciencias Marinas*, 19, 343-351.

Powell, R. T., Wilson-Finelli, A., 2003. Importance of organic Fe complexing ligands in the Mississippi River plume, *Est. Coast. Shelf Sci*., 58, 757–763.

Prahl, F.G., Ertel, J.R., Goni, M.A., Sparrow, M.A., Eversmeyer, B., 1994. Terrestrial organic carbon contributions to sediment on the Washington margin, *Geochim. Cosmochim. Acta*, 58, 3035-3048.

Pramodbabu, K.R ., 2007. PhD thesis . Mahatma Gandhi University, Kottayam, India.

Pusceddu, A. Dell'Anno, R., Danovaro, E., Manini, G., Sarà, Fabiano, M.,2003. Enzymatically hydrolyzable protein and carbohydrate sedimentary pools

as indicators of the trophic state of detritus sink systems: A case study in the Mediterranean coastal lagoon, *Estuaries*, 26, 641-650.

Pusceddu, A., Dell'Anno, A., Danovaro, R., Manini, E., Sara, G, Fabiano, M., 2003. Enzymatically hydrolyzable protein and carbohydrate sedimentary pools as indicators of the trophic state of detritus sink systems: a case study in the Mediterranean coastal lagoon. Estuaries, 26,641-650.

Qasim and Gopinathan, C. K., 1969. Tidal cycle and the environmental features of Cochin Backwater (a tropical estuary). *Proc. Indian Acad. Sci.,* B 69 , 336-348.

Qasim, S. Z., 2003. Indian estuaries (p. 259). Mumbai: Allied.

Raiswell, R., Buckley, F., Berner, R. A., Anderson, T. F., 1987. Degree of pyritization of iron as a palaeoenvironmental indicator of bottom-water oxygenation. *Journal of Sedimentary Petrology,* 58, 812-819.

Rajasegar, M., 1998. Environmental inventory on Vellar estuary Southeast coast of India in relation to shrimp farming. Ph.D. Thesis, Annamalai University, India.

Rajasegar, M., 2003.Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. *J . Env iron. Biol* ., 24, 95-101 .

Ramamirtham, C. P., Muthusamy , S.. 1986. Estuarine oceanography of the Vembanad lake. Part 11: The region between Cochin and Azhikode. *Indian J. Fish.,* 33, 218-224.

Reddi.K.R.,.Jayaraju. N., Suryakumar, I and. Sreenivas, K., Tidal fluctuation in relation to certain physico-chemical parameters in Swarnamukhi river estuary, East coast of India. 1993. *Ind. J. Mar. Sci*., 22, 232-234.

Redfield, A. C., 1958. The biological control of chemical factors in the environment. *American Scientist*, 46, 205-222.

Reitzel, K., Ahlgren, J., DeBrabandere, H., Waldebäck, M., Gogoll, A., Tranvik, L., 2007. Degradation rates of organic phosphorus in lake sediment. *Biogeochemistry*, 82, 15-28.

Renjith, K. R., Chandramohanakumar, N., Joseph, M. M., 2010. Fractionation and bioavailability of phosphorus in a tropical estuary, Southwest India. *Environ. Monit. Assess.* 174, 299-312.

Renjith, K. R., Chandramohanakumar, N., Joseph, M. M., 2011. Fractionation and bioavailability of phosphorus in a tropical estuary, Southwest India. *Environ. Monit. Assess.*, 174, 299–312.

Renjith, K. R., Manju Mary Joseph, Prosenjit Ghosh, Habeeb Rahman, K., Ratheesh Kumar, C. S., Chandramohanakumar N., 2012. Biogeochemical. Facsimile of the organic matter quality and trophic status of a micro-tidal tropical estuary, *Environ. Earth. Sci*. DOI 10.1007/s12665-012-2159-0.

Russel-Hunter, W.D., 1970. Aquatic productivity: An introduction to some basic aspects of biological oceanography and limnology, Collier-Macmillan, London. pp 306 .

Rutenberg, K. C., Berner, R. A., 1993. Authigenic apatite formation and burial in sediments from non upwelling continental margin environments. *Geochemica et Cosmochemica Acta*, 57, 991-1007.

Ruttenberg, K., 1992. Development of a sequential extraction method for different forms of phosphorus in marine sediments, *Limnology and Oceanography*, 37, 1460-1482.

Ryden, J. C., Mclaughlin, J. R., Syer, J. K., 1997. Mechanism of phosphate sorption and hydrous ferric oxide gel. *Journ. Soil Sci.*, 21, 353.

Sanchez-Carrillo, S., Alatorre, L C., Sanchez-Andres, R., Garatuza- Payan, J., 2006. Eutrophication and Sedimentation Patterns in Complete Exploitation of Water Resources Scenarios: An Example from *Sedimented Nitrogen and Phosphorus* Northwestern Semi-arid Mexico. *Environ. Monit. Assess.*38, 125-132.

Santhanam, P., Perumal P., 2003. Diversity of zooplankton in Parangipettai coastal waters, southeast coast of India. *J. Mar. Biol. Ass. India*, 45, 144-151.

Sarala Devi, K., Venugopal, P., 1989. Benthos of Cochin backwaters receiving industrial effluents. *Ind. J. Mar. Sci*. 18, 165-169.

Saraladevi, K., Jayalakshmi, K.V., Venugopal, P., 1991. Distribution of nutrients in Periyar river estuary. *Ind. J. Mar. Sci.*, 20(4), 141-145.

Schnitzer, M., Khan, S. U., 1972. Humic Substances in the Environment. Marcel Dekker, New York, pp. 327.

Segar, K., Hariharan, V., 1989. Seasonal distribution of nitrate, nitrite, ammonia and plankton in effluent discharge area of Mangalore, West coast of India. *Ind.J. Mar. Sci*., 18, 170-173.

Senthilkumar, S., Santhanam, P., Perumal, P., 2002. Diversity of phytoplankton in Vellar estuary, southeast coast of India. The 5th Indian fisheries forum proceedings (Eds.: S. Ayyappan, J.K. Jena and M. Mohan Joseph). Published by AFSIB, Mangalore and AeA, Bhubanewar, India. pp. 245-248.

Sholkovitz, E. R., 1978. Flocculation of dissolved Fe, Mn, Al, Cu, Ni,Co and Cd during estuarine mixing, *Earth Planet. Sci. Lett*., 41, 77-86.

Silva, C. A. R., Mozeto, A. A., 1997. Release and retention of phosphorus in mangrove sediments: Sepetiba Bay, Brazil, In: *Mangrove*

Ecosystem Studies in Latin America and Africa, Kjerfve, B., Lacerda, L. D., Diop, E. H. S., (Eds.), United Nations Educational Publisher, The Hague, pp 179-190.

Sivakumar, V., 1982. An environmental inventory of the tidal zone of the Vellar estuary. Ph.D. Thesis, Annamalai University, India. pp 78.

Soman, K., 1997. Geology of Kerala. Geological Society of India, Bangalore, India.

Srinivas, K., 1999. Seasonal and interannual variability of sea level and associated surface meteorological parameters at Cochin, PhD Thesis, Cochin University of Science and Technology, Cochin, India.

Stevens, R. J., Stewart, B. M., 1982. Concentration, fractionation and characterisation of soluble organic phosphorus in river water entering Lough Neagh. *Wat. Res., 16*, 1507-1519.

Subramanian, B., Mahadevan, A. 1999. Seasonal and diurnal variations of hydro biological characters of coastal waters of Chennai (Madras) Bay of Bengal. *Ind. J. Mar. Sci.*, 28, 429-433.

Sun, M., Aller, R.C., Lee, C., 1991. Early diagenesis of chlorophyll a in Long Island Sound sediments: a measure of carbon flux and particle reworking. *J. Mar. Res.*, 49, 279-401.

Sun, M.Y., Cai, W.J., Joye, S.B., Ding, H., Dai, J., Hollibaugh, J.T., 2002. Degradation of algal lipids in microcosm sediments with different mixing regimes. *Org. Geochem.,* 33, 445–459.

Tsujimoto, A., Nomura, R., Yasuhara, M., Yamazaki , H., Yoshikawa. S., 2006. Impact of eutrophication on shallow marine benthic foraminifers over the last 150 years in Osaka Bay, Japan. *Mar. Micro. paleontol*. 60, 258-268.

Urakawa, H., Kurata, S. Fujiwara, T., Kuroiwa, D., Maki, H., Kawabata, S., Hiwatari, T., Ando, H., Kawai, T., Watanabe M., Kohata, K. (2006) Characterization and quantification of ammonia oxidizing bacteria in eutrophic coastal marine sediments using polyphasic molecular approaches and immune fluorescence staining. *Environ. Microbiol.,* 8, 787-803.

Verma A., Subramanian, V., 2002. Organic matter and amino acid concentrations in surface sediments of Vembanad Lake – a tropical estuary, West coast of India, *Reg. Environ. Change* 2 , 143–149.

Vijayakumar, S.K., Rajesh, K.M., Mridula, R., Mendon., Hariharan, V.2000. Seasonal distribution and behaviour of nutrients with reference to tidal rhythm in the Mulki estuary, southwest coast of India. *J. Mar.Biol. Ass.* India, 42, 21-31.

Viollier, E., Rabouille, C., Apitz, S. E., Breuerd, E., Chaillou, G., Dedieub, K., Furukawaf, Y., Grenz, C., Hall, P., Janssen, F., 2003. Benthic biogeochemistry: State of the art technologies and guidelines for the future of in situ survey. *Journ. Exper. Mar. Biol. Ecol.*, 285-286, 5-31.

Viollier, E., Rabouille, C., Apitz, S. E., Breuerd, E., Chaillou, G., Dedieub, K., Furukawaf, Y., Grenz, C., Hall, P., Janssen, F., 2003. Benthic biogeochemistry: State of the art technologies and guidelines for the future of in situ survey. *Journ. Exper. Mar. Biol. Ecol.,* 285-286, 5-31.

Volkman, J.K., 2003. Sterols in microorganisms. Applied Microbiology and Biotechnology 60, 495–506.

Waite T. D., 2001. Thermodynamics of the iron system in seawater. In: *The Biogeochemistry of Iron in Seawater,* Turner, D. R., and K. A. Hunter (Eds.), Wiley, New York, 291–342.

Wakeham, S. G., Lee, C., 1989. Organic geochemistry of particulate matter in the ocean: The role of particles in oceanic sedimentary cycles. *Org. Geochem.*, 14, 83-96.

Wakeham, S.G., 1995. Lipid biomarkers for heterotrophic alteration of suspended particulate matter in oxygenated and anoxic water columns of the ocean. *Deep-Sea Research* I 42, 1749-1771.

Wen, L.S., Santschi, P., Gill, G., Paternostro, C., 1999. Estuarine trace metal distributions in Galveston Bay: importance of colloidal forms in the speciation of the dissolved phases. *Mar. Chem*. 63, 185-212.

Williams, P. M., Carlucci, A. F., 1976. Bacterial utilization of organic matter in the deep sea. *Nature*, 262, 810-811.

Yamamuro, M., 2000. Chemical tracers of sediment organic matter origins in two coastal lagoons, *J. Mar. Syst*. 26, 127-134.

Zegouagh, Y., Derenne, S., Largeau, C., Bertrand, P., Sicre, M.-A., Saliot et al., 1999. Refractory organic matter in sediments from the north-west African upwelling system:-abundance, chemical structure and origin. *Org.Geochem.,* 30, 101-117.

Zwolsman, J. J. G., 1994. Seasonal variability and biogeochemistry of phosphorus in the Scheldt Estuary, South-west Netherlands. *Est. Coast. Shelf Sci.*, 39, 227-248.

Chapter 4

NUTRIENT DYNAMICS ON TROPHIC STRUCTURE AND INTERACTIONS

Contents

Nutrient levels are important determinants of biodiversity, influencing the processes of competition and community structure in the water bodies. In the pelagic waters, concentration of inorganic nutrients such as nitrate, phosphate and silicate in the water dictate population growth of planktonic primary producers. Nutrients are generally considered to be the limiting factors for phytoplankton productivity. The nutrient content of estuaries is determined by their concentration in the riverine and coastal water sources. Generally nitrate, nitrite, phosphate and silicate are regarded as essential nutrients for plankton growth which affects the survival and population fluctuation of other fauna and flora in the food chain (Pramodbabu, 2007). The changes and seasonal cycles of these nutrients control most of the biological activities in estuarine systems. The nitrogen as nitrate and phosphorus as phosphate greatly augment the primary productivity and both are essential for the survival of primary producers, yet they subsist in very small concentration in the surrounding medium.

Phytoplankton and zooplankton in water samples collected from 15 selected stations spread across the Cochin backwater system were analysed to evaluate seasonal and spatial variation in their distribution and abundance. An attempt was made to unravel the primary production ,secondary production and tertiary production of the estuarine system using phytoplankton, primary productivity, phytopigments, zooplankton and fishes. The effect of general hydrography and nutrients on trophic structure was assessed by statistical methods.

4.1 Results

Results of quantitative and qualitative analysis of phytoplankton species, primary productivity and phytoplankton pigments, zooplankton species, fish landings, gut content analysis and proximate composition are described in this section.

4.1.1. a Spatial and Seasonal Distribution of Phytoplankton

Species belonging to different groups of phytoplankton were observed in the present study. They include: Chlorophyceae, Bacillariophyceae, Myxophyceae, Silicoflagellates, Cyanobacteria, Zygnematophyceae and Desmidaceae and are presented in the tables 4.1 to 4.5. Figure 4.1 provides information about spatiotemporal variation of phytoplanktons in the Cochin backwater system.

Chlorophyceae

Among the phytoplankton studied, eleven species belongs to Chlorophyceae were identified and quantified in the present investigation during POM 08 (tables 4.1 - 4.5 and figure 4.1). The present study recorded the occurrence of *Chlorella* at all stations except at S1, S13 and S14. *Microspora* was observed throughout the entire study area except at S1. It was noticed that *Tetraspora* was recorded at almost all stations except at S4. However, *Volvox* was absent in S12 and all other species shown in the table were present in all stations during POM 08.

Table 4.1 Spatial and seasonal distribution of Chlorophyceae during POM 08(No./m^3)

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	600	600	400	200	800	400	600	1400	2600	1600	600	200	400	200	200
Arthrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorella	0	200	800	800	600	400	400	600	600	400	800	600	0	0	1400
Chlorococcum	200	400	400	600	400	400	400	400	600	400	400	600	400	800	600
Closterium sp.	1400	2200	1200	2400	1400	2000	800	600	800	1600	1600	1400	200	600	1000
Micrasterias foliacea	400	2400	1600	400	1800	600	200	400	1000	1200	800	600	600	400	400
Microspora	0	200	200	800	400	200	200	400	600	200	400	200	200	400	400
Pediastrum duplex	1800	1600	1400	1000	200	600	1400	400	1000	200	800	600	1600	1200	1000
Pediastrum simples	200	1200	800	1400	600	1400	1600	1000	2200	1800	1600	2200	1800	600	1400
Pledorina	600	400	800	600	600	400	800	600	200	400	600	400	800	600	400
Scenedesmus quadricauda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum sp.	400	2400	1200	2000	200	600	2800	2000	600	1800	400	600	2800	1800	600
Tetraspora	200	400	200	0	800	400	1000	400	600	400	800	200	400	400	400
Ulothrix tenuissima Kuetzing	1400	1600	400	1000	1000	1800	2200	1200	1400	2000	400	600	600	1000	200
Volvox aureas Ehrenberg	200	1200	400	400	200	400	200	400	600	1200	200	0	200	200	400

Table 4.2 Spatial and seasonal distribution of Chlorophyceae during PRE 09(No./m^3)

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	600	600	400	400	200	200	0	0	0	0	0	0	0	100	300
Arthrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorella	200	200	400	200	400	200	300	400	400	300	300	400	800	1000	2000
Chlorococcum	800	800	600	400	600	800	800	800	1200	600	1200	1000	800	1200	1400
Closterium sp.	1000	600	800	600	800	800	800	600	600	600	1000	800	800	1000	800
Micrasterias foliacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microspora	400	200	200	400	200	200	400	600	400	200	200	400	400	400	200
Pediastrum duplex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum simples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pledorina	400	800	800	600	800	600	800	400	400	400	600	800	600	800	400
Scenedesmus quadricauda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum sp.	600	600	1200	600	200	800	800	600	600	400	400	600	600	800	200
Tetraspora	400	200	400	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix tenuissima Kuetzing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Volvox aureas Ehrenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.3 Spatial and seasonal distribution of Chlorophyceae during MON 09(No./m^3)

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arthrodesmus	600	400	600	200	400	200	600	400	600	800	600	400	600	800	600
Chlorella	200	200	400	600	200	600	800	600	400	400	200	400	200	200	400
Chlorococcum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium sp.	200	0	200	200	400	200	200	200	400	200	200	400	200	200	200
Micrasterias foliacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum duplex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum simples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pledorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus quadricauda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix tenuissima Kuetzing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Volvax aureas Ehrenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.4 Spatial and seasonal distribution of Chlorophyceae during POM 09(No./m^3)

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	2400	4000	1600	400	1200	1600	1200	1800	2400	2400	1200	200	1600	200	600
Arthrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorella	2400	1800	2000	2800	2200	1200	1800	1200	1400	3200	3000	2800	1800	2600	2200
Chlorococcum	3200	2000	4400	4000	3200	4000	4000	2800	3200	2400	2400	3200	1200	1200	3200
Closterium sp.	3200	3200	1600	3200	2800	2400	1800	1400	1600	2000	3200	2400	1000	1200	2000
Micrasterias foliacea	400	3600	2000	1000	200	200	200	200	600	1000	1000	600	400	400	200
Microspora	200	200	600	1200	1000	800	600	1400	800	400	800	800	1000	1200	1400
Pediastrum duplex	200	200	200	200	200	800	400	800	600	1000	600	1000	1200	600	1400
Pediastrum simples	800	600	400	400	400	400	400	600	600	1400	1800	2200	2400	1000	1600
Pledorina	3600	3000	2400	2400	1600	800	1800	800	1200	800	1600	1000	800	1200	1600
Scenedesmus quadricauda	400	400	200	200	200	800	400	800	600	1000	600	1200	800	1200	1200
Staurastrum sp.	600	400	200	200	200	600	1400	1200	1400	800	1800	800	600	800	600
Tetraspora	200	800	800	600	600	400	800	400	1000	400	400	200	400	600	800
Ulothrix tenuissima Kuetzing	2400	2400	1000	400	2000	2400	2400	1800	2000	3600	1200	1000	1600	1800	800
Volvox aureas Ehrenberg	2800	2400	1600	1200	800	1200	200	800	1600	2000	800	400	600	600	400

Table 4.5 Spatial and seasonal distribution of Chlorophyceae during PRE 10(No./m^3)

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arthrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorella	400	400	200	400	400	200	200	200	200	400	400	400	600	200	800
Chlorococcum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium sp.	1400	800	1800	1000	1000	1400	1400	1000	1000	1400	1000	800	600	1000	1800
Micrasterias foliacea	1200	800	1200	600	200	200	200	0	0	0	0	0	0	0	0
Microspora	1800	2400	1600	1000	800	1000	200	400	600	1200	200	0	200	200	0
Pediastrum duplex	0	2000	1200	200	400	600	1200	400	1200	200	800	1400	1600	1200	1000
Pediastrum simples	400	1800	1000	1800	1000	1600	1600	800	1600	2400	1600	2800	1800	600	1400
Pledorina	200	200	200	1200	200	200	0	400	200	200	200	200	200	0	800
Scenedesmus quadricauda	400	200	600	600	800	200	400	400	600	200	200	200	400	400	200
Staurastrum sp.	1000	1000	1800	1000	800	1000	1600	1800	1000	1600	400	800	800	1000	800
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix tenuissima Kuetzing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Volvox aureas Ehrenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

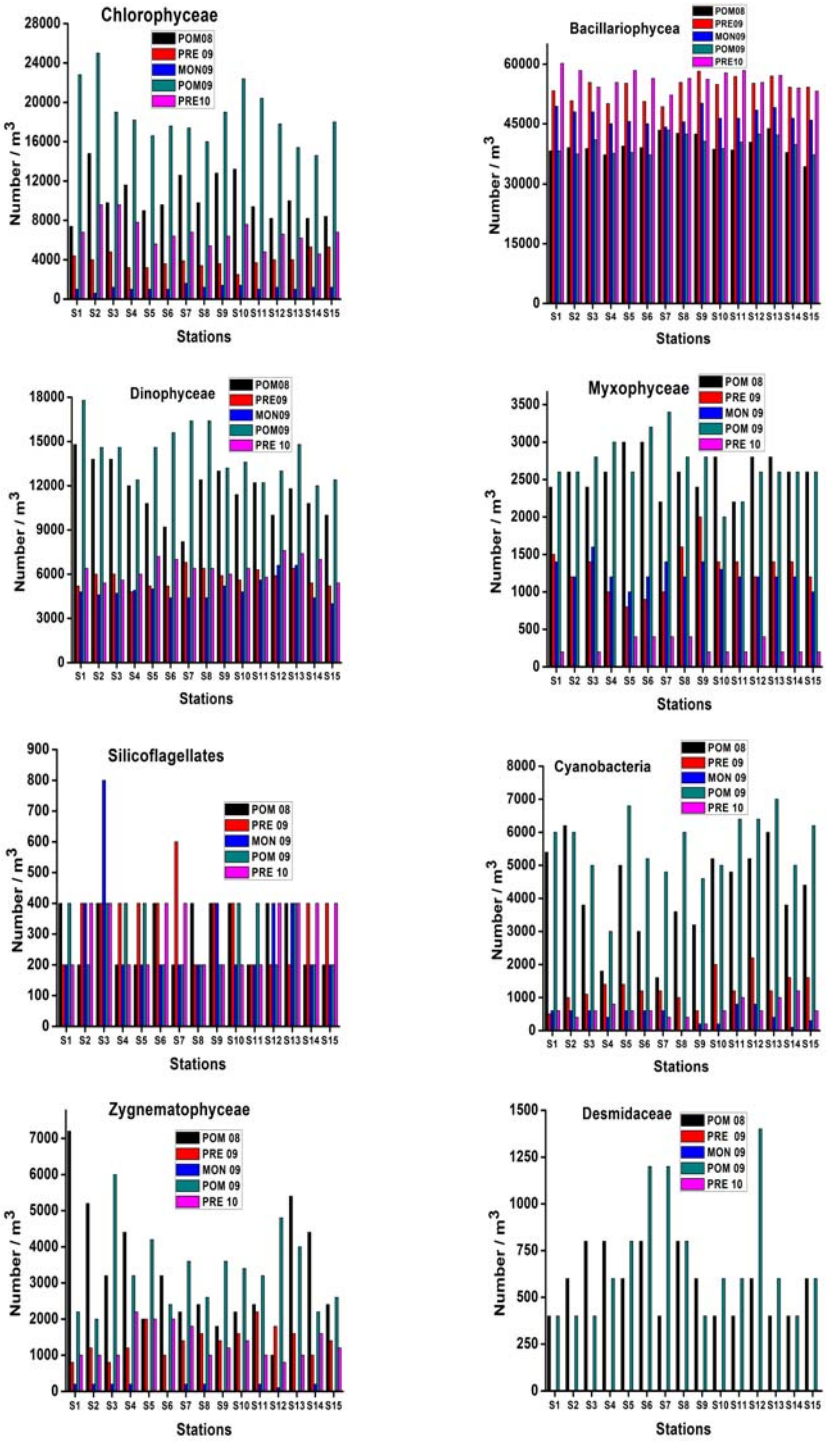


Figure 4.1 Spatial and Seasonal variation in distribution of phytoplanktons in the study area.

Ankistrodesmus falcans was present in few stations except S7 to S13 during PRE 09. *Arthrodesmus* sp.*, Micrasterias foliacea, Pediastrum duplex, Pediastrum simples, Pledorina sp.*, *Scenedesmus quadricauda, Ulothrix* sp.*, Volvox aureus* were absent in all stations. *Tetraspora* was observed at a few stations, ie. S1, S2 and S3. Among Chlorophyceae, six species were abundant in all stations and one species was common during PRE 09.

However in MON 09, occurrence of *Arthrodesmus*, *Chlorella*, *and Closterium* were recorded at all stations. All other species of phytoplaktons were absent during monsoon season. Among Chlorophyceae two species were abundant, one species was common and all others were absent in the study area.

In the present investigation, 14 planktons were identified which is shown in the table 4.4 and seen in all stations during (POM 09).

Meanwhile during PRE 10, plankton *Ankistrodesmus falcans*, *Arthrodesmus* sp., *Chlorococcum* sp., *Tetraspora* sp., *Ulothrix* sp., and *Volvox* sp., that belongs to Chlorophyceae were absent. Presence of *Micrasterias foliaceae* was observed at all stations except S8 to S15. *Microspora* was present in all stations except at S12 and S15.

Bacillariophyceae

All species belonging to Bacillariophyceae are given in table 4.6 to 4.10. *Asterionella formosa* was present in all stations except in station S5 and S6 during POM 08. *Asteremphalus flabellatus* was present in all stations except at S6. *Asterionella japonica* was present in all stations except at S6. However, most of the stations recorded *Bacillaria paradoxa*

except at stations S7, S12 and S15 during this season. It could be noticed that *Pleurosigma normanii* occurred at all stations (except S2, S3, S6, S7, S8 and S13). *Pleurosigma elongatum* was observed in all stations except in S1. *Rhizosolenia stolterfothii* was present in all stations except in S6 and S13. *Cyclotella meneghiniana* was present in all stations except at S3. *Pseudonitzschia* was present in all stations except at S15. *Thalassiothrix longissima* was present at all stations except at S9, S10 and S15. However, *Triceratium reticulatum* was present in all stations except in station S5 to S7 and S10 to S14. In the case of *Chaetoceros decipiens* presence was detected in all stations except at stations S12 and S15. *Chaetoceros denticulatum* was observed in all stations except station S3, S4 and S12. *Pseudonitzschia* sp. was present in all stations except S15. Among Bacillariophyceae, 21 species were abundant and 19 were common and others were not found in the study area of the five sampling campaigns, PRE 09 exhibited the presence of *Bacteriastrum hyalinum* at almost all stations. *Bellerochea malleus* was present in all stations except at S1. However all stations except S2 recorded *Coscinocira polychorda* and *Coscinodiscus* asteromphalus. *Fragilaria intermedia* were present in all stations except S2, S14, and S15. *Hemiaulus sinensis* was present in some stations except S1 and S4. *Leptocylindrus danicus* was present in few stations except S1, S2, and S3. Meanwhile *Lithodesmium undulatum* was present at all stations except S13, S14, and S15. Melosira sulcata was present in all stations except S6 andS8. *Pleurosigma directum* was present in all stations except S4. 32 species of phytoplankton belonging to Bacillariophyceae were abundant in the study area and 23 species were common and all others were absent during PRE 09.

Table 4.6 Spatial and seasonal distribution of Bacillariophyceae during POM 08 (No/m^3)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	1000	1200	800	600	0	0	400	400	200	800	800	600	400	200	400
Amphiprora gigantea var.sulcata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterempha lus flabellatus	200	200	400	200	400	0	400	400	200	400	400	200	400	200	400
Asterionella japonica	2400	2800	2800	2200	3000	2600	2600	2400	2200	2200	2600	2200	2600	2800	2400
Aulacoseira granulata	3600	1200	2000	3800	4000	800	2000	1200	2600	2200	800	2400	2200	2200	1600
Bacillaria paradoxa	400	200	200	400	400	200	0	200	400	200	200	0	1800	200	0
Bacteriastrum hyalinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bacteriastrum varians	400	400	200	0	400	200	400	200	400	200	200	400	200	200	400
Bellerochea malleus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biddulphia aurita	200	200	200	400	200	400	200	400	200	200	400	400	200	200	200
Biddulphia heteroceros	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerataulina bergonii	4000	5200	5200	4600	5400	5400	5800	4000	4600	4200	4600	4800	4400	4000	4000
Chaetoceros lorenzianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros affinis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros coarctatus	400	400	200	200	400	200	400	400	200	400	400	200	400	200	400
Chaetoceros curvisetus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros decipiens	200	200	400	200	200	200	200	200	400	200	400	0	400	200	0
Chaetoceros denticulatum	200	200	0	0	400	200	400	400	400	200	400	0	200	200	200
Climacodium frauenfeldianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus concinnus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinocira polychorda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus perforatus	800	800	800	600	800	1000	1000	1000	800	800	600	600	600	800	600
Coscinodiscus asteromphalus	1600	1200	1200	1400	1400	1200	1200	1600	1600	1000	1000	1200	1400	1400	1200
Coscinodiscus centralis	1000	1800	1200	800	1200	3600	4400	6600	4000	2200	1800	3400	3000	2800	2600
Coscinodiscus gigas var.paretexia	1200	1200	1200	1000	1600	1200	1800	1600	1600	1800	2000	1400	1000	1600	1400
Coscinodiscus granii	400	400	200	200	200	400	200	400	200	400	400	400	400	400	400
Coscinodiscus marginatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus oculis -iridis	1800	1200	1200	1200	1000	1400	1200	1200	1200	1000	1000	1200	1200	1200	1600
Cyclotella meneghiniana	400	400	0	200	400	400	400	200	200	400	200	400	200	400	400
Cymbella marina	200	400	200	400	400	400	200	200	400	200	400	400	400	200	200
Eucampia zoodiacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragillaria intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragellariopsis	400	200	800	400	400	200	600	400	200	400	200	400	200	200	200

Table 4.6 Spatial and seasonal distribution of Bacillariophyceae during POM 08 (No/m^3) (Continued....)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Grammatophora marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora undulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyrosigma balticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiaulus sinensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemidiscus hardmannianus	200	200	200	400	400	200	200	400	400	400	200	200	200	200	200
Hyalodiscus subtilis	1000	1000	1200	1400	1000	1000	1000	1200	1200	1200	1000	1200	1200	1000	0
Leptocylindrus danicus	800	600	200	600	600	600	600	800	800	600	600	800	600	400	400
Lithodesmium undulatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melosira sulcata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula hennedyii	200	400	200	200	400	400	200	400	200	200	200	400	200	200	200
Nitzschia closterium	400	200	400	200	200	200	400	400	200	200	400	400	400	400	200
Nitzschia longissima	2400	2000	3000	2400	2400	2600	2400	2000	2400	2800	2400	2800	2400	2400	2200
Nitzschia seriata	2200	2400	2600	3200	2400	2400	2000	3200	2200	2400	2000	2400	2600	2600	2400
Pseudonitzschia sp	1200	2200	1400	1000	1200	1600	1200	1200	2400	1200	400	1200	2800	400	0
Nitzschia sigma var . Indica	400	200	400	200	400	200	200	400	200	400	200	200	400	400	200
pleurosigma normanii	0	200	200	0	0	200	400	200	0	0	0	0	200	0	0
Pleurosigma directum	400	400	200	400	200	400	200	200	400	200	400	200	200	400	400
Pleurosigma elongatum	0	200	200	200	400	400	400	200	400	400	200	200	400	200	200
Rhizosolenia alata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia calcar-avis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia imbricata	200	200	400	400	400	200	200	400	400	400	200	200	400	400	400
Rhizosolenia robusta	1600	1200	1600	1800	1000	1200	1600	1400	1200	1600	1800	1000	1200	1600	1400
Rhizosolenia stolterfothii	200	800	400	400	400	0	400	400	400	400	400	400	0	200	200
Rhizosolenia styliformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schroderella delicatula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanopyxis palmariana	400	400	200	0	0	0	0	0	0	0	200	200	400	200	200
Stephanopyxis turris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skeletonema costatum	600	400	400	200	800	2000	3200	2000	2400	2200	4400	2800	3200	2400	1600
Streptotheca indica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassionema nitzschioides	1200	1600	1600	1200	1200	1600	1200	1000	1200	1200	1400	1400	1400	1200	1200
Thalassiosira subtilis	1200	1600	1800	1000	1200	1600	1400	1000	1200	1000	1000	1200	1200	1000	1200
Thalassiosira decipiens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiothrix frauenfeldii	2400	2200	2400	2400	2200	2000	2200	2200	2400	2200	2000	2400	2400	2200	2800
Thalassiothrix longissima	200	400	200	400	400	200	200	0	0	200	200	200	400	400	0
Triceratium reticulatum	200	400	400	400	0	0	0	200	400	0	0	0	0	0	200

Table 4.7 Spatial and seasonal distribution of Bacillariophyceae during PRE 09 (No/m^3)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	1600	200	2000	600	1000	800	600	2200	1200	200	400	600	600	800	1400
Amphiprora gigantea var. sulcata	400	200	400	400	200	400	200	200	200	400	200	400	200	200	400
Asteremphalus flabellatus	200	400	200	400	200	200	200	400	200	400	400	200	400	400	400
Asterionella japonica	1600	1000	1000	1000	1200	1000	1000	1200	1200	1000	1200	1000	1200	1200	1200
Aulacoseira granulata	800	400	1400	1200	1200	1200	1000	200	1400	1800	1600	1600	1600	1800	1600
Bacillaria paradoxa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bacteriastrum hyalinum	400	400	400	400	200	0	400	200	400	400	400	400	400	400	400
Bacteriastrum varians	200	400	200	400	400	400	400	200	400	200	400	200	200	400	400
Bellerochea malleus	0	200	200	200	200	200	400	400	400	200	200	200	200	400	400
Biddulphia aurita	1200	1000	1200	1000	1400	1000	1200	1200	1000	1200	1400	1400	1600	1400	1000
Biddulphia heteroceros	200	400	200	200	200	400	200	200	200	200	200	400	200	200	400
Cerataulina bergonii	1100	2400	2200	2200	2200	2400	2200	2200	2200	2200	2200	2200	2200	2400	2400
Chaetoceros lorenzianus	5000	4400	4600	4200	4800	5200	5000	5400	5200	5400	5000	4200	4200	4000	4000
Chaetoceros affinis	2200	4800	4400	4400	5000	4600	4400	4200	4800	4400	4800	5800	4600	5000	4400
Chaetoceros coarctatus	400	400	200	200	200	400	200	200	200	200	400	200	200	200	200
Chaetoceros curvisetus	1200	1600	1200	1200	1200	1400	1200	1400	1400	1200	1400	1400	1400	1200	1200
Chaetoceros decipiens	1200	1200	1800	1400	1600	1000	1200	1600	1400	3000	2800	3000	2400	2400	2400
Chaetoceros denticulatum	1200	2200	2400	2400	2200	1200	1600	1400	1200	1200	2200	2400	2400	2200	2000
Climacodium frauenfeldianum	200	200	400	400	200	400	400	400	400	400	200	200	200	400	200
Coscinodiscus concinnus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinocira polychorda	400	0	400	200	200	200	200	400	400	400	400	400	400	400	400
Coscinodiscus perforatus	400	400	200	400	400	200	200	200	400	400	200	200	400	400	400
Coscinodiscus asteromphalus	400	0	200	400	200	200	200	200	200	400	200	400	400	200	400
Coscinodiscus centralis	1000	400	2000	200	400	800	200	3600	2800	1400	3200	1400	4000	2400	1800
Coscinodiscus gigas var *.partetexia*	200	400	400	200	400	200	400	200	200	200	400	400	200	400	400
Coscinodiscus granii	4200	3600	5000	4200	4800	4200	2800	4000	4800	3800	4200	3600	3600	3600	4200
coscinodiscus marginatus	200	400	400	400	200	400	200	400	400	200	200	400	200	400	400
Coscinodiscus oculis -iridis	1000	1200	1200	1000	1200	1200	1000	1200	1400	1200	1400	1400	1400	1200	1400
Cyclotella meneghiniana	600	200	400	1400	400	400	600	400	400	400	400	400	200	200	400
Cymbella marina	200	200	200	200	200	400	400	600	400	400	400	400	400	400	400
Eucampia zoodiacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragellariopsis	400	200	200	200	200	200	600	800	600	600	400	400	600	800	600
Fragilaria intermedia	200	0	200	400	200	200	200	200	200	400	200	200	200	0	0
Grammatophora marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.7 Spatial and seasonal distribution of Bacillariophyceae during PRE 09 (No/m^3) (Continued...)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Grammatophora undulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyrosigma balticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiaulus sinensis	0	400	400	0	400	400	400	400	400	400	200	200	200	400	400
Hemidiscus hardmannianus	400	200	400	200	200	200	400	400	400	400	200	400	400	200	400
Hyalodiscus subtilis	400	400	400	400	400	200	400	400	600	200	400	400	400	400	400
Leptocylindrus danicus	0	0	0	400	400	400	200	200	400	400	200	200	200	400	400
Lithodesmium undulatum	200	400	400	400	400	200	200	200	400	400	400	400	0	0	0
Melosira sulcata	200	400	400	200	400	0	200	0	400	200	200	200	400	400	200
Navicula hennedyii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia closterium	200	200	400	400	400	200	200	400	200	200	200	400	200	400	1400
Nitzschia longissima	1000	1000	1200	1200	1400	1200	1000	1600	1000	1000	1000	1200	1200	800	800
Nitzschia seriata	2400	1400	1200	1100	1200	1200	1100	1200	1800	1500	1200	1200	2200	1200	2400
Pseudonitzschia sp	1200	1400	1200	600	800	400	1600	800	1600	1400	800	400	1200	400	800
Nitzschia sigma var *.indica*	400	200	200	400	200	400	400	400	200	400	200	400	200	200	200
Pleurosigma directum	1800	1800	200	0	1200	800	400	800	1200	800	1000	400	400	200	400
pleurosigma normanii	400	400	200	1000	1800	1200	1600	1400	1000	1400	800	600	800	600	600
Pleurosigma elongatum	1400	1000	1000	1200	1200	1400	1400	1000	1200	1000	1200	1600	1200	1200	1400
Rhizosolenia alata	1200	1200	1200	1200	1400	1400	1400	1200	1200	1000	1400	1200	1200	1600	400
Rhizosolenia calcar-avis	400	400	200	200	400	400	200	200	200	400	400	400	400	400	400
Rhizosolenia imbricata	400	200	400	200	400	200	200	200	200	400	200	400	400	200	200
Rhizosolenia robusta	400	200	400	200	400	200	200	200	200	400	400	400	400	200	200
Rhizosolenia stolterfothii	200	200	0	200	200	200	400	200	400	400	400	400	400	200	200
Rhizosolenia styliformis	200	200	400	400	400	200	200	200	400	400	400	400	200	200	400
Schroderella delicatula	2200	1400	1200	800	400	600	600	400	1400	1200	1100	1200	1400	1400	400
Stephanopyxis palmariana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanopyxis turris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skeletonema costatum	2800	3000	2200	2000	2600	2400	1600	1400	1200	1200	1200	1000	1400	1000	1400
Streptotheca indica	2400	2400	2400	2200	2400	2400	2200	2400	2400	2000	2000	2200	2400	2600	2000
Thalassionema nitzschioides	400	400	400	200	200	200	400	200	200	400	400	200	200	400	400
Thalassiosira subtilis	2800	2000	2200	2200	2200	2000	2000	2400	2200	2200	2200	2600	2000	2400	2000
Thalassiosira decipiens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiothrix frauenfeldii	1200	1000	1400	1200	1000	1200	1200	1400	1600	1200	1400	1000	1200	1200	1000
Thalassiothrix longissima	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triceratium reticulatum	400	200	200	200	400	200	400	400	200	200	400	400	200	200	200

Table 4.8 Spatial and seasonal distribution of Bacillariophyceae during MON 09 (No/m^3)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	1000	800	1800	600	400	1000	1200	800	1200	1000	1000	1200	1600	800	1000
Amphiprora gigantea var.sulcata	200	400	200	400	200	200	200	200	400	200	200	200	200	400	200
Asteremphalus flabellatus	1600	1200	1200	1200	1200	1200	1200	1800	1200	1400	1200	1800	1800	1200	1400
Asterionella japonica	2600	2200	3200	3200	2800	3000	3000	3200	3200	2600	2400	2800	2800	3200	2200
Aulacoseira granulata	1200	1400	800	600	800	800	600	800	1400	600	800	800	1000	800	400
Bacillaria paradoxa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bacteriastrum hyalinum	400	400	200	400	200	400	400	400	200	200	200	200	200	200	200
Bacteriastrum varians	200	400	200	400	400	400	200	200	200	200	200	200	200	400	200
Bellerochea malleus	400	400	200	200	200	400	200	200	200	200	200	200	400	400	200
Biddulphia aurita	2400	2200	2600	2400	2400	2800	2600	2400	2800	2600	2000	2400	2600	2800	2600
Biddulphia heteroceros	200	400	200	400	400	200	400	200	200	400	200	200	400	400	0
Cerataulina bergonii	1400	1200	1400	1200	1100	1600	1200	1600	1600	1200	1400	1200	1200	1100	1000
Chaetoceros lorenzianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros affinis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros coarctatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros carvisetus	1400	1400	1200	1200	1400	1600	1400	1400	1200	1200	1400	1600	1200	1200	1000
Chaetoceros decipiens	2200	2200	2800	3000	2800	2400	2400	2600	2600	2800	2400	2600	3000	2200	2200
Chaetoceros denticulatum	2600	2400	2200	2200	2400	2400	2200	2400	2400	2400	2600	2200	2200	2400	2200
Climacodium frauenfeldianum	200	400	200	0	200	400	0	200	200	200	200	200	400	200	200
Coscinodiscus concinnus	400	400	400	400	400	400	200	200	200	200	400	400	400	400	400
Coscinocira polychorda	400	400	400	400	200	200	400	200	400	400	200	200	400	400	200
Coscinodiscus perforatus	800	3600	2200	2000	2200	1600	2000	1500	1800	1000	1800	1600	1400	1800	1600
Coscinodiscus asteromphalus	1000	1200	1200	1000	1400	1400	1600	1400	1200	1400	1200	1200	1400	1200	1400
Coscinodiscus centralis	1800	400	1200	400	1200	200	400	400	2800	2000	3000	2400	3600	3200	1800
Coscinodiscus gigas var.pareltexia	1200	1000	1200	1200	1000	1400	1200	1400	1400	1200	1200	1200	1200	1400	1200
Coscinodiscus granii	400	200	400	400	200	200	200	200	400	200	400	400	200	200	400
Coscinodiscus marginatus	800	800	600	800	600	600	600	800	800	600	600	800	600	800	800
Coscinodiscus oculis -iridis	800	800	600	400	400	600	400	400	400	600	400	800	400	200	400
Cyclotella meneghiniana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella marina	1200	1200	1000	1000	1200	1400	1200	1400	1200	1200	1000	1000	1200	1200	1000
Eucampia zoodiacus	200	200	400	200	200	400	400	200	400	400	200	200	200	200	200
Fragellariopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria intermedia	2000	1800	1200	1200	1800	1200	1200	1400	1400	1600	1600	1800	1600	1200	1100
Grammatophora marina	600	400	400	200	400	200	400	400	200	200	200	400	400	200	600

Table 4.8 Spatial and seasonal distribution of Bacillariophyceae during MON 09 (No/m^3) (Continued.....)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Grammatophora undulata	400	200	200	200	400	200	200	200	400	200	400	200	400	200	200
Guinardia flaccida	200	200	200	400	400	200	0	0	400	400	200	200	200	400	0
Gyrosigma balticum	200	400	200	400	200	200	200	400	200	400	200	200	200	200	400
Hemiaulus sinensis	400	200	200	400	200	200	200	200	200	200	200	200	200	200	200
Hemidiscus hardmannianus	200	200	200	400	200	200	200	200	200	200	200	200	200	200	200
Hyalodiscus subtilis	200	200	200	200	0	200	200	200	200	200	0	200	200	200	200
Leptocylindrus danicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithodesmium undulatum	200	400	400	200	200	400	200	200	400	400	400	200	200	400	400
Melosira sulcata	400	400	400	200	400	200	200	400	200	200	400	400	400	400	400
Navicula hennedyii	200	400	200	400	200	200	200	400	400	200	400	200	200	200	200
Nitzschia closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia longissima	1200	1000	1200	1200	1200	1200	1400	1400	1200	1200	1200	1400	1400	1200	1200
Nitzschia seriata	2400	2200	2400	2200	2200	1200	1400	1400	1400	1400	1400	1200	1600	1200	1200
Pseudonitzschia sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia sigma var . Indica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma normanii	200	200	400	200	200	200	200	400	600	200	200	200	200	0	0
Pleurosigma directum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma elongatum	1000	1000	1200	1200	1400	1200	1200	1400	1800	1800	1600	1600	1300	1200	1200
Rhizosolenia alata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia calcar-avis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia imbricata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia robusta	1400	1200	1400	1600	1600	1200	1000	1200	1600	2000	1200	2000	1200	1200	1400
Rhizosolenia stolterfothii	200	200	400	400	400	200	400	200	400	200	400	400	400	200	400
Rhizosolenia styliformis	200	400	200	400	400	200	400	200	400	200	400	200	400	200	400
Schroderella delicatula	400	400	400	400	200	400	400	200	200	200	200	200	200	400	200
Stephanopyxis palmariana	200	0	200	200	200	0	0	0	0	200	200	200	0	200	200
Stephanopyxis turris	200	0	200	200	0	0	0	0	0	0	0	200	0	200	0
Skeletonema costatum	1600	1600	1200	600	400	1600	2000	1200	2000	1200	1600	1600	1800	1100	2000
Streptotheca indica	800	600	600	800	800	600	800	600	600	600	800	800	600	600	2000
Thalassionema nitzschioides	1800	1600	1200	1200	1300	1400	1200	1400	1200	1800	1200	1200	1200	1200	2000
Thalassiosira subtilis	1800	1400	1000	1200	1000	1200	1000	1400	1200	1200	1000	1400	1000	1000	1200
Thalassiosira decipiens	1200	1000	1200	1000	1200	1000	1200	1400	1000	1000	1200	1000	1000	1200	1400
Thalassiothrix frauenfeldii	1200	1200	1200	1000	1400	1400	1200	1200	1200	1200	1400	1200	1200	1400	1200
Thalassiothrix longissima	1200	1400	1400	1200	1200	1000	1000	1200	1000	1200	1000	1200	1000	1000	1200
Triceratium reticulatum	400	200	400	200	200	400	400	200	200	200	400	200	200	400	400

Table 4.9 Spatial and seasonal distribution of Bacillariophyceae during POM 09 (No/m^3)

Bacillariophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	1000	2000	1600	600	0	0	400	400	200	800	1000	600	400	200	400
Amphiprora gigantea var. sulcata	200	400	400	200	200	200	400	200	400	200	200	200	400	200	400
Asteromphalus flabellatus	400	200	400	200	400	200	200	400	400	200	400	200	400	200	200
Asterionella japonica	3200	3000	3000	2800	3000	2400	2200	3000	2800	2200	2600	2200	2400	2200	2400
Aulacoseira granulata	3600	1200	2000	3200	3200	800	2000	1200	2600	2000	800	2400	2200	2200	1600
Bacillaria paradoxa	400	200	200	0	200	0	0	200	400	200	200	200	0	200	200
Bacteriastrum hyalinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bacteriastrum varians	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bellerochea malleus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biddulphia aurita	200	200	400	400	200	400	200	400	200	400	400	200	200	400	0
Biddulphia heteroceros	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerataulina bergonii	2200	2400	2600	2800	2400	2400	2200	2000	2600	2000	2600	2400	2400	2200	2200
Chaetoceros lorenzianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros affinis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros coarctatus	400	200	400	400	200	400	400	0	0	400	400	0	0	400	400
Chaetoceros curvisetus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros decipiens	400	200	400	200	400	200	200	400	400	400	200	200	400	400	200
Chaetoceros denticulatum	200	400	200	400	200	400	200	400	200	400	200	400	200	200	200
Climacodium frauenfeldianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus concinnus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinocira polychorda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus perforatus	1200	1200	800	1000	800	800	1000	1200	1000	800	1000	800	600	800	600
Coscinodiscus asteromphalus	1800	1600	1200	1400	1400	1200	1400	1200	1200	1400	1400	1600	1200	1800	1200
Coscinodiscus centralis	1000	1800	1200	800	400	400	4400	6600	4000	2200	1800	3400	3000	2800	2600
Coscinodiscus gigas var. paretexia	1800	1600	1200	1400	1400	1200	1400	1000	1200	1600	1600	1400	1600	1600	1400
Coscinodiscus granii	400	400	200	200	200	400	200	200	400	400	400	200	200	400	200
Coscinodiscus marginatus	200	0	400	400	200	200	400	400	400	400	400	400	600	200	200
Coscinodiscus oculis - iridis	1600	1200	1200	1400	1200	1400	1200	1200	1000	1200	1400	1400	1600	1400	1200
Cyclotella meneghiniana	1400	1400	1800	1600	1400	1600	1600	1600	1800	1000	1600	1200	1600	1600	1200
Cymbella marina	0	400	400	200	200	400	200	200	200	200	400	400	400	200	400
Eucampia zoodiacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria intermedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragellariopsis	400	200	600	400	600	600	1000	800	800	400	800	600	1200	600	800
Grammatophora marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora undulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.9 Spatial and seasonal distribution of Bacillariophyceae during POM 09 (No/m^3) (continued)

Bacillariophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Guinardia flaccida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyrosigma balticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiaulus sinensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemidiscus hardmannianus	400	200	200	200	400	400	400	400	400	200	200	400	400	200	200
Hyalodiscus subtilis	1000	1200	1000	1200	1200	1400	1600	1200	1200	1400	1400	1200	800	1000	1000
Leptocylindrus danicus	1200	1000	1000	1200	1200	1400	1000	1200	1200	1400	1400	1600	1200	1000	1000
Lithodesmium undulatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melosira sulcata	0	0	0	0	0	0	0	0	0	0	0	0	200	400	200
Navicula hennedyii	200	400	400	200	400	400	200	200	200	200	200	400	200	200	200
Nitzschia closterium	200	400	400	200	200	400	200	400	200	200	400	200	400	400	200
Nitzschia longissima	2200	2400	2400	2400	2600	2800	2800	2000	2000	3200	2400	2800	2400	2400	2200
Nitzschia seriata	2400	2200	2400	2000	2200	2000	2400	2000	2000	2200	2200	2200	2000	2200	2000
Pseudonitzschia sp.	400	400	1800	1400	800	1800	1400	1000	800	1400	1800	2400	1400	1000	2000
Nitzschia sigma var . indica	200	200	400	400	400	200	200	400	200	200	200	400	400	400	400
Pleurosigma normanii	1200	800	1600	400	1200	600	1200	800	800	1600	1200	1200	1600	600	1000
Pleurosigma directum	200	400	1000	400	800	800	800	1200	1200	800	2000	2400	800	800	400
Pleurosigma elongatum	200	200	200	200	400	400	200	200	400	400	200	200	400	200	200
Rhizosolenia alata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia calcar-avis	0	400	200	200	400	0	200	200	200	400	400	400	0	0	0
Rhizosolenia imbricata	400	400	400	400	0	200	400	400	200	400	400	200	400	400	400
Rhizosolenia robusta	200	400	400	400	400	400	200	400	400	200	400	400	400	400	400
Rhizosolenia stolterfothii	200	400	400	400	400	400	200	400	400	400	200	200	400	400	200
Rhizosolenia styliformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schroderella delicatula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanopyxis palmariana	400	400	400	200	200	200	200	400	200	200	200	200	200	200	200
Skeletonema costatum	800	800	800	400	800	2000	3200	1600	800	400	800	200	2800	2000	1600
Stephanopyxis turris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Streptotheca indica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassionema nitzschioides	1200	1200	1200	1200	1400	1600	1400	1400	1200	1200	1400	1200	1200	1200	1200
Thalassiosira subtilis	1200	1200	1400	1000	1200	1400	1200	1400	1400	1200	1000	1400	1000	1600	1200
Thalassiosira decipiens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiothrix frauenfeldii	2000	2000	2200	2800	2800	2600	2400	2200	2800	2400	2000	2200	2400	2600	2800
Thalassiothrix longissima	0	200	200	400	200	200	400	0	200	0	200	200	200	0	200
Triceratium reticulatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.10 Spatial and seasonal distribution of Bacillariophyceae during PRE 10 (No/m^3)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	1600	400	1600	600	1000	800	600	1400	1200	200	400	600	600	800	1000
Amphiprora gigantea var.sulcata	200	400	200	400	400	200	400	200	400	200	200	400	400	200	400
Asteremphalus flabellatus	400	400	400	0	200	200	200	200	200	200	400	200	400	200	200
Asterionella japonica	1000	1200	1000	1200	1000	1200	1000	1400	1600	1400	1000	1400	1400	1200	1200
Auliscoseira granulata	1800	1600	1400	1000	1400	1200	1200	1400	1600	1200	1000	1200	1000	1400	1200
Bacillaria paradoxa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bacteriastrum hyalinum	200	200	200	200	200	200	200	200	200	200	400	200	400	400	400
Bacteriastrum varians	400	400	200	400	400	400	200	400	200	400	200	200	200	200	400
Bellerochea malleus	400	400	200	200	200	400	200	200	400	200	200	200	200	200	200
Biddulphia aurita	1200	1200	1200	1400	1200	1200	1000	1000	1200	1200	1400	1200	1600	1200	1200
Biddulphia heteroceros	200	200	200	400	0	200	200	200	200	400	0	400	400	0	400
Cerataulina bergonii	2400	2200	2400	2600	2200	2600	2400	2400	2800	2600	2400	2200	2400	2400	2200
Chaetoceros lorenzianus	4400	5000	5000	4400	5600	4800	5200	5600	4400	4000	4800	4600	4200	4400	4200
Chaetoceros affinis	5200	5400	4600	4200	4400	4600	4400	4400	5200	5200	5600	5200	5200	5200	5400
Chaetoceros coarctatus	400	400	200	0	400	200	400	400	400	200	0	200	0	200	400
Chaetoceros curvisetus	1200	1000	1200	1400	1200	1000	1200	1000	1200	1400	1400	1000	1200	1200	1200
Chaetoceros decipiens	3000	2400	2200	2200	2200	2400	2200	2200	2000	3000	2000	2200	2400	2400	2200
Chaetoceros denticulatum	2400	2200	2200	2200	2400	2200	2200	2000	3000	2000	2200	2400	2400	2200	2200
Climacodium frauenfeldianum	200	400	200	400	400	200	200	400	400	200	400	0	200	200	200
Coscinodiscus concinnus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinocira polychorda	400	400	200	400	400	200	400	400	200	400	400	400	400	200	400
Coscinodiscus perforatus	600	600	200	0	600	400	400	200	200	200	400	400	200	400	600
Coscinodiscus asterompahlus	400	400	200	200	400	400	200	400	200	200	400	400	200	200	400
Coscinodiscus centralis	0	400	0	0	200	400	200	400	0	800	0	400	400	0	0
Coscinodiscus gigas var.paretexia	200	400	400	400	200	400	400	400	200	400	400	400	400	200	200
Coscinodiscus granii	4400	3200	3600	4400	3600	4200	3600	2800	3200	4200	4000	4000	2800	2000	4200
coscinodiscus marginatus	400	400	200	400	200	400	200	200	400	400	200	400	200	200	400
Coscinodiscus oculis -iridis	1200	1200	1200	1400	1200	1400	1400	1200	1400	1400	1200	1200	1400	1200	1200
Cyclotella meneghiniana	200	400	400	400	400	200	200	200	400	400	200	200	0	400	200
Cymbella marina	0	0	400	400	400	200	400	400	200	200	0	400	400	200	0
Eucampia zoodiacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragellariopsis	400	400	400	200	400	800	200	800	400	1200	1200	1200	1200	400	0
Fragilaria intermedia	400	200	200	400	400	200	200	200	200	400	400	200	200	200	0
Grammatophora marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora undulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.10 Spatial and seasonal distribution of Bacillariophyceae during PRE 10 (No/m^3) (Continued...)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Guinardia flaccida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyrosigma balticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiaulus sinensis	200	400	400	400	200	400	400	400	200	400	400	400	200	200	200
Hemidiscus hardmannianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hyalodiscus subtilis	400	200	200	400	400	200	200	400	400	200	400	200	200	200	200
Leptocylindrus danicus	400	400	400	400	200	400	400	400	200	200	200	400	200	200	200
Lithodesmium undulatum	200	0	200	200	400	200	200	400	400	400	400	400	200	200	400
Melosira sulcata	400	400	200	200	200	200	400	400	400	400	400	200	200	200	200
Navicula hennedyii	200	400	400	200	400	200	200	200	200	400	200	200	200	200	400
Nitzschia closterium	200	400	400	200	200	400	200	400	400	200	200	200	200	400	200
Nitzschia longissima	1000	1000	1200	1000	1200	1000	1200	1200	1000	1400	1200	1000	1600	1600	1000
Nitzschia seriata	2000	2600	2400	2200	2200	2200	2200	3200	2400	2600	2400	2200	2800	2200	2200
Pseudonitzschia sp	600	400	400	800	200	400	400	600	800	600	400	400	600	600	400
Nitzschia sigma var *indica*	200	400	200	200	200	200	200	400	400	400	400	200	200	400	0
Pleurosigma directum	600	800	600	400	400	600	400	400	600	800	400	600	400	400	400
pleurosigma normanii	400	400	200	1000	800	600	800	1000	1000	1400	800	600	800	600	800
Pleurosigma elongatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia alata	1000	1600	1600	1400	1600	1200	1400	1200	1200	1000	2000	1600	1600	1200	1400
Rhizosolenia calcar-avis	400	400	200	200	200	200	200	400	400	400	200	200	400	400	200
Rhizosolenia imbricata	200	200	200	200	200	400	200	400	400	200	200	200	200	400	200
Rhizosolenia robusta	400	200	200	200	400	200	200	200	400	200	400	200	400	400	200
Rhizosolenia stolterfothii	400	400	400	400	400	400	400	400	200	200	400	400	200	200	200
Rhizosolenia styliformis	400	200	200	200	200	200	200	200	200	400	400	200	200	400	200
Schroderella delicatula	2200	2000	2200	2200	2400	2600	2400	2400	2800	2400	2600	2400	2400	2400	2400
Stephanopyxis palmariana	400	0	200	400	400	400	400	200	200	400	400	200	200	400	400
Stephanopyxis turris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skeletonema costatum	4800	4000	2400	3600	3000	2400	1200	1600	1000	1200	3600	2000	3600	3600	2000
Streptotheca indica	2200	2600	2200	2200	2800	2400	2200	2200	2400	2200	2600	2200	2200	2200	2200
Thalassionema nitzschioides	400	200	200	200	400	200	200	200	200	400	400	200	400	0	0
Thalassiosira subtilis	2200	2800	2400	2400	3200	3000	2000	2400	2200	2600	2200	2000	2400	2200	2200
Thalassiosira decipiens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiothrix frauenfeldii	1200	1200	1200	1000	1400	1000	1200	1400	1200	1200	1000	1400	1200	1600	1400
Thalassiothrix longissima	1600	1000	1000	1200	1200	1400	1400	1000	1200	1000	1200	1600	1200	1200	1400
Triceratium reticulatum	400	400	400	200	400	200	200	200	200	200	200	200	400	400	0

During MON09 (table 4.8), *Guinardia flaccida* was found in all stations except S7, S8 and S15. *Hyalodiscus subtilis* was observed in all stations except S5 and S11. All stations of the study area recorded *Lithodesmium undulatum, Melosira sulcata, Navicula hennedyii, Nitzschia longissima, Nitzscia seriata, Pleurosigma elongatum, Rhizosolenia robusta, Rhizosolenia, Rhizosoleniastolterfothii, Rhizosolenia styliformis, Shroderella delicatula, Sleletonema costatum, Streptotheca indica, Thalassionema nitzschioides, Thalassiosira subtilis, Thalassiosira decipiens, Thalassiothrix frauenfeldii, Thalssiothrix longissima and Triceratium reticulatum*. Although *Pleurosigma normanii* was present in all stations (except S14 and S15) *Stephanopyxix palmarina* was observed in a few stations (except at S2, S6, S7, S8, S9 and S13). *Stephanopyxix turris* was found only at some stations- S1, S3, S4, S12 and S14. During this season 23 species were common and 26 species were rare 5 species were rare and all others were not observed.

Asterionella formosa was recorded at almost all stations except S5 and S6. *Bacillaria paradoxa* was seen in all stations except S4, S6 and S7 during POM 09. *Biddulphia aurita* was present at all stations except at S15. *Chaetoceros coarctatus* was found in all stations except in S8, S9, S12 and S13. *Cymbella marina* was present in all stations except S1. But few cells of *Melosira sulcata* which is a fresh water species could seen in S13, S14 and S15. *Rhizosolenia calcar-avis* was present in all stations except S1, S6, and S13, S14 and S15. The occurrence of *Rhizosolenia imbricata* was noticed in all stations except S 14. In the present study, Bacillariophyceae are the most abundant species among phytoplankton in the study area and the pigment characterization done by Aneeshkumar and Sujatha (2012) support the above finding. The presence of pigment fucoxanthin in CBW pointed out the occurrence of diatoms (Bacillariophyceae) as the most abundant group.

In the present investigation, PRE 10 exhibited the the presence of species like *Bacillaria paradoxa, Coscinodiscus concinnus, Eucampia zoodiacus, Grammatophora marina, G.undulata, Guinardia flaccida, Gyrosigma balticum* are completely absent in all stations. In the case of *Asteramphalus flabellatus* was absent in S4. *Biddulphia heteroceros* was found in all stations except S5, S11 and S14. However, Chaetoceros coarctatus was absent in S4, S11 and S13. However, *Climacodium* sp.was not seen in S5. *Coscinodiscus centralis* was present in few stations except S1, S3, S4, S9, S11, S14 and S15. *Cyclotella meneghiniana* was present in all stations except in S13. *Cymbella marina* was present in all stations except S1, S2, S11 and S15. *Fragillariopsis, Fragillaria intermedia* was observed in all stations except in S15. *Lithodesmium undulatum* was found in all stations except in S2. *Nitschia sigma* var. *indica* was present in all stations except in S15. *Pleurosigma elongatum* was absent during this season due to higher salinity exhibited during the pre monsoon. However *Thalssiothrix longissima* and *T. frauenfeldii* was recorded at all stations.

Dinophyceae

Spatial and seasonal distribution of Dinophyceae during the various seasons of the investigation period is depicted in tables 4.11 to 4.15 and figure 4.1. Among Dinophyceae, *Ceratium macroceros* was present in all stations except S5, S6 and S7 during POM 08. The occurrence of *Ceratium vulture* var. *sumatranum* was noticed in S2 and S3. *Ceratium lineatum* was present in all stations except in S11, S12, S13 and S15. Ceratocorys horrida was observed at a few stations (S2, S4, S13, S14 and S15). *Cladopyxix caryophyllum* was found in stations S2 to S8 and S15. *Dinophysis miles* was absent in stations 9, 10 and 13. The present study recorded *Goniaulux* sp. at all stations except S6, S7, and S8. *Phalacroma rotudatum* was present in stations S5, S6 and S8. *Peridinium limbatum* was present in two stations viz., S4 and S11. Among Dinophyceae, 15 species were abundant and 2 species were common and others were absent throughout the study area.

Table 4.11 Spatial and seasonal distribution of Dinophyceae during POM 08(No/m^3)

Dinophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium tripos	1600	200	800	600	400	800	1000	1600	1200	1000	1200	1000	800	1000	1800
Ceratium breve	800	600	800	400	200	200	400	400	600	200	400	200	400	400	400
Ceratium fusus	2200	400	400	400	1600	2000	1000	800	1400	1600	1800	1800	1600	800	1200
Ceratium macroceros	2400	600	800	800	0	0	0	1600	1200	1400	1800	1200	1400	600	400
*Ceratium vultureva*r. Sumatranum	0	800	200	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium lineatum	2800	2000	1600	2400	1600	800	400	2200	800	1200	0	0	0	600	0
Ceratocorys horrida	0	1000	0	200	0	0	0	0	0	0	0	0	400	200	200
Cladopyxis caryophyllum	0	1200	1200	600	400	200	400	600	0	0	0	0	0	0	200
Dinophysis caudata	400	200	200	400	200	400	200	200	400	200	400	400	200	400	200
Dinophysis miles	200	200	400	400	200	400	400	200	0	0	200	400	0	400	200
Goniaulax sp.	400	2400	3200	1600	1200	0	0	0	3200	1200	1600	1000	2200	2000	800
Gymnodinium sp.	400	400	400	200	400	200	400	400	400	200	400	200	200	400	200
Noctiluca miliaris	200	200	400	200	200	200	400	200	200	400	200	200	400	200	200
Ornithocercus magnificus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium claudicans	1200	1200	1000	1200	1400	1200	1400	1600	1200	1400	1400	1000	1400	1400	1200
Peridinium divergens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium oceanicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium pentagonum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium limbatum	0	0	0	200	0	0	0	0	0	0	200	0	0	0	0
Peridinium steinii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phalacroma rotundatum	0	0	0	0	800	200	0	200	0	0	0	0	0	0	0
Podolampas bipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prorocentrum micans	2200	2400	2400	2400	2200	2600	2200	2400	2400	2600	2600	2600	2800	2400	3000
Pyrocystis fusiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrophacus horologium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.12 Spatial and seasonal distribution of Dinophyceae during PRE 09(No/m^3)

Dinophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
Ceratium tripos	200	200	800	200	200	400	200	400	400	200	400	200	400	200	200
Ceratium breve	400	400	400	200	600	600	800	600	400	200	1200	1000	1200	400	400
Ceratium fusus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium macroceros	400	200	400	200	400	400	1800	600	800	600	400	800	600	400	200
Ceratium vulture var. *Sumatranum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratocorys horrida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladopyxix caryophyllum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinophysis caudata	200	800	400	200	200	400	400	600	200	200	200	200	400	600	200
Dinophysis miles	200	400	200	400	200	200	200	400	400	200	200	200	400	200	0
Goniaulax sp.	400	1000	800	600	200	400	200	200	300	400	500	600	400	400	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Noctiluca milaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
Ornithocercus magnificus	200	400	200	400	400	200	200	200	400	400	400	200	200	200	400
Peridinium claudicans	400	200	0	200	200	200	400	400	200	400	400	200	200	400	200
Peridinium divergns	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium oceanicum	400	200	400	200	200	200	400	400	400	400	400	400	400	400	0
Peridinium pentagonum	400	200	200	200	200	200	400	400	400	400	200	400	400	400	400
Peridinium limbatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
Peridinium steinii	400	400	200	200	200	400	200	400	200	200	400	200	200	400	0
Phalacroma rotundatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
Podolampas bipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
Prorocentrum micans	1000	1200	1400	1200	1400	1200	1400	1200	1400	1200	1000	1200	1200	1200	0
Ceratium lineatum	600	400	600	600	800	400	200	600	400	800	600	300	400	200	400
Pyrocystis fusiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrophacus horologium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.13 Spatial and seasonal distribution of Dinophyceae during MON 09(No/m^3)

Dinophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	0	200	400	200	400	400	400	400	200	400	200	400	200	400	200
Ceratium tripos	0	200	100	100	0	0	0	0	0	0	0	0	0	0	200
Ceratium breve	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium fusus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium macroceros	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium vulture var. *sumatranum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratocorys horrida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladopyxix caryophyllum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinophysis caudata	1200	1200	1400	1400	1600	1400	1400	1200	1400	1200	1600	1400	1600	600	400
Dinophysis miles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Goniaulax sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	400	200	200	400	400	200	200	400	400	200	200	400	400	200	200
Noctiluca miliaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ornithocercus magnificus	400	400	200	400	400	400	200	200	200	200	200	200	200	200	200
Peridinium claudicans	200	400	400	400	200	200	200	400	400	200	400	400	400	400	200
Peridinium divergens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium oceanicum	200	200	200	400	400	200	200	200	400	200	400	200	200	400	400
Peridinium pentagonum	400	400	200	200	400	400	200	200	200	200	200	200	400	400	400
Peridinium limbatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium steinii	400	0	400	400	200	200	400	200	200	400	400	400	200	400	200
Phalacroma rotundatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Podolampas bipes	0	0	0	200	0	0	0	0	0	0	0	0	0	0	0
Prorocentrum micans	1200	1000	400	400	600	400	600	600	400	800	600	1800	1800	800	1400
Ceratium lineatum	200	200	400	200	200	400	200	400	400	800	1000	1000	1000	400	0
Pyrocystis fusiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrophacus horologium	200	200	400	200	200	200	400	200	1000	200	400	200	200	200	200

Table 4.13 Spatial and seasonal distribution of Dinophyceae during POM 09(No/m^3)

Dinophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium tripos	2000	800	800	400	800	400	200	400	400	800	400	800	400	400	200	200
Ceratium breve	2200	400	400	400	1200	2000	1000	800	1200	1200	1600	1600	1600	800	1200	1200
Ceratium fusus	2200	800	800	800	400	400	2000	1600	1200	1400	1800	1200	1400	600	400	400
Ceratium lineatum	200	200	200	200	200	200	200	200	200	200	200	200	600	400	400	400
Ceratium macroceros	800	400	200	200	200	200	200	200	200	200	200	200	200	0	0	0
Ceratium vulture var. Sumatranum	400	800	1000	200	200	200	200	200	200	200	200	200	200	0	0	0
Ceratocorys horrida	800	1600	1200	600	400	200	400	600	200	200	200	200	200	200	200	200
Cladopyxix caryophyllum	400	1600	800	400	1000	1200	1000	1400	400	200	400	400	800	1200	200	200
Dinophysis caudata	400	200	200	400	200	400	200	200	200	200	200	400	400	200	200	200
Dinophysis miles	200	400	400	200	400	200	400	400	200	200	200	400	200	200	200	200
Goniaulax sp.	200	1200	1200	1000	1400	1200	1400	800	800	800	400	600	800	400	1200	1200
Gymnodinium sp.	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Noctiluca milaris	200	400	200	400	200	200	200	400	200	200	400	200	400	200	200	200
Ornithocercus magnificus	200	400	400	400	400	400	200	400	400	400	400	400	400	200	200	200
Peridinium claudicans	1400	1200	1200	1200	1200	1200	1200	1400	1200	1400	1400	1200	1400	1400	1200	1200
Peridinium divergens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium limbatum	800	200	200	600	1200	1600	2400	2800	2400	800	200	400	600	800	1600	1600
Peridinium oceanicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium pentagonum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium steinii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phalacroma rotundatus	200	400	600	800	1000	600	200	600	200	200	200	200	200	200	0	0
Podolampas bipes	1800	1200	2400	1600	1600	2600	2200	1600	1000	2400	1000	1600	2200	1800	2400	2400
Prorocentrum micans	3200	2200	2200	2400	2400	2200	2600	2200	2400	2400	2600	2600	2600	2800	2400	2400
Pyrocystis fusiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrophacus horologium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.15 Spatial and seasonal distribution of Dinophyceae during PRE 10(No/m^3)

Dinophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium tripos	200	200	400	0	200	400	200	400	200	200	400	400	200	200	800
Ceratium breve	400	200	200	200	200	200	200	200	0	0	200	200	200	200	0
Ceratium fusus	600	0	200	400	800	800	200	200	400	400	800	800	400	200	400
Ceratium macroceros	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
Ceratium vultore var. Sumatranum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratocorys horrida	0	200	200	400	400	400	400	400	200	400	400	200	400	400	200
Cladopyxix caryophyllum	0	400	200	400	400	200	400	400	600	400	400	600	0	0	0
Dinophysis caudata	200	400	400	200	200	200	200	400	400	200	200	400	400	400	200
Dinophysis miles	200	400	200	400	200	200	400	200	200	200	200	400	400	200	200
Goniaulax sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Noctiluca milaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ornithocercus magnificus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium claudicans	200	200	200	400	400	200	200	200	0	400	200	400	400	400	200
Peridinium divergns	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium oceanicum	200	200	400	200	200	200	400	400	400	200	200	0	400	200	400
Peridinium pentagonum	200	200	400	200	200	400	200	400	400	200	200	200	200	200	400
Peridinium limbatum	1800	800	400	1000	1400	1600	1200	400	400	600	200	1000	1800	1800	400
Peridinium steinii	400	200	200	200	200	200	200	400	200	400	200	400	400	400	200
Phalacroma rotundatus	0	200	400	200	400	200	400	200	400	600	200	600	400	400	200
Podolampas bipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Proracentrum micans	1000	1000	1000	1200	1200	1200	1400	1200	1400	1200	1000	1200	1200	1200	1200
Ceratium lineatum	1000	800	800	600	800	600	400	1000	800	1000	1000	800	600	800	400
Pyrocystis fusiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrophacus horologium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

In the sampling period, PRE 09 revealed that *Ceratium tripos, Ceratium breve, Ceratium macroceros, Dinophysis caudata, Dinophysis miles Goniaulux* sp., *Ornithocerus magnificus, Peridinium claudicans, Peridinium oceanicum, Peridinium pentagonium, Peridinium steinii, Prorocentrum micans* and *Ceratium lineatum* were seen in all stations. *Amphisolenis bidentata* was present in all stations except S1 (MON 09). *Ceratium tripos* was present in S2-S4 and S15. *Dinophysis caudata, Gymnodinium* sp., *Ornithocercus magnificus, Peridinium claudicans, Peridinium oceanicum, Peridinium pentagonum*, *P.steinii, Prorocentrum micans* and *Pyrophacus horologum* were present in all stations. *Ceratium lineatum* was present in all stations except in S15. *Podolampas bipes* and *Ceratium triops* were rare during MON 09 in the study area.

During POM 09, *Ceratium macroceros* and *Ceratium vulture sumatranum* was found in all stations except S14 and S15. *Phalacroma rotundatus* occur in all stations except in S15.

Among Dinophyceae *Amphisolenia bidentata* was absent in all stations during POM09 and PRE 10. During PRE10, *Ceratium tripos* was present in all stations except S4. *Ceratium fusus* was present in all stations except in S2. *Ceratium breve* was present in all stations except S9, S10 and S15. *Ceratium horrida* and *Phalacroma rotundatus* was observed in all stations except S1. The occurrence of *Cladopyxis caryophyllum* was noticed at all stations except S1, 13, 14 and S15. Majority of the stations exhibited the presence of *Peridinium oceanicum* (except S14).

Myxophyceae

The spatio-temporal variation of Myxophyceae is furnished in figure 4.1 and tables 4.16 to 4.20. During the present study, POM 08

revealed the presence of *Katagnymene spiralis* in all stations except at S3, S9 and S11. *Trichodesmium theibautii* was observed in all stations.

Table 4.16 Spatial and seasonal distribution of Myxophyceae during POM 08 (No./m^3)

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	200	200	0	400	400	200	200	400	0	200	0	400	200	400	200
Oscillatoria sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichodesmium theibautii	2200	2400	2400	2200	2600	2800	2000	2200	2400	2600	2200	2400	2600	2200	2400

Table 4.17 Spatial and seasonal distribution of Myxophyceae during PRE09 (No./m^3)

Myxophyceae(PRE09)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	600	400	600	400	200	300	200	400	400	400	600	200	600	600	400
Oscillatoria sp.	200	200	400	200	200	400	200	400	400	200	200	200	200	200	200
Trichodesmium theibautii	700	600	400	400	400	200	600	800	1200	800	600	800	600	600	600

Table 4.18 Spatial and seasonal distribution of Myxophyceae during MON 09(No./m^3)

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria sp.	1400	1200	1600	1200	1000	1200	1400	1200	1400	1300	1200	1200	1200	1200	1000
Trichodesmium theibautii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.19 Spatial and seasonal distribution of Myxophyceae during POM 09(No./m^3)

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	2200	2400	2400	2400	2200	2600	2800	2400	2200	1600	1800	2400	2400	2200	2000
Oscillatoria sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichodesmium theibautii	400	200	400	600	400	600	600	400	600	400	400	200	200	400	600

Table 4.20 Spatial and seasonal distribution of Myxophyceae during PRE 10(No./m^3)

Myxophyceae (PRE10)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichodesmium theibautii	200	0	200	0	400	400	400	400	200	200	200	400	200	200	200

However during PRE 09, *Katagnymene spiralis* and *Trichodesmium theibautii* and *Oscillatoria* sp.were found during this season throughout the study area. MON 09 revealed the presence of *Oscillatoria* sp. in the study area and their occurrence was noticed at all stations. *Katagnymene spiralis* and *Trichodesmium theibautii* were present in all stations during POM 09. Among Myxophyceae, *Katagnymene spiralis* and *Oscillatoria* sp.were completely absent in all stations during PRE 10. *Trichodesmium erythreum* was present in all stations except S2 and S4.

Silicoflagellates

Tables 4.21 to 4.25 depicts the seasonal and spatial distribution of Silicoflagellates in the study area. Few cells of *Dictyocha fibula* could be seen in all stations during the study period. Seasonal and spatial variation of Silicoflagellates is depicted in (figure 4.1). Silicoflagellates exhibited significant positive correlation with Zygnematophyceae and significant negative correlation with Desmidaceae.

Table 4.21 Spatial and seasonal distribution of Silicoflagellates during POM 08 (No./m^3)

Silicoflagellates	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	400	200	400	200	200	400	200	400	400	400	200	400	400	200	200

Table 4.22 Spatial and seasonal distribution of Silicoflagellates during PRE 09

Silicoflagellates	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	200	400	400	400	400	400	600	200	400	400	200	200	200	400	400

Table 4.23 Spatial and seasonal distribution of Silicoflagellates during MON 09 (No./m^3)

Silicoflagellates	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	200	400	800	200	200	200	200	200	400	200	200	400	400	200	200

Table 4.24 Spatial and seasonal distribution of Silicoflagellates during POM 09 (No./m^3)

Silicoflagellate	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	400	200	400	400	400	200	200	200	200	400	400	200	400	200	200

Table 4.25 Spatial and seasonal distribution of Silicoflagellates during PRE 10 (No./m^3)

Silicoflagellate	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	200	400	400	200	200	400	400	200	200	200	200	400	400	400	400

Cyanobacteria

Spatiotemporal variation in the abundance of Cyanobacteria is furnished in table 4.26 to 4.29. Seasonal and spatial variation of Cyanobacteria in the study area is depicted in figure 4.1. Among Cyanobacteria, *Nostoc* colony is present in all stations except S6, S7 and S8 (POM 08). Few cells of *Anabaena* sp. were observed in few stations except S4 to S10, S14 and S15. *Merismopedia* sp. was present in very few stations except S4 and S6 to S15. *Anabaena* sp. (except S9) and *Nostoc* colonies

were present at all stations during PRE 09. *Merismopedia* sp. and *Tolypothrix* sp.were absent at all stations (PRE 09). MON 09 revealed the presence of colonies of *Anabaena sp.* in all stations except at S8 and *Nostoc* colony in a few stations except S8 to S10 and S14.

Table 4.26 Spatial and seasonal distribution of Cyanobacteria during POM 08 (No./m^3)

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	400	200	400	0	0	0	0	0	0	0	400	600	800	0	0
Merismopedia sp.	400	800	400	0	400	0	0	0	0	0	0	0	0	0	0
Nostoc colony	1400	2400	800	200	200	0	0	0	1000	4400	3200	3400	3200	1600	800
Tolypothrix sp.	3200	2800	2200	1600	4400	3000	1600	3600	2200	800	1200	1200	2000	2200	3600

Table 4.27 Spatial and seasonal distribution of Cyanobacteria during PRE 09 (No./m^3)

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	200	400	600	800	600	400	400	600	0	400	600	400	600	800	600
Merismopedia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nostoc colony	100	200	100	200	400	400	200	200	200	1200	400	1600	400	400	600
Tolypothrix sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.28 Spatial and seasonal distribution of Cyanobacteria during MON 09 (No./m^3)

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	400	200	400	200	200	400	400	0	200	200	400	400	200	100	100
Merismopedia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nostoc colony	200	400	200	200	400	200	200	0	0	0	400	400	200	0	200
Tolypothrix sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.29 Spatial and seasonal distribution of Cyanobacteria during POM 09 (No./m^3)

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	200	800	800	400	400	400	400	400	400	400	400	400	400	200	200
Merismopedia sp.	1400	800	1200	800	2200	800	1800	1400	1600	1400	1600	1600	1800	800	1600
Nostoc colony	1200	2000	800	200	200	1000	600	600	400	2400	3200	3200	2800	1600	1200
Tolypothrix sp.	3200	2400	2200	1600	4000	3000	2000	3600	2200	800	1200	1200	2000	2400	3200

Table 4.30 Spatial and seasonal distribution of Cyanobacteria during PRE 10 (No./m^3)

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	200	200	200	400	200	400	200	200	0	400	600	400	600	800	200
Merismopedia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nostoc colony	400	200	400	400	400	200	200	200	200	200	400	200	400	400	400
Tolypothrix sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

However during POM 09 *Anabaena* sp., *Merismopedia* sp., *Nostoc* colony and Tolypothrix sp., were found at all stations. Cyanobacteria recorded significant positive correlation with DO.

Among Cyanobacteria, *Merismopedia* sp., and *Tolypothrix* sp., was completely absent in all stations (during PRE 10). *Anabaena* sp., (except S9) and *Nostoc* colony in all stations were observed during PRE10.

Zygnematophyceae

Spatiotemporal variation and abundance of Zygnematophyceae are shown in figure 4.1 and tables 4.31 to 4.35. All species were absent during POM 08 except the abundant presence of S*pirogyra condensata*. Among Zygnematophyceae *Spirogyra condensata* and *Zygnema* sp. were present in all stations PRE 09. *Cosmarium* sp. was present in some stations except S6, S8, S9, S12, S13, S14 and S15. *Spirogyra condensata* was seen in S1 to S8, S11, S12 and S14 during MON 09. *Zygnema sp.,Cosmarium* sp.and *Spirogyra condensata* were present in all stations during POM 09 and PRE 10.

Table 4.31 Spatial and seasonal distribution of Zygnematophyceae during POM 08 (No./m^3)

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Zygnema sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirogyra condensata	7200	5200	3200	4400	2000	3200	2200	2400	1800	2200	2400	1000	5400	4400	2400

Table 4.32 Spatial and seasonal distribution of Zygnematophyceae during PRE 09 (No./m^3)

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Zygnema sp.	400	600	200	400	600	400	400	600	400	600	800	600	600	400	600
Cosmarium sp.	200	200	400	200	200	0	200	0	0	200	200	0	0	0	0
Spirogyra condensata	200	400	200	600	1200	600	800	1000	1000	800	1200	1200	1000	600	800

Table 4.33 Spatial and seasonal distribution of Zygnematophyceae during MON 09 (No./m^3)

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Zygnema sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirogyra condensata	200	200	200	200	0	0	200	200	0	0	200	100	0	200	0

Table 4.34 Spatial and seasonal distribution of Zygnematophyceae during POM09 (No./m^3)

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Zygnema sp.	400	400	1000	600	1400	800	800	600	1000	600	400	200	1600	1200	1800
Cosmarium sp.	1000	800	600	600	400	200	1600	1200	1200	1000	800	1000	1200	600	600
Spirogyra condensata	800	800	4400	2000	2400	1400	1200	800	1400	1800	2000	3600	1200	400	200

Table 4.35 Spatial and seasonal distribution of Zygnematophyceae during PRE 10 (No./m^3)

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Zygnema sp.	200	200	400	1200	1400	1200	1200	400	800	600	400	200	400	1000	400
Cosmarium sp.	200	200	200	400	200	400	200	200	200	400	200	200	200	400	400
Spirogyra condensata	600	600	400	600	400	400	400	400	200	400	400	400	400	200	400

Desmidaceae

Desmidium sp.,was commonly present in all stations (during POM 08). However, POM 09 revealed *Desmidium* sp., as the most common species in all stations. Desmidaceae were completely absent in all stations during PRE 09 and MON 09.Spatiotemporal variation of this species of phytoplankton is depicted in figure 4.1.

The maximum population density was recorded $72x10^2$No. /m^3 for the species, *Spirogyra condensata* from S1**.** During POM 09, population density recorded its maximum ($68x10^2$No. /m^3) was observed for the same species. The study illustrates that during PRE 09, maximum population density was observed in S12 for the species *Chaetoceros affinis* ($58x10^2$ No./cells.

The highest population density recorded was $36x10^2$No. /m^3 for the species, *Coscinodiscus centralis* from S13. During MON 09, population

density recorded its maximum ($54x10^2$No. /m^3) was found for the species *Cymbella marina* in the stations S8 and S9. During POM09 it was observed that *Coscinodiscus centralis* showed the maximum population density ($66x10^2$ No./m^3).

During PRE10, the maximum population density ($56x10^2$ No./m^3) was recorded from S5, S8 and S11 for *Chaetoceros lorenzianus* and it pointed out sewage and industrial pollution as *Chaetoceros* sp., is considered as estuarine pollution algae (APHA, 2005).

The spatial and seasonal occurrence of different species of phytoplankton in the study area are shown in tables 4.36 to 4.75. Percentage contribution of each group of Phytoplankton during POM **08** was in the following order:-

S1→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Zygnematophyceae> Cyanobacteria> Myxophyceae>Silicoflagellates=Desmidaceae

S2→ Bacillariophyceae> Chlorophyceae> Dinophyceae> Cyanobacteria> Zygnematophyceae>Myxophyceae> Desmidaceae> Silicoflagellates

S3→ Bacillariophyceae> Dinophyceae> Chlorophyceae>Cyanobacteria > Zygnematophyceae> Myxophyceae> Desmidaceae> Silicoflagellates

S4→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Zygnematophyceae> Myxophyceae> Cyanobacteria> Desmidaceae> Silicoflagellates

S5→ Bacillariophyceae> Dinophyceae> Chlorophyceae>Cyanobacteria > Myxophyceae> Zygnematophyceae> Desmidaceae> Silicoflagellates

S6→ Bacillariophyceae > Chlorophyceae > Dinophyceae > Zygnematophyceae >Cyanobacteria=Myxophyceae > Desmidaceae> Silicoflagellates

S7→ Bacillariophyceae> Chlorophyceae> Dinophyceae> Myxophyceae= Zygnematophyceae>Cyanobacteria > Desmidaceae> Silicoflagellates

S8→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Myxophyceae>Zygnematophyceae> Desmidaceae> Silicoflagellates

S9→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Myxophyceae>Zygnematophyceae> Desmidaceae> Silicoflagellates

S10→ Bacillariophyceae> Chlorophyceae> Dinophyceae> Cyanobacteria > Myxophyceae> Zygnematophyceae> Desmidaceae= Silicoflagellates

S11→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Zygnematophyceae> Myxophyceae>Desmidaceae> Silicoflagellates

S12→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Myxophyceae>Zygnematophyceae> Desmidaceae> Silicoflagellates

S13→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Zygnematophyceae> Myxophyceae > Silicoflagellates= Desmidaceae

S14→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Zygnematophyceae>Cyanobacteria > Myxophyceae > Desmidaceae>Silicoflagellates

S 15→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Myxophyceae >Zygnematophyceae > Desmidaceae > Silicoflagellates

Table 4.36 Occurrence of Chlorophyceae during POM 08

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	F	F	R	R	F	R	F	C	C	C	F	R	R	R	R
Arthrodesmus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorella sp.	-	R	F	F	F	R	R	F	F	R	F	F			C
Chlorococcum sp.	R	R	R	F	R	R	R	R	F	R	R	F	R	F	F
Closterium sp.	C	C	C	C	C	C	F	F	F	C	C	C	R	F	C
Micrasterias foliacea	R	C	C	R	C	F	R	R	C	C	F	F	F	R	R
Microspora sp.	-	R	R	F	R	R	R	R	F	R	R	R	R	R	R
Pediastrum duplex	C	C	C	C	R	F	C	R	C	R	F	F	C	C	C
Pediastrum simples	R	C	F	C	R	C	C	C	C	C	C	C	C	F	C
Pledorina sp.	F	R	F	F	F	R	F	F	R	R	F	R	F	F	R
Scenedesmus quadricauda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Staurastrum sp.	R	C	C	C	R	F	C	C	F	C	R	F	C	C	F
Tetraspora sp.	R	R	R	-	F	R	C	R	F	R	F	R	R	C	R
Ulothrix tenuissima Kuetzing	C	C	R	C	C	C	C	C	C	C	R	F	F	C	R
Volvox aureas Ehrenberg	R	C	R	R	R	R	R	R	F	C	R	-	R	C	R

(A-abundant (≥ 5000 cells), C-common (≥1000 cells), F – few (≥250 cells) R-rare (≤250), -Absent)

Table 4.37 Occurrence of Bacillariophyceae during POM 08

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	C	C	F	F	-	-	R	R	R	F	F	F	R	R	R
Amphiprora gigantea var.sulcata	-	-	-	-	-	-	-	-	-						
Asteremphalus flabellatus	R	R	R	R	R	-	R	R	R	R	R	R	R	R	R
Asterionella japonica	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Aulacoseira granulata	C	C	C	C	C	F	C	C	C	C	R	C	C	C	C
Bacillaria paradoxa	R	R	R	R	R	R	-	R	R	R	R	-	C	R	-
Bacteriastrum hyalinum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum varians	R	R	R	-	R	R	R	R	R	R	R	R	R	R	R
Bellerochea malleus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biddulphia aurita	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Biddulphia heteroceros	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cerataulina bergonii	C	A	A	A	A	A	A	C	C	C	C	C	C	C	C
Chaetoceros lorenzianus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros coarctatos	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Chaetoceros curvisetus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros decipiens	R	R	R	R	R	R	R	R	R	R	R	-	R	R	-
Chaetoceros denticulatum	R	R	-	-	R	R	R	R	R	R	R	-	R	R	R
Climacodium frauenfeldianum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinodiscus concinnus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinocira polychorda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinodiscus perforatus	F	F	F	F	F	C	C	C	F	F	F	F	F	F	F
Coscinodiscus asteromphalus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coscinodiscus centralis	C	C	C	F	C	C	C	A	C	C	C	C	C	C	C
Coscinodiscus gigas var.paretexia	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coscinodiscus granii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
coscinodiscus marginatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinodiscus oculis -iridis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cyclotella meneghiniana	R	R	-	R	R	R	R	R	R	R	R	R	R	R	R
Cymbella marina	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Eucampia zoodiacus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragilaria intermedia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragellariopsis	R	R	F	R	R	R	F	R	R	R	R	R	R	R	R
Grammatophora marina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grammatophora undulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.37 Occurrence of Bacillariophyceae during POM 08

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Guinardia flaccida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyrosigma balticum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiaulus sinensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemidiscus hardmannianus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hyalodiscus subtilis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	-
Leptocylindrus danicus	F	F	R	F	F	F	F	F	F	F	F	F	F	R	R
Lithodesmium undulatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melosira sulcata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Navicula hennedyii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Nitzschia closterium	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Nitzschia longissima	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Nitzschia seriata	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Pseudonitzschia sp	C	C	C	C	C	C	C	C	C	C	R	C	C	R	-
Nitzschia sigma var . Indica	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
pleurosigma normanii	-	R	R	-	-	R	R	R	-	-	-	-	R	-	-
Pleurosigma directum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Pleurosigma elongatum	-	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia alata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia calcar-avis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia imbricata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia robusta	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Rhizosolenia stolterfothii	R	F	R	R	R	-	R	R	R	R	R	R	-	R	R
Rhizosolenia styliformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schroderella delicatula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stephanopyxis palmariana	R	R	R	-	-	-	-	-	-	-	R	R	R	R	R
Stephanopyxis turris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skeletonema costatum	F	R	R	R	F	C	C	C	C	C	C	C	C	C	C
Streptotheca indica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassionema nitzschioides	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira subtilis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira decipiens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiothrix frauenfeldii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiothrix longissima	R	R	R	R	R	R	R	-	-	R	R	R	R	R	-
Triceratium reticulatum	R	R	R	R	-	-	-	R	R	-	-	-	-	-	R

Table 4.38 Occurrence of Myxophyceae during POM 08

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	R	R	-	R	R	R	R	R	-	R	-	R	R	R	R
Oscillatoria sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichodesmium theibautii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

Table 4.39 Occurrence of Dinophyceae during POM 08

Dinophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium tripos	C	R	F	F	R	F	C	C	C	C	C	C	F	C	C
Ceratium breve	F	F	F	R	R	R	R	R	F	R	R	R	R	R	R
Ceratium fusus	C	R	R	R	C	C	C	F	C	C	C	C	C	F	C
Ceratium macroceros	C	F	F	F	-	-	-	C	C	C	C	C	C	F	R
Ceratium vulture var. Sumatranum	-	F	R	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium lineatum	C	C	C	C	C	F	R	C	F	C	-	-	-	F	-
Ceratocorys horrida	-	C	-	R	-	-	-	-	-	-	-	-	R	R	R
Cladopyxix caryophyllum	-	C	C	F	R	R	R	F	-	-	-	-	-	-	R
Dinophysis caudata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Dinophysis miles	R	R	R	R	R	R	R	R	-	-	R	R	-	R	R
Goniaulax sp.	R	C	C	C	C	-	-	-	C	C	C	C	C	C	F
Gymnodinium sp.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Noctiluca milaris	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Ornithocercus magnificus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium claudicans	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Peridinium divergens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium oceanicum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium pentagonum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium limbatum	-	-	-	R	-	-	-	-	-	-	R	-	-	-	-
Peridinium steinii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phalacroma rotundatum	-	-	-	-	F	R	-	R	-	-	-	-	-	-	-
Podolampas bipes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prorocentrum micans	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Pyrocystis fusiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrophacus horologium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.40 Occurrence of Zygnematophyceae during POM 08

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Cosmarium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zygnema sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spirogyra condensate	A	A	C	C	C	C	C	C	C	C	C	C	A	C	C

Table 4.41 Occurrence of Cyanobacteria during POM 08

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	R	R	R	-	-	-	-	-	-	-	R	R	F	-	-
Merismopedia sp.	R	F	R	-	R	-	-	-	-	-	-	-	-	-	-
Nostoc colony	C	C	F	R	R	-	-	C	C	C	C	C	C	C	F
Tolypothris sp.	C	C	C	C	C	C	C	C	C	F	C	C	C	C	C

Table 4.42 Occurrence of Desmidaceae during POM 08

Desmidaceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Desmidium sp.	R	F	F	F	F	F	R	F	F	R	R	F	R	R	F

Table 4.43 Occurrence of Silicoflagellate during POM 08

Silicoflagellatae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Percentage contribution of each group of Phytoplankton during **PRE 09** was in the following order:-

S1→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Myxophyceae >Zygnematophyceae >Cyanobacteria > Silicoflagellates

S2→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Myxophyceae =Zygnematophyceae >Cyanobacteria > Silicoflagellates

S3→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Myxophyceae > Cyanobacteria >Zygnematophyceae > Silicoflagellates

S4→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria >Zygnematophyceae > Myxophyceae >Silicoflagellates

S5→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Zygnematophyceae >Cyanobacteria > Myxophyceae >Silicoflagellates

S6→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Zygnematophyceae > Myxophyceae > Silicoflagellates

S7→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Zygnematophyceae >Cyanobacteria > Silicoflagellates

S8→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Myxophyceae >Zygnematophyceae >Cyanobacteria > Silicoflagellates

S9→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Myxophyceae >Zygnematophyceae >Cyanobacteria > Silicoflagellates

S10→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Zygnematophyceae > Silicoflagellates

S11→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Zygnematophyceae > Myxophyceae >Cyanobacteria > Silicoflagellates

S12→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria >Zygnematophyceae > Myxophyceae > Silicoflagellates

S13→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Zygnematophyceae > Myxophyceae >Cyanobacteria > Silicoflagellates

S14→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Cyanobacteria > Myxophyceae >Zygnematophyceae > Silicoflagellates

S15→ Bacillariophyceae> Chlorophyceae> Cyanobacteria >Zygnematophyceae > Myxophyceae >Silicoflagellates

Table 4.44 Occurrence of Chlorophyceae during PRE 09

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	F	F	R	R	R	R	-	-	-	-	-	-	-	R	R
Arthrodesmus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorella sp.	R	R	R	R	R	R	R	R	R	R	R	R	F	R-	R-
Chlorococcum sp.	F	F	F	R	F	F	F	F	C	F	C	C	F	C	C
Closterium sp.	C	F	F	F	F	F	F	F	F	F	C	F	F	R-	F
Micrasterias foliacea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microspora sp.	R	R	R	R	R	R	R	F	R	R	R	R	R	R	R
Pediastrum duplex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pediastrum simples	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pledorina sp.	R	F	F	F	F	F	F	R	R	R	F	F	F	F	R
Scenedesmus quadricauda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Staurastrum sp.	F	F	C	F	R	F	F	F	F	R	R	F	F	F	R
Tetraspora sp.	R	R	R	-	-	-	-	-	-	-	-	-	-	-	-
Ulothrix tenuissima Kuetzing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Volvox aureas Ehrenberg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.45 Occurrence of Bacillariophyceae during PRE 09

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	C	R	C	F	R	F	F	R	R	R	R	F	F	F	C
Amphiprora gigantea var.sulcata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Asteremphalus flabellatus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Asterionella japonica	C	C	C	C	C	R	R	R	R	R	R	R	R	R	R
Aulacoseira granulata	F	R	C	R	R	R	R	R	C	C	C	C	C	C	C
Bacillaria paradoxa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum hyalinum	R	R	R	R	R	-	R	R	R	R	R	R	R	R	R
Bacteriastrum varians	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Bellerochea malleus	-	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Biddulphia aurita	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Biddulphia heteroceros	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Cerataulina bergonii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros lorenzianus	A	C	C	C	C	A	A	A	A	A	A	C	C	C	C
Chaetoceros affinis	C	C	C	C	A	C	C	C	C	C	C	A	C	A	C
Chaetoceros coarctatus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Chaetoceros curvisetus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros decipiens	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros denticulatum	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Climacodium frauenfeldianum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus concinnus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinocira polychorda	R	-	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus perforatus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus asteromphalus	R	-	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus centralis	C	R	C	R	R	F	R	C	C	C	C	C	C	C	C
Coscinodiscus gigas var.paretexia	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus granii	C	C	A	C	C	C	C	C	C	C	C	C	C	C	C
coscinodiscus marginatus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus oculis -iridis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cyclotella meneghiniana	F	R	R	C	R	R	F	R	R	R	R	R	R	R	R
Cymbella marina	R	R	R	R	R	R	R	F	R	R	R	R	R	R	R
Eucampia zoodiacus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragellariopsis	R	R	R	R	R	R	F	F	F	F	R	R	F	F	F
Fragilaria intermedia	R	-	R	R	R	R	R	R	R	R	R	R	R	-	-
Grammatophora marina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.45 Occurrence of Bacillariophyceae during PRE 09 (Continued...)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Grammatophora undulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Guinardia flaccida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyrosigma balticum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiaulus sinensis	-	R	R	-	R	R	R	R	R	R	R	R	R	R	R
Hemidiscus hardmannianus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hyalodiscus subtilis	R	R	R	R	R	R	R	R	F	R	R	R	R	R	R
Leptocylindrus danicus	-	-	-	R	R	R	R	R	R	R	R	R	R	R	R
Lithodesmium undulatum	R	R	R	R	R	R	R	R	R	R	R	R	-	-	-
Melosira sulcata	R	R	R	R	R	-	R	-	R	R	R	R	R	R	R
Navicula hennedyii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitzschia closterium	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C
Nitzschia longissima	C	C	C	C	C	C	C	C	C	C	C	C	C	F	F
Nitzschia seriata	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Pseudonitzschia sp	C	C	C	F	F	R	C	F	C	C	F	R	C	R	F
Nitzschia sigma var . Indica	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Pleurosigma directum	C	C	R	-	R	F	R	F	C	F	C	R	R	R	R
pleurosigma normanii	R	R	R	C	F	R	R	R	F	R	F	F	F	F	F
Pleurosigma elongatum	C	C	C	C	R	R	R	F	R	F	F	F	R	R	R
Rhizosolenia alata	C	C	C	C	R	R	R	R	R	F	R	R	R	F	R
Rhizosolenia calcar-avis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia imbricata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia robusta	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia stolterfothii	R	R	-	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia styliformis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Schroderella delicatula	C	C	C	F	R	F	F	R	C	C	C	C	C	C	R
Stephanopyxis palmariana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stephanopyxis turris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skeletonema costatum	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Streptotheca indica	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassionema nitzschioides	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Thalassiosira subtilis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira decipiens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiothrix frauenfeldii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiothrix longissima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triceratium reticulatum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Table 4.46 Occurrence of Myxophyceae during PRE 09

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	F	R	F	R	R	R	R	R	R	R	F	R	F	F	R
Oscillatoria sp.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Trichodesmium theibautii	F	F	R	R	R	R	F	F	C	F	F	F	F	F	F

Table 4.47 Occurrence of Dinophyceae during PRE 09

DINOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S1-	S11	S12	S13	S14	S15
Amphisolenia bidentata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R
Ceratium tripos	R	R	F	R	R	R	R	R	R	R	R	R	R	R	R
Ceratium breve	R	R	R	R	F	F	F	F	R	R	C	C	C	R	R
Ceratium fusus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium macroceros	R	R	R	R	R	R	1F	F	F	F	R	F	F	R	R
Ceratium vulture var. Sumatranum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratocorys horrida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladopyxix caryophyllum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophysis caudata	R	F	R	R	R	R	R	F	R	R	R	R	R	F	R
Dinophysis miles	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Goniaulax sp.	R	C	F	F	R	R	R	R	R	R	R	F	R	R	R
Gymnodinium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Noctiluca milaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ornithocercus magnificus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium claudicans	R	R	-	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium divergns	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium oceanicum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium pentagonum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium limbatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium steinii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Phalacroma rotundatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Podolampas bipes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prorocentrum micans	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ceratium lineatum	F	R	F	F	F	R	R	F	R	F	F	R	R	R	R
Pyrocystis fusiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrophacus horologium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.48 Occurrence of Zygnematophyceae during PRE 09

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Spirogyra condensata	R	R	R	F	C	F	F	C	C	F	C	C	C	F	F
Cosmarium sp.	R	R	R	R	R	-	R	-	-	R	R	-	-	-	-
Zygnema sp.	R	F	R	R	F	R	R	F	R	F	F	F	F	R	F

Table 4.49 Occurrence of Cyanobacteria during PRE 09

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	R	R	F	F	F	R	R	F	-	R	F	R	F	F	F
Merismopedia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nostoc colony	R	R	R	R	R	R	R	R	R	C	R	C	R	R	F
Tolypothris sp.	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-

Table 4.50 Occurrence of Desmidaceae during PRE 09

Desmidaceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Desmidium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.51 Occurrence of Silicoflagellate during PRE 09

Silicoflagellates	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	R	R	R	R	R	R	F	R	R	R	R	R	R	R	R

Percentage contribution of each group of Phytoplankton during **MON 09** was in the following order:-

S1→ Bacillariophyceae> Dinophyceae> Myxophyceae >Chlorophyceae> Cyanobacteria >Zygnematophyceae = Silicoflagellates

S2→ Bacillariophyceae> Dinophyceae> Myxophyceae >Chlorophyceae= Cyanobacteria > Silicoflagellates> Zygnematophyceae

S3→ Bacillariophyceae> Dinophyceae> Myxophyceae >Chlorophyceae>Silicoflagellates> Cyanobacteria >Zygnematophyceae

S4→ Bacillariophyceae> Dinophyceae> Myxophyceae >Chlorophyceae> Cyanobacteria >Zygnematophyceae = Silicoflagellates

S5→ Bacillariophyceae> Dinophyceae> Myxophyceae =Chlorophyceae> Cyanobacteria > Silicoflagellates

S6→ Bacillariophyceae> Dinophyceae> Myxophyceae >Chlorophyceae> Cyanobacteria > Silicoflagellates

S7→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Myxophyceae >Cyanobacteria >Zygnematophyceae = Silicoflagellates

S8→ Bacillariophyceae> Dinophyceae> Myxophyceae =Chlorophyceae >Zygnematophyceae = Silicoflagellates

S9→ Bacillariophyceae> Dinophyceae> Myxophyceae =Chlorophyceae> Silicoflagellates>Cyanobacteria

S10→ Bacillariophyceae> Dinophyceae> Chlorophyceae> Myxophyceae >Cyanobacteria = Silicoflagellates

S11→ Bacillariophyceae> Dinophyceae> Myxophyceae >Chlorophyceae> Cyanobacteria >Zygnematophyceae = Silicoflagellates

S12→ Bacillariophyceae> Dinophyceae> Myxophyceae =Chlorophyceae> Cyanobacteria > Silicoflagellates >Zygnematophyceae

S13→Bacillariophyceae> Dinophyceae> Myxophyceae >Chlorophyceae> Cyanobacteria = Silicoflagellates

S14→Bacillariophyceae>Dinophyceae> Myxophyceae=Chlorophyceae>Zygnematophyceae = Silicoflagellates

S15→ Bacillariophyceae> Dinophyceae >Chlorophyceae> Myxophyceae > Cyanobacteria > Silicoflagellates

Table 4.52 Occurrence of Chlorophyceae during MON 09

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arthrodesmus sp.	F	R	F	R	R	R	F	R	F	F	F	R	F	F	F
Chlorella sp.	R	R	R	F	R	F	F	F	R	R	R	R	R	R	R
Chlorococcum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Closterium sp.	R	-	R	R	R	R	R	R	R	R	R	R	R	R	R
Micrasterias foliacea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microspora sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pediastrum duplex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pediastrum simples	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pledorina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scenedesmus quadricauda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Staurastrum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetraspora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ulothrix tenuissima Kuetzing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Volvox aureas Ehrenberg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.53 Occurrence of Bacillariophyceae during MON 09

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	C	F	C	F	R	C	C	R	C	C	C	C	C	F	C
Amphiprora gigantea var.sulcata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Asterempholus flabellatus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Asterionella japonica	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Aulacoseira granulata	C	C	F	F	F	F	F	F	C	F	F	F	C	F	R
Bacillaria paradoxa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum hyalinum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Bacteriastrum varians	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Bellerochea malleus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Biddulphia aurita	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Biddulphia heteroceros	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Cerataulina bergonii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros lorenzianus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros coarctatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros curvisetus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros decipiens	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros denticulatum	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Climacodium frauenfeldianum	R	R	R	-	R	R	-	R	R	R	R	R	R	R	R
Coscinodiscus concinnus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinocira polychorda	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus perforatus	F	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coscinodiscus asteromphalus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coscinodiscus centralis	C	C	R	R	C	R	R	R	C	C	C	C	C	C	C
Coscinodiscus gigas var.paretexia	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coscinodiscus granii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus marginatus	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Coscinodiscus oculis -iridis	F	F	F	R	R	F	R	R	R	F	R	F	R	R	R
Cyclotella meneghiniana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cymbella marina	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Eucampia zoodiacus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Fragellariopsis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragilaria intermedia	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Grammatophora marina	F	R	R	R	R	R	R	R	R	R	R	R	R	R	F
Grammatophora undulata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Table 4.53 Occurrence of Bacillariophyceae during MON 09 (Continued..)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Guinardia flaccida	R	R	R	R	R	R	-	-	R	R	R	R	R	R	-
Gyrosigma balticum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hemiaulus sinensis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hemidiscus hardmannianus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hyalodiscus subtilis	R	R	R	R		R	R	R	R	R	-	R	R	R	R
Leptocylindrus danicus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithodesmium undulatum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Melosira sulcata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Navicula hennedyii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Nitzschia closterium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitzschia longissima	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Nitzschia seriata	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Pseudonitzschia sp	-	-	-	-	-	-	-	-	-	-	-	-		-	-
Nitzschia sigma var . Indica	-	-	-	-	-	-	-	-	-	-	-	-		-	-
Pleurosigma normanii	R	R	R	R	R	R	R	R	R	R	R	R	R		-
Pleurosigma directum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleurosigma elongatum	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Rhizosolenia alata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia calcar-avis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia imbricata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia robusta	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Rhizosolenia stolterfothii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia styliformis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Schroderella delicatula	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Stephanopyxis palmariana	R	-	R	R	R	-	-	-	-	R	R	R	-	R	R
Stephanopyxis turris	R	-	R	R	-	-	-	-	-	-	-	R	-	R	-
Skeletonema costatum	C	C	C	F	C	C	C	C	C	C	C	C	C	C	C
Streptotheca indica	F	F	F	F	F	F	F	F	F	F	F	F	F	F	C
Thalassionema nitzschioides	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira subtilis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira decipiens	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiothrix frauenfeldii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiothrix longissima	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Triceratium reticulatum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Table 4.54 Occurrence of Myxophyceae during MON 09

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oscillatoria sp.	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Trichodesmium theibautii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.55 Occurrence of Dinophyceae during MON 09

DINOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S1-	S11	S12	S13	S14	S15
Amphisolenia bidentata	-	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Ceratium tripos	-	R	R	R	-	-	-	-	-	-	-	-	-	-	R
Ceratium breve	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium fusus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium macroceros	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium vulture var. Sumatranum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratocorys horrida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladopyxix caryophyllum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophysis caudata	C	C	C	C	C	C	C	C	C	C	C	C	C	R	R
Dinophysis miles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Goniaulax sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gymnodinium sp.	R	R	R	F	R	R	R	R	R	R	R	R	R	R	R
Noctiluca milaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ornithocercus magnificus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium claudicans	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium divergens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium oceanicum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium pentagonum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium limbatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium steinii	R	-	R	R	R	R	R	R	R	R	R	R	R	R	R
Phalacroma rotundatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Podolampas bipes	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
Prorocentrum micans	C	C	R	R	F	R	F	F	R	R	F	F	C	R	C
Ceratium lineatum	R	R	R	R	R	R	R	R	R	R	C	F	C	R	-
Pyrocystis fusiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrophacus horologium	R	R	R	R	R	R	R	R	C	R	R	R	R	R	R

Table 4.56 Occurrence of Zygnematophyceae during MON 09

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Zygnema sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cosmarium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spirogyra condensata	R	R	R	R	-	-	R	R	-	-	R	R	-	R	-

Table 4.57 Occurrence of Cyanobacteria during MON 09

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	R	R	R	R	R	R	R	-	R	R	R	R	R	R	R
Merismopedia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nostoc colony	R	R	R	R	R	R	R	-	-	-	R	R	R	-	R
Tolypothrix sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.58 Occurrence of Desmidaceae during MON 09

Desmidaceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Desmidium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.59 Occurrence of Silicoflagellate during MON 09

Silicoflagellate	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Percentage contribution of each group of Phytoplankton during POM 09 was in the following order:-

S1→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Myxophyceae > Zygnematophyceae >Silicoflagellates

S2 →Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Myxophyceae > Zygnematophyceae >Desmidaceae>Silicoflagellates

S3→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria > Myxophyceae > Desmidaceae=Silicoflagellates

S4→Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Myxophyceae > Cyanobacteria >Desmidaceae>Silicoflagellates

S5→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Zygnematophyceae >Myxophyceae > Desmidaceae>Silicoflagellates

S6→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Zygnematophyceae > Desmidaceae>Silicoflagellates

S7→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Zygnematophyceae >Myxophyceae > Desmidaceae

S8→ Bacillariophyceae> Dinophyceae > Chlorophyceae> Cyanobacteria > Myxophyceae > Zygnematophyceae >Desmidaceae>Silicoflagellates

S9→Bacillariophyceae> Dinophyceae > Chlorophyceae>Cyanobacteria > Myxophyceae > Zygnematophyceae >Desmidaceae>Silicoflagellates

S10→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Zygnematophyceae >Myxophyceae > Desmidaceae>Silicoflagellates

S11→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Zygnematophyceae > Myxophyceae

S12→Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Zygnematophyceae > Myxophyceae > Desmidaceae

S13→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Zygnematophyceae > Myxophyceae >Desmidaceae>Silicoflagellates

S14→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Myxophyceae > Zygnematophyceae >Desmidaceae>Silicoflagellates

S15→ Bacillariophyceae> chlorophyceae> dinophyceae > cyanobacteria > myxophyceae > zygnematophyceae >desmidaceae>silicoflagellates

Table 4.60 Occurrence of Chlorophyceae during POM 09

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	C	C	C	R	C	C	C	C	C	C	C	R	C	R	F
Arthrodesmus sp.	-	--	--	--	--	--	--	--	--	--	--	--	--	--	-
Chlorella sp.	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chlorococcum sp.	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Closterium sp.	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Micrasterias foliacea	R	R	R	R	R	R	R	R	F	C	C	F	R	R	R
Microspora sp.	R	R	F	F	F	F	F	C	F	R	F	F	C	C	C
Pediastrum duplex	R	R	R	R	R	F	R	F	F	C	F	C	C	F	C
Pediastrum simples	F	F	R	R	R	R	R	F	F	C	C	C	C	C	C
Pledorina sp.	C	C	C	C	C	F	C	F	C	F	C	C	F	C	C
Scenedesmus quadricauda	R	R	R	R	R	F	R	F	F	C	F	C	F	C	C
Staurastrum sp.	F	R	R	R	R	F	C	C	C	F	C	F	F	F	F
Tetraspora sp.	R	F	F	F	F	R	F	R	C	R	R	R	R	F	F
Ulothrix tenuissima Kuetzing	C	C	C	R	C	C	C	C	C	C	C	C	C	C	F
Volvox aureas Ehrenberg	C	C	C	C	F	C	R	F	C	C	F	R	F	F	R

Table 4.61 Occurrence of Bacillariophyceae during POM 09

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	C	C	C	F	-	-	R	R	R	F	C	F	R	R	R
Amphiprora gigantea var.sulcata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Asteromphalus flabellatus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Asterionella japonica	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Aulacoseira granulata	C	C	C	C	C	F	C	C	C	C	F	C	C	C	C
Bacillaria paradoxa	R	R	R	-	R	-	-	R	R	R	R	R		R	R
Bacteriastrum hyalinum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum varians	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bellerochea malleus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biddulphia aurita	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-
Biddulphia heteroceros	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cerataulina bergonii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros lorenzianus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros coarctatus	R	R	R	R	R	R	R	-	-	R	R	-	-	R	R
Chaetoceros curvisetus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros decipiens	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Chaetoceros denticulatum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Climacodium frauenfeldianum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinodiscus concinnus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinocira polychorda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinodiscus perforatus	C	C	F	C	F	F	C	C	C	F	C	F	F	F	F
Coscinodiscus asteromphalus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coscinodiscus centralis	C	C	C	F	R	R	C	C	C	C	C	C	C	C	C
Coscinodiscus gigas var.paretexia	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coscinodiscus granii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus marginatus	R		R	R	R	R	R	R	R	R	R	R	F	R	R
Coscinodiscus oculis -iridis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cyclotella meneghiniana	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cymbella marina	-	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Eucampia zoodiacus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragilaria intermedia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragellariopsis	R	R	F	R	F	F	C	F	F	R	F	F	C	F	F
Grammatophora marina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grammatophora undulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.61 Occurrence of Bacillariophyceae during POM 09 (Continues...)

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Guinardia flaccida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyrosigma balticum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiaulus sinensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemidiscus hardmannianus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hyaladiscus subtilis	C	C	C	C	C	C	C	C	C	C	C	C	F	C	C
Leptocylindros danicus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Lithodesmium undolatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melosira sulcata	-	-	-	-	-	-	-	-	-	-	-	-	R	R	R
Navicula hennedyii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Nitzschia closterium	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Nitzschia longissima	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Nitzschia seriata	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Pseudonitzschia sp.	R	R	C	C	F	C	C	C	F	C	C	C	C	C	C
Nitzschia sigma var. indica	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Pleurosigma normanii	C	F	C	R	C	F	C	F	F	C	C	C	C	F	C
Pleurosigma directum	R	R	C	R	F	F	F	C	C	F	C	C	F	F	R
Pleurosigma elongatum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia alata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia calcar-avis	-	R	R	R	R	-	R	R	R	R	R	R	-	-	-
Rhizosolenia imbricata	R	R	R	R		R	R	R	R	R	R	R	R	R	R
Rhizosolenia robusta	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia stolterfothii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia styliformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schroderella delicatula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stephanopyxis palmariana	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Skeletonema costatum	F	F	F	R	F	C	C	C	F	R	F	R	C	C	C
Stephanopyxis turris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Streptotheca indica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassionema nitzschioides	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira subtilis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira decipiens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiothrix frauenfeldii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiothrix longissima	-	R	R	R	R	R	R		R		R	R	R		R
Triceratium reticulatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.62 Occurrence of Myxophyceae during POM 09

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Oscillatoria sp.															
Trichodesmium theibautii	R	R	R	F	R	F	F	R	F	R	R	R	R	R	F

Table 4.63 Occurrence of Dinophyceae during POM 09

DINOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ceratium tripos	C	F	F	R	F	R	R	R	R	F	R	F	R	R	R
Ceratium breve	C	R	R	R	C	C	C	F	C	C	C	C	C	F	C
Ceratium fusus	C	F	F	F	R	R	C	C	C	C	C	C	C	F	R
Ceratium lineatum	R	R	R	R	R	R	R	R	R	R	R	R	F	R	R
Ceratium macroceros	F	R	R	R	R	R	R	R	R	R	R	R	R	--	--
Ceratium vulture var. Sumatranum	R	F	C	R	R	R	R	R	R	R	R	R	R	--	--
Ceratocorys horrida	F	C	C	F	R	R	R	F	R	R	R	R	R	R	R
Cladopyxix caryophyllum	R	c	F	R	C	C	C	C	R	R	R	R	F	C	R
Dinophysis caudata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Dinophysis miles	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Goniaulax sp.	R	C	C	C	C	C	C	F	F	F	R	F	F	R	C
Gymnodinium sp.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Noctiluca milaris	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Ornithocercus magnificus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium claudicans	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Peridinium divergens	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Peridinium limbatum	F	R	R	F	C	C	C	C	C	F	R	R	F	F	C
Peridinium oceanicum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Peridinium pentagonum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Peridinium steinii	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Phalacroma rotundatus	R	R	F	F	C	F	R	F	R	R	R	R	R	R	--
Podolampas bipes	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Prorocentrum micans	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Pyrocystis fusiformis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pyrophacus horologium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 4.64 Occurrence of Zygnematophyceae during POM 09

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Zygnema sp.	R	R	C	F	C	F	F	F	C	F	R	R	C	C	C
Cosmarium sp.	C	F	F	F	R	R	C	C	C	C	F	C	C	F	F
Spirogyra condensata	F	F	C	C	C	C	C	F	C	C	C	C	C	R	R

Table 4.65 Occurrence of Cyanobacteria during POM 09

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	R	F	F	R	R	R	R	R	R	R	R	R	R	R	R
Merismopedia	C	F	C	F	F	F	C	C	C	C	C	C	C	F	C
Nostoc colony	C	C	F	R	R	C	F	F	R	C	C	C	C	C	C
Tolypothris sp.	C	C	C	C	C	C	C	C	C	F	C	C	C	C	C

Table 4.66 Occurrence of Desmidaceae during POM 09

Desmidaceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Desmidium sp.	R	R	R	F	F	C	C	F	R	F	F	C	F	R	F

Table 4.67 Occurrence of Silicoflagellate during POM 09

Silicoflagellate	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Percentage contribution of each group of Phytoplankton during PRE 10 was in the following order:-

S1→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Cyanobacteria > Myxophyceae > Zygnematophyceae >Desmidaceae>Silicoflagellates

S2→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria > Myxophyceae = Silicoflagellates

S3→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria >Silicoflagellates> Myxophyceae

S4→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria > Myxophyceae >Silicoflagellates

S5→ Bacillariophyceae> Dinophyceae > Chlorophyceae > Zygnematophyceae >Cyanobacteria > Myxophyceae> Silicoflagellates

S6→ Bacillariophyceae> Dinophyceae > Chlorophyceae > Zygnematophyceae >Cyanobacteria > Myxophyceae = Silicoflagellates

S7→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria = Myxophyceae = Silicoflagellates

S8→ Bacillariophyceae> Dinophyceae > Chlorophyceae > Zygnematophyceae > Myxophyceae >Cyanobacteria > Silicoflagellates

S9→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria = Myxophyceae = Silicoflagellates

S10→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria > Myxophyceae = Silicoflagellates

S11→ Bacillariophyceae> Dinophyceae >Chlorophyceae> Zygnematophyceae =Cyanobacteria > Myxophyceae = Silicoflagellates

S12→ Bacillariophyceae> Dinophyceae > Chlorophyceae> Zygnematophyceae >Cyanobacteria > Myxophyceae = Silicoflagellates

S13→ Bacillariophyceae> Dinophyceae >Chlorophyceae> Zygnematophyceae >Cyanobacteria > Silicoflagellates >Myxophyceae

S14→ Bacillariophyceae> Dinophyceae > Chlorophyceae> Zygnematophyceae >Cyanobacteria > Silicoflagellates >Myxophyceae

S15→ Bacillariophyceae> Chlorophyceae> Dinophyceae > Zygnematophyceae >Cyanobacteria > Silicoflagellates >Myxophyceae

Table 4.68 Occurrence of Chlorophyceae during PRE 10

Chlorophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Ankistrodesmus falcans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arthrodesmus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorella	R	R	R	R	R	R	R	R	R	R	R	R	F	R	F
Chlorococcum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Closterium sp.	C	F	C	C	C	C	C	C	C	C	C	F	F	C	C
Micrasterias foliacea	C	F	C	F	R	R	R	-	-	-	-	-	-	-	-
microspora	C	C	C	C	F	C	R	R	F	C	R	-	R	R	-
Pediastrum duplex	-	C	C	R	R	F	C	R	C	R	F	C	C	C	C
Pediastrum simples	R	C	C	C	C	C	C	F	C	C	C	C	C	F	C
Pledorina	R	R	R	C	R	R	-	R	R	R	R	R	R	-	F
Scenedesmus quadricauda	R	R	F	F	F	R	R	R	F	R	R	R	R	R	R
Staurastrum sp.	C	C	C	C	F	C	C	C	C	C	R	F	F	C	F
Tetraspora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ulothrix tenuissima Kuetzing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Volvox aureas Ehrenberg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.69 Occurrence of Bacillariophyceae during PRE 10

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Asterionella formosa	C	R	C	F	C	F	F	C	C	R	R	F	F	F	C
Amphiprora gigantea var.sulcata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Asteremphalus flabellatus	R	R	R	-	R	R	R	R	R	R	R	R	R	R	R
Asterionella japonica	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Aulacoseira granulata	C	C	C	C	C	C	C	C	C	C	C	C	C	F	C
Bacillaria paradoxa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum hyalinum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Bacteriastrum varians	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Bellerochea malleus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Bidduliphia aurita	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Bidduliphia heteroceros	R	R	R	R	-	R	R	R	R	R	-	R	R	-	R
Cerataulina bergonii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros lorenzianus	C	A	A	C	A	C	A	A	C	C	C	C	C	C	C
Chaetoceros affinis	A	A	C	C	C	C	C	C	A	A	A	A	A	A	A
Chaetoceros coarctatus	R	R	R	-	R	R	R	R	R	R		R	-	R	R
Chaetoceros curvisetus	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros decipiens	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Chaetoceros denticulatum	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Climacodium frauenfeldianum	R	R	R	R	R	R	R	R	R	R	R	-	R	R	R
Coscinodiscus concinnus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coscinocira polychorda	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus perforatus	F	F	R	-	F	R	R	R	R	R	R	R	R	R	F
Coscinodiscus asteromphalus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus centralis	-	R	-	-	R	R	R	R	-	F	-	R	R	-	-
Coscinodiscus gigas var.paretexia	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus granii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
coscinodiscus marginatus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Coscinodiscus oculis -iridis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cyclotella meneghiniana	R	R	R	R	R	R	R	R	R	R	R	R	-	R	R
Cymbella marina	-	-	R	R	R	R	R	R	R	R	-	R	R	R	-
Eucampia zoodiacus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragellariopsis	R	R	R	R	R	F	R	F	R	C	C	C	C	R	-
Fragilaria intermedia	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-
Grammatophora marina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.69 Occurrence of Bacillariophyceae during PRE 10

BACILLARIOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Grammatophora undulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Guinardia flaccida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyrosigma balticum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiaulus sinensis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hemidiscus hardmannianus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyalodiscus subtilis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Leptocylindrus danicus	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Lithodesmium undulatum	R	-	R	R	R	R	R	R	R	R	R	R	R	R	R
Melosira sulcata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Navicula hennedyii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Nitzschia closterium	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Nitzschia longissima	C	C	C	C	C	C	C	C	C	1R	C	C	C	C	C
Nitzschia seriata	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Pseudonitzschia sp	F	R	R	F	R	R	R	F	F	F	R	R	F	F	R
Nitzschia sigma var . Indica	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-
Pleurosigma directum	F	F	F	R	R	F	R	R	F	F	R	F	R	R	R
pleurosigma normanii	R	R	R	C	F	F	F	C	C	C	F	F	F	F	F
Pleurosigma elongatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolenia alata	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Rhizosolenia calcar-avis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia imbricata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia robusta	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia stolterfothii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Rhizosolenia styliformis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Schroderella delicatula	2R	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Stephanopyxis palmariana	R	-	R	R	R	R	R	R	R	R	R	R	R	R	R
Stephanopyxis turris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skeletonema costatum	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Streptotheca indica	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassionema nitzschioides	R	R	R	R	R	R	R	R	R	R	R	R	R	-	-
Thalassiosira subtilis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiosira decipiens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiothrix frauenfeldii	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thalassiothrix longissima	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Triceratium reticulatum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	-

Table 4.70 Occurrence of Myxophyceae during PRE 10

Myxophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Katagnymene spiralis	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Oscillatoria sp.	-	--	--	--	--	--	--	--	--	--	-	--	--	--	--
Trichodesmium theibautii	R	R	R	F	R	F	F	R	F	R	R	R	R	R	F

Table 4.71 Occurrence of Dinophyceae during PRE 10

DINOPHYCEAE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Amphisolenia bidentata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium tripos	R	R	R	-	R	R	R	R	R	R	R	R	R	R	F
Ceratium breve	R	R	R	R	R	R	R	R	-	-	R	R	R	R	-
Ceratium fusus	F	-	R	R	F	F	R	R	R	R	F	F	R	R	R
Ceratium macroceros	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R
Ceratium vulture var. Sumatranum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratocorys horrida	-	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Cladopyxix caryophyllum	-	R	R	R	R	R	R	R	F	R	R	F	-	-	-
Dinophysis caudata	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Dinophysis miles	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Goniaulax sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gymnodinium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Noctiluca milaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ornithocercus magnificus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium claudicans	R	R	R	R	R	R	R	R	-	R	R	R	R	R	R
Peridinium divergns	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peridinium oceanicum	R	R	R	R	R	R	R	R	R	R	R	-	R	R	R
Peridinium pentagonum	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Peridinium limbatum	C	F	R	C	C	C	C	R	R	F	R	C	C	C	R
Peridinium steinii	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Phalacroma rotundatus	-	R	R	R	R	R	R	R	R	F	R	F	R	R	R
Podolampas bipes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prorocentrum micans	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ceratium lineatum	C	F	F	F	F	F	R	C	F	C	C	F	F	F	R
Pyrocystis fusiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrophacus horologium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.72 Occurrence of Zygnematophyceae during PRE 10

Zygnematophyceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S1-	S11	S12	S13	S14	S15
Zygnema sp.	R	R	R	C	C	C	C	R	F	F	R	R	R	C	R
Cosmarium sp.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Spirogyra condensata	F	F	R	F	R	R	R	R	R	R	R	R	R	R	R

Table 4.73 Occurrence of Cyanobacteria during PRE 10

Cyanobacteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Anabaena sp.	R	R	R	R	R	R	R	R	-	R	F	R	F	F	R
Merismopedia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nostoc colony	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Tolypothrix sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.74 Occurrence of Desmidaceae during PRE 10

Desmidaceae	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Desmidium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.75 Occurrence of Silicoflagellate during PRE 10

Silicoflagellate	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Dictyocha fibula	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

4.1.1. b Seasonal variation in primary productivity (PP)

Spatial and seasonal variation of PP in the study area is represented in table 4.76 and figure 4.2. During POM 08, PP varied from 0.11 to 0.53 mg C/m^3/day and estimated average was 0.25±0.13 mg C/m^3/day. In PRE 09, PP of the study area ranged between 0.05 and 0.50 mg C/m^3/day and the recorded average was 0.15±0.11 mg C/m^3/day. MON 09 exhibited PP ranging from 0.03 to 0.35 mg C/m^3/day (average: 0.15±0.11 mg C/m^3/day). It was observed that during POM 09, PP in the study area varied from 0.16 to 0.63 mg C/m^3/day and exhibited an average value of 0.33±0.12 mg C/m^3/day. However in PRE 10, it exhibited a range from 0.02 to 0.38 mg C/m^3/day with an average of 0.18 ±0.12 mg C/m^3/day.

Table 4.76 Spatial and Seasonal variation of Primary productivity (mgC/m^3/day) in the study aera

SEASON	POM 08	PRE 09	MON 09	POM 09	PRE10
S1	0.19	0.22	0.16	0.31	0.016
S2	0.3	0.32	0.13	0.31	0.35
S3	0.16	0.17	0.16	0.31	0.18
S4	0.16	0.05	0.03	0.35	0.14
S5	0.19	0.16	0.31	0.31	0.12
S6	0.35	0.30	0.22	0.41	0.20
S7	0.18	0.11	0.06	0.22	0.16
S8	0.15	0.14	0.06	0.16	0.10
S9	0.20	0.17	0.31	0.31	0.30
S10	0.50	0.50	0.35	0.31	0.35
S11	0.14	0.14	0.25	0.31	0.09
S12	0.53	0.49	0.09	0.63	0.38
S13	0.22	0.22	0.06	0.47	0.10
S14	0.30	0.30	0.03	0.31	0.06
S15	0.11	0.11	0.06	0.16	0.09
Maximum	0.53	0.50	0.35	0.63	0.38
Minimum	0.11	0.05	0.03	0.16	0.02
Average	0.25±0.13	0.23±0.13	0.15±0.11	0.33±0.12	0.18±0.12
ANOVA					
Spatial	<<0.01				
Seasonal	<<0.01				

4.1.1.c Seasonal Distribution of Phytoplankton Pigments Chlorophyll a

During POM 08, concentration of Chl a in the water samples varied from 1.08(S1) to 26.22µg/L (S14) (table 4.77 and figure 4.2) with an average of 8.92±7.96 µg/L. Meanwhile in PRE 09, it ranged between 0.20 (S1) and 4.90µg/ L (S7) (average: 1.53±1.32 µg/L). During MON 09, the content of Chl a varied from 0.63 (S2) to 11.55µg/L (S15) and recorded an average of 3.0±2.76 µg/L. However during POM 09, it ranged from 2.61(S8) to 39.62µg/L (S11) (average: 9.73±9.49µg/L). While during PRE 10 concentration of Chl a in water samples ranged from 2.76 (S2) to 20.88 µg/ L (S7) and the estimated average concentration was 6.74±5.01 µg/L.

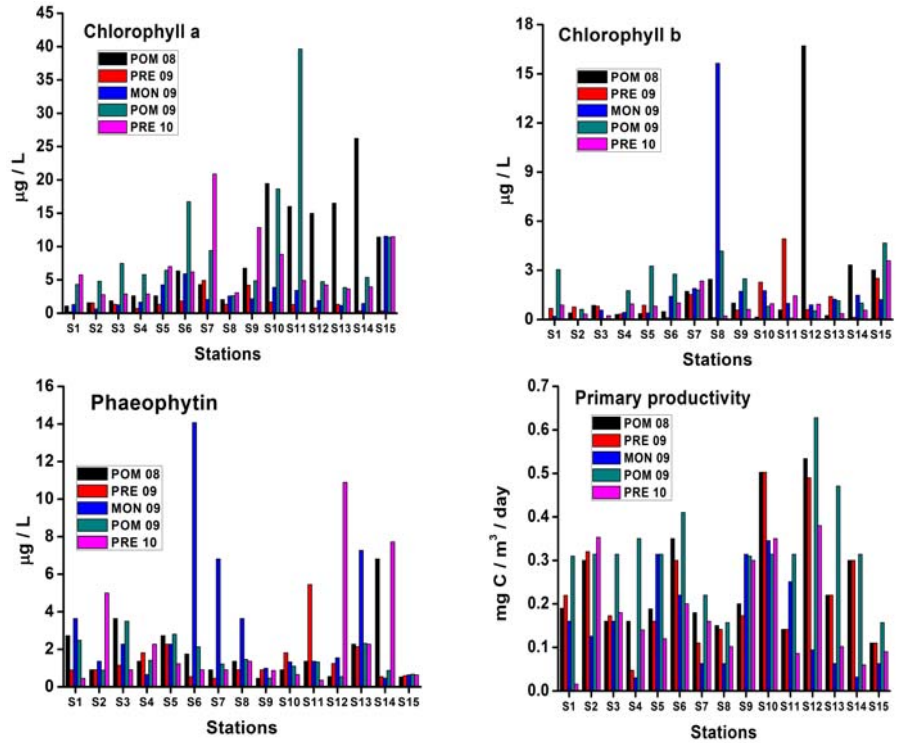


Figure 4.2 Spatial and seasonal variation in distribution of pigments and primary productivity

Table 4.77 Spatial and Seasonal variation of Chlorophyll a (μg/L) in the study area

SEASONS	POM 08	PRE 09	MON 09	POM 09	PRE10
S1	1.08	0.20	1.30	4.31	5.74
S2	1.56	1.54	0.63	4.78	2.76
S3	1.85	1.32	1.23	7.47	2.87
S4	2.60	0.71	1.65	5.79	2.87
S5	2.60	1.32	4.25	6.44	6.99
S6	6.33	1.82	5.92	16.74	6.18
S7	4.30	4.90	2.07	9.41	20.88
S8	2.04	1.33	2.58	2.61	3.05
S9	6.76	4.18	2.15	4.86	12.83
S10	19.46	1.67	3.88	18.63	8.81
S11	16.02	1.30	3.41	39.62	4.89
S12	14.99	0.77	1.91	4.74	4.25
S13	16.51	1.31	1.13	3.86	3.62
S14	26.22	0.33	1.43	5.38	3.94
S15	11.42	0.34	11.55	11.39	11.47
Maximum	26.22	4.90	11.55	39.62	20.88
Minimum	1.08	0.20	0.63	2.61	2.76
Average	8.92±7.96	1.53±1.33	3.00±2.76	9.74±9.50	6.74±5.01
ANOVA					
Spatial	0.20				
Seasonal	0.06				

Chlorophyll b

The spatio-temporal variation of Chl b is furnished in table 4.78 and figure 4.2. During POM 08, Chl b ranged from 0.05 to 16.70µg/L with an average of 2.11±4.18 µg/L. In the case of PRE 09, it varied from 0.10 to 4.92 µg/ L and displayed an average content of 1.17±1.27 µg/L. MON 09 recorded a Chlb content ranging from 0.02 to 15.63µg/L (average: 1.99±3.82 µg/L). POM 10 exhibited Chl b of surface water varying from 0.06 to 4.67 µg/L and recorded an average content of 1.88±1.46 µg/L. However in PRE 10, it ranged from 0.21 to 3.59µg/L and exhibited an average concentration of 1.02±0.89 µg/L.

Table 4.78 Spatial and Seasonal variation of Chlorophyll b (µg/L) in the study area

SEASON	POM 08	PRE 09	MON 09	POM 09	PRE10
S1	0.05	0.67	0.19	3.04	0.88
S2	0.40	0.76	0.02	0.62	0.33
S3	0.86	0.81	0.56	0.06	0.23
S4	0.30	0.33	0.43	1.75	0.95
S5	0.36	0.87	0.40	3.26	0.81
S6	0.48	0.10	1.41	2.77	1.00
S7	1.72	1.52	1.90	1.80	2.35
S8	2.46	0.12	15.63	4.18	0.21
S9	1.00	0.58	1.72	2.49	0.61
S10	0.14	2.28	1.76	0.80	0.96
S11	0.59	4.92	0.98	0.08	1.44
S12	16.70	0.61	0.89	0.52	0.93
S13	0.24	1.40	1.23	1.14	0.36
S14	3.33	0.13	1.48	0.99	0.57
S15	3.01	2.51	1.21	4.67	3.59
Maximum	16.70	4.92	15.63	4.67	3.59
Minimum	0.05	0.10	0.02	0.06	0.21
Average	2.11±4.18	1.17±1.27	1.99±3.82	1.88±1.46	1.02±0.89
ANOVA					
Spatial	0.44				
Seasonal	0.72				

Pheophytin

Pheophytin in the water samples, during POM 08 varied from 0.45 to 6.81µg/L with an average of 1.88±1.65 µg/L. In PRE 09, pheophytin content in water samples of the study region exhibited minimum value of 0.45 and a maximum of 5.45 µg/ L (average: 1.44±1.26 µg/L). MON 09 recorded pheophytin content ranging between 0.46 and 14.07 µg/L and recored an average of 3.22±3.67µg/L. All the sites revealed a pheophytin content during POM 09 varying from 0.46 (S9) to 3.49 µg/L(S3) (average: 1.54±0.90 µg/L) and in PRE 10, it varied from 0.36(S11) to 10.89µg/L(S12) (Average: 2.43±3.08 µg/L). The spatio-temporal variation of pheophytin is furnished in table 4.79 and figure 4.2.

Table 4.79 Spatial and Seasonal variation of Pheophytin (µg/L) in the study area

SEASONS	POM 08	PRE 09	MON 09	POM 09	PRE10
S1	2.72	0.90	3.63	2.48	0.45
S2	0.91	0.91	1.36	0.89	4.99
S3	3.63	1.15	2.27	3.49	0.91
S4	1.36	1.82	0.65	1.41	2.27
S5	2.72	2.27	2.27	2.80	1.23
S6	1.75	0.54	14.07	2.13	0.91
S7	0.91	0.45	6.81	1.21	0.91
S8	1.36	0.91	3.63	1.45	1.36
S9	0.45	0.91	0.99	0.46	0.87
S10	0.91	1.82	1.33	1.10	0.65
S11	1.36	5.45	1.36	1.33	0.36
S12	0.55	1.23	1.54	0.54	10.89
S13	2.27	2.13	7.26	2.31	2.27
S14	6.81	0.54	0.46	0.87	7.72
S15	0.52	0.59	0.63	0.67	0.63
Maximum	6.81	5.45	14.07	3.49	10.89
Minimum	0.45	0.45	0.46	0.46	0.36
Average	1.88±1.65	1.44±1.26	3.22±3.67	1.54±0.90	2.43±3.08
ANOVA					
Spatial	0.73				
Seasonal	0.26				

4.1.2 Secondary Production- Seasonal and spatial distribution of zooplankton.

The qualitative and quantitative seasonal and spatial occurrence of zooplankton species collected from the study region is furnished in the tables 4.80 and 4.81 and figure 4.3. Five types of zooplankton were identified. The major zooplankton groups from the study area were comprised of Cladocera, Copepoda, Rotifera and fish eggs. A gradual increase in the total density of zooplankton population during PRE 09 and PRE 10 played significant role in the trophic food web. Copepods were found to be the predominant groups and showed strong seasonality in abundance and diversity suggesting their dominant role in all the seasons.

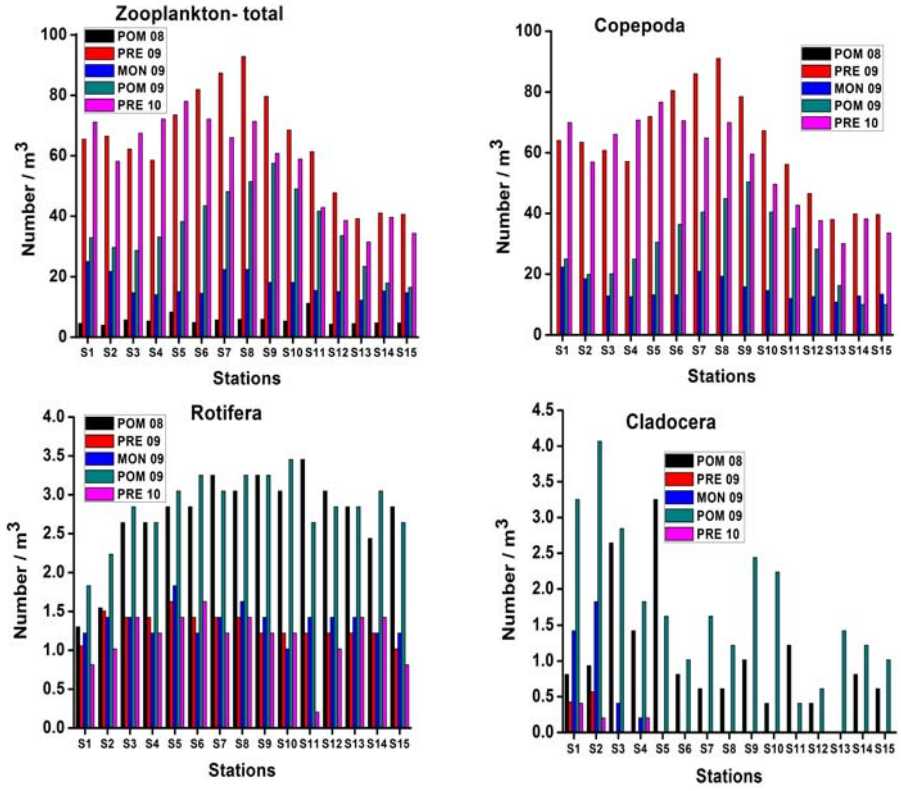


Figure 4.3 Population density of zooplankton in the study region.

Table 4.80 Total zooplankton distribution in CBW (No./m^3)

Stations	POM08	PRE09	MON09	POM09	PRE10
S1	26.50	65.51	25.00	32.93	71.14
S2	61.63	66.50	21.75	29.67	58.13
S3	36.59	62.20	14.63	28.66	67.48
S4	31.91	58.54	14.02	33.13	72.15
S5	38.62	73.58	15.04	38.21	78.05
S6	40.65	81.91	14.43	43.50	72.15
S7	48.17	87.40	22.36	48.17	66.06
S8	50.81	92.89	22.36	51.42	71.34
S9	55.89	79.67	18.09	57.52	60.77
S10	45.12	68.50	18.09	48.98	58.94
S11	43.09	61.38	15.45	41.67	42.89
S12	31.91	47.76	15.04	33.54	38.62
S13	25.20	39.23	12.20	23.37	31.50
S14	25.00	41.06	15.24	17.89	39.63
S15	23.98	40.65	14.63	16.46	34.35
Total	585.08	966.77	258.33	545.12	863.21
Maximum	61.63	92.89	25.00	57.52	78.05
Minimum	23.98	39.23	12.20	16.46	31.50
Average	39.01±11.81	64.45±17.02	17.22±3.86	36.34±12.24	57.55±15.85

Total zooplankton population density during POM 08 ranged from 23.98 No./m^3 at S15 to 61.63 No./m^3 at S2(average: 39.01±11.81 No./m^3). In the present study the total zooplankton population density during PRE 09 ranged from 39.23 No. /m^3 at S13 to 92.89 No./m^3 (average: 64.45±17.02) at S8. It was observed that the total population zooplankton density during MON 09 was found to be in the range 12.20 No./m^3at S 13 to 25.0 No./m^3at S1(average: 17.22±3.86 No./m^3). It was recorded that the total zooplankton density was maximum at S9 (57.52No./m^3) and minimum (16.46No./m^3) at S15 (average:36.34±12.24No./m3).

During PRE 10, it was found that total population density showed a minimum of 31.50 No./m^3 at S13 and a maximum of 78.05 No. /m^3 at S5 (average: 57.55±15.85 No./m^3).

Table 4.81 Seasonal and spatial distribution of Copepods in the study area

Copepod sps.	S1				S2				S3				S4				S5			
	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10
Acartia centrura	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia spinicauda	P	A	A	P	A	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia bowmani	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia tropica	P	A	A	P	A	P	P	A	P	A	P	P	A	P	A	P	A	A	P	P
Acartia bilobata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia southwelli	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia pacifica	A	P	A	A	P	P	P	A	P	P	A	P	A	P	A	P	P	A	P	P
Acartia plumosa	A	P	A	A	P	A	P	A	P	A	A	P	A	P	A	A	P	A	P	P
Acartiella keralensis	A	P	A	A	P	A	P	A	P	A	A	P	A	P	P	A	P	A	P	P
Acartiella gravelyi	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Pseudodiaptomous serricaudata	A	P	A	A	P	A	P	P	P	P	A	P	A	P	P	A	P	A	P	P
Pseudodiaptomous jonsei	P	A	A	P	A	P	A	A	P	P	P	P	A	P	P	P	P	A	P	P
Pseudodiaptomous annandaleii	A	A	A	A	P	A	P	A	A	P	A	P	A	A	P	A	P	A	P	P
Pseudodiaptomous bingami malayalus	A	A	P	A	A	A	A	P	A	A	A	P	P	P	P	A	P	P	P	P
Pseudodiaptomous tollingerae	P	A	A	P	A	P	A	A	P	A	P	P	A	P	P	P	P	A	P	P
Paracalanus crassirostris	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Paracalanus aculeatus	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Centropages alocki	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Labodacera pectinata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Bestiola similis	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Oithona brevicornis	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Corycaeus danae	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P

Table 4.81 Seasonal and spatial distribution of Copepods in the study area (Continued....)

	S6					S7					S8					S9					S10				
Copepod species	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10
Acartia centrura	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia spinicauda	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia bowmani	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia tropica	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia bilobata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia southwelli	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia pacifica	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia plumosa	A	P	A	A	P	P	P	A	A	P	P	P	A	A	P	P	P	A	A	P	P	P	A	A	A
Acartiella keralensis	A	P	A	A	P	P	P	A	A	P	P	P	A	A	P	P	P	A	A	P	P	P	A	A	P
Acartiella gravelyi	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Pseudodiaptomous serricaudata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Pseudodiaptomous jonsei	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Pseudodiaptomous annandaleii	A	P	A	A	P	P	P	A	A	P	P	P	A	A	P	P	P	A	A	P	P	P	A	A	P
Pseudodiaptomous bingami malayalus	A	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P
Pseudodiaptomous tollingerae	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Paracalanus crassirostris	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Paracalanus aculeatus	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Centropages alocki	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Labodocera pectinata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Bestiola similis	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Oithona brevicornis	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Corycaeus danae	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P

Table 4.81 Seasonal and spatial distribution of Copepods in the study area (Continued....)

	S11					S12					S13					S14					S15				
Copepod sps.	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10	POM 08	PRE 09	MON 09	POM 09	PRE10
Acartia centrura	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia spinicauda	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia bowmani	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia tropica	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia bilobata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia southwelli	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia pacifica	P	P	A	P	P	P	P	A	P	P	A	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Acartia plumosa	P	P	A	P	A	P	A	A	P	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Acartiella keralensis	P	P	A	A	P	P	P	A	A	P	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Acartiella gravelyi	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Pseudodiaptomous serricaudata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	A	P	A	P	P	A	P	A	P	P
Pseudodiaptomous jonsei	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	A	P	A	P	P	A	P	A	P	P
Pseudodiaptomous annandaleii	P	P	A	A	P	P	P	A	A	P	A	P	A	A	P	A	P	A	A	P	A	P	A	A	P
Pseudodiaptomous bingami malayalus	P	P	P	A	P	P	P	P	A	P	P	A	P	A	P	P	A	P	A	P	P	A	P	A	P
Pseudodiaptomous tollingerae	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Paracalanus crassirostris	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Paracalanus aculeatus	P	P	A	P	P	P	P	A	P	P	P	A	A	P	P	P	A	A	P	P	P	A	A	P	P
Centropages alocki	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Labodocera pectinata	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Bestiola similis	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Oithona brevicornis	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P	P	P	A	P	P
Corycaeus danae	P	P	A	P	P	P	P	A	P	P	A	P	A	P	P	A	P	A	P	P	A	P	A	P	P

A-Absent. P-Present

4.1.3 Tertiary Production

Seasonal variation in fish landings, gut content analysis and proximate composition of selected fishes were investigated.

4.1.3. a Seasonal variation in fish landings

The seasonal abundance of various fishes and crustaceans collected from the Cochin back water system is presented in table 4.82 and figure 4.4. The peak abundance of *Anabas testudineus* was in PRE 09 and minimum during POM 08. The fishes such as *Etroplus suratensis, Anguilla bicolor, Arius arius, Channa maruleus, Channa striatus, Cyprinus carpio, Etroplus maculatus, Mugil cephalus, Mystus armatus, Oreochromis mossambicus* showed its maximum during POM 09. All the crustaceans except *Macrobrachium idella* showed the peak (4760 kg) during POM 09. In the case of *Metapenaeus monoceros* maximum occurrence during POM 08(1205 kg) and minimum during MON 09 (1235kg). In the case of *Metapenaeus dobsoni,* maximum abundance was observed during POM 09.The present study reported the total landings of fishes were 260816 kg and the total landing of crustaceans was 50816 kg.

Sixteen (16) species of major food fishes and 5 crustacean species were identified in the study area and they were found to be valued and marketed in the local markets. Relative composition of various fishes and crustaceans covering the study area is presented in the table 4.82. In total out of the 16 commercially important species, *Etroplus suratensis* represented the maximum landings of 133429kg (42.82%) which is followed by *Horabagrus brachysoma* 33147kg (10.64%), *Channa maruleus* 23269kg (7.47%), *Wallago attu* 20720kg (6.65%), *Channa striatus* 17985 kg (5.77%). The minimum composition was shown by *Wallao attu* 1887 kg (0.61%). Among crustaceans *Macrobrachium idella* formed the dominant crustacean group with 20720 kg (6.65%) which is followed by *Metapenaeus dobsoni* with 10324 kg (3.31%). The total landings of *Macrobrachium rosenbergii* was7872 kg (2.53%), *Penaeus indicus* 6078 kg (1.95%), *Metapenaeus momoceros* 5822 kg (1.87%).

The reduction in prawn fisheries can be attributed to the decreasing salinity during MON 09.

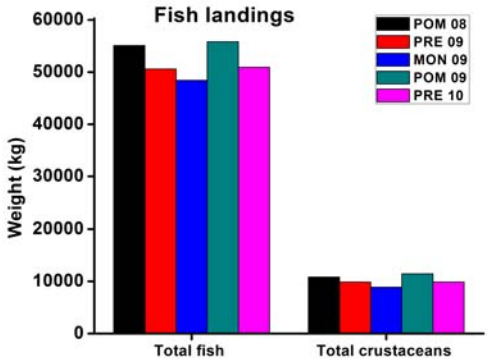


Figure 4.4 seasonal variations of total fish landings in the study area

Table 4.82 Seasonal variation of fish landings in the study area

FISH SPECIES	POM 08	PRE 09	MON 09	POM 09	PRE 10	total	%
Anabas testudineus	1700	2810	2650	1704	2705	11569	3.71
Anguilla bicolor	365	370	365	394	320	1814	0.58
Arius arius	506	501	430	553	475	2465	0.79
Channa maruleus	4710	4674	4674	4946	4265	23269	7.47
Channa striatus	3918	3345	3160	4185	3377	17985	5.77
Cyprinus carpio	1205	930	755	1210	843	4943	1.59
Etroplus maculatus	1351	1273	1142	1400	1305	6471	2.08
Etroplus surataensis	28735	25372	24417	28995	25910	133429	42.82
Hemirhampus	455	385	354	399	365	1958	0.63
Horabagrus brachysoma	6968	6530	6269	6675	6705	33147	10.64
Labeo dussumeiri	966	855	808	925	890	4444	1.43
Mugil cephalus	1400	1115	1060	1523	1260	6358	2.04
Mystus armatus	697	600	593	735	655	3280	1.05
Oreochromis mossambicus	1315	1012	990	1445	1085	5847	1.88
Scatophagus argus	430	425	375	365	355	1950	0.63
Wallago attu	372	385	363	364	403	1887	0.61
Macrobrachium idella	4400	3965	3595	4760	4000	20720	6.65
Macrobrachium rosenbergii	1668	1582	1337	1797	1488	7872	2.53
Metapenaeus monoceros	1235	1162	1050	1205	1170	5822	1.87
Metapenaeus dobsoni	2263	1933	1755	2410	1963	10324	3.31
Penaeus indicus	1244	1205	1128	1266	1235	6078	1.95
Total	65903	60429	57270	67256	60774	311632	100
Minimum	365	370	354	364	320	1814	0.58
Maximum	28735	25372	24417	28995	25910	133429	42.82
Average	3138.24± 6113.51	2877.57± 5407.83	2727.14± 5215.49	3202.67± 6162.84	2894± 5520.09	14839.62± 28405.08	4.76± 9.11

4.1.3. b Gut content analysis

Assessment on the food and feeding habits of the fish helps us to determine its niche in the ecosystem and its preferred food items. It described how much the food spectrum of a fish overlaps with that of the coexisting fishes. The analysis of food components in the gut of a species from different ecosystem provides the information that how much that fish is flexible in feeding on different types of food items. Feeding habit is one of the primary criteria in deciding on transplantation of species to new ecosystems with least possible damage or competition to the native fauna, or its utility in overall production enhancement.

The study of the fish feeding based upon analysis of stomach content has become a standard practice (Hyslop, 1980). Mainly there are four groups of fishes based on their feeding habit viz., carnivores, herbivores, omnivores and limnivores (mud eaters). The following food fishes are used for gut content analysis.

1. *Etroplus suratensis*

The food of the pearlspot, *Etroplus suratensis* in the CBW was dominated by filamentous algae (43%) followed by detritus (35%), macrophytes (12%), diatoms (9%) and undigested molluscan shells (1%) in all seasons (table 4.83). Filamentous algae were the major food throughout the year. Feeding intensity was higher during PRE 09.

Table 4.83 Gut content analysis of *Etroplus suratensis*

***Etroplus suratensis* (Omnivore)**					
	POM 08	**PRE09**	**MON09**	**POM09**	**PRE10**
Diatoms(Bacillariophyceae)	P	P	P	P	P
leaves of aquatic macrophytes	P	P	P	P	A
Chlorophyceae	P	P	P	P	P
Filamentous algae	P	A	A	P	P
Minute crustaceans	P	A	P	P	A
Insects	P	P	P	P	P
Copepods	P	A	A	A	A
Small fishes	A	P	A	P	P
Detritus	P	A	P	P	A
Others	P	P	P	P	P

A-absent, P-present

2. Oreochromis mossambicus:

Present study revealed that the occurrence of Chlorophyceae (table 4.84), constituted 53.6%, the diatoms (Bacillariophaceae) 19.7%, aquatic invertebrates (mainly Copepoda, Cladocera and Rotifera) 12.9% desmids (Desmidaceae) 7.7% and lastly the green algae (Chlorophyceae) 6.2% observed during the PRE 09.

Table 4.84 Gut content analysis of *Oreochromis mossambicus*

***Oreochromis mossambicus* (Omnivore)**					
	POM 08	**PRE09**	**MON09**	**POM09**	**PRE10**
Diatoms(Bacillariophyceae)	P	P	P	P	P
Leaves of aquatic macrophytes	P	P	P	P	p
Chlorophyceae	P	P	P	P	p
Filamentous algae	P	P	P	P	p
Minute crustaceans	A	P	P	A	A
Insects-Waterfleas	P	P	P	P	P
Copepods	A	A	A	A	A
Small fishes	P	P	P	P	P
Detritus,Mud	P	P	P	P	P
Prawns(semidigested)	P	A	A	P	P
Rotifers	P	P	P	P	P
Others	P	P	P	p	P

A-absent, P-present

3. Labeo fimbriatus:

The present study revealed that *L. fimbriatus* is a herbivore. Highly coiled long intestine was observed and that indicated the herbivorous feeding habit. During POM 08, POM 09 the gut showed the presence of few species of Bacillariophyceae, Chlorophyceae, filamentous algae, detritus and mud (table 4.85). The analysis showed that during PRE 09, the presence of diatoms (Bacillariophyceae), leaves of macrophytes, filamentous algae in the gut of *Labeo fimbriatus*. Along with this vegetation traces of mud could be observed. Zooplankton and animal matter were totally absent in all seasons. The same trend was observed in the PRE 10 and MON 09 also

Table 4.85 Gut content analysis of *Labeo fimbriatus*

Labeo fimbriatus **(Herbivore)**					
	POM 08	**PRE09**	**MON09**	**POM09**	**PRE10**
Diatoms(Bacillariophyceae)	**P**	**P**	**P**	A	**P**
leaves of aquatic macrophytes	**P**	**P**	**P**	A	**P**
Chlorophyceae	**P**	**P**	**P**	A	**P**
Filamentous algae	**P**	**P**	**P**	A	**P**
Minute crustaceans	A	A	A	A	A
Insects-Waterfleas	A	A	A	A	A
Copepods	A	A	A	A	A
Small fishes	A	A	A	A	A
Detritus,Mud	**P**	**P**	**P**	**P**	**P**
Rotifers	A	A	A	A	A
Prawns(semidigested)	A	A	A	A	A
Others	**P**	**P**	**P**	**P**	**P**

A-absent, P-present

4. Anabas testudineus

Gut content analysis of Anabas testudineus is furnished in table 4.86. Larvae and young fry feed on both phytoplankton and zooplankton,

and adults feed on crustaceans, worms, molluscs, insect, algae, soft higher plants and organic debris (Potogkam, 1972). *A. testudineus* has been described as a predator, carnivore (Pandey et al., 1995). However gut content analysis of 25 specimens of *A. testudineus* showed that the stomach comprised of 19% crustaceans, 3.5% insects, 6% molluscs, 9.5% fishes, 47% plant debris and 1.6% semi-digested matter (Nargis and Hossain, 1987). Irrespective to spatial and seasonal distribution, major food item in the gut were found to be more or less consistent throughout the study (Nargis and Hossain, 1987) indicating *A. testudineus is* an omnivore. Insects and waterfleas were also present in some samples collected from the freshwater regime.

Table 4.86 Gut content analysis of *Anabas testudineus*

***Anabas testudineus* (Omnivore)**					
	POM 08	**PRE09**	**MON09**	**POM09**	**PRE10**
Diatoms(Bacillariophyceae)	P	P	P	P	P
leaves of aquatic macrophytes	P	P	P	P	P
Chlorophyceae	P	P	P	P	P
Filamentous algae	P	P	P	P	P
Minute crustaceans	A	A	A	A	A
Insects-Waterfleas	P	P	P	P	P
Copepods	A	A	A	A	A
Small fishes	P	P	P	P	P
Detritus,Mud	P	P	P	P	P
Prawns(semidigested)	P	P	P	P	P
Others,Fish scales	P	P	P	P	P
Benthos(Chironomids)	P	P	P	A	P

A-absent, P-present

5. Channa striatus

Throughout the study, crustaceans, molluscs, plant parts, fish scales, algal filaments, sand and mud were present in the gut of *Channa striatus* and these fishes were distributed (table 4.87). Therefore on the basis of

different food items found in the stomach contents, *C. striatus* could be conveniently regarded as carnivore.

Table 4.87 Gut content analysis of *Channa striatus*

Channa striatus (Carnivore)					
	POM 08	PRE09	MON09	POM09	PRE10
Diatoms(Bacillariophyceae)	A	A	A	A	A
leaves of aquatic macrophytes	A	A	A	A	A
Chlorophyceae	A	A	A	A	A
Filamentous algae	A	A	A	A	A
Minute crustaceans	P	P	P	P	A
Insects-Waterfleas	P	P	P	P	P
Copepods	P	P	P	A	A
Small fishes,fish scales	P	P	P	P	P
Detritus,Mud	P	P	P	P	P
Prawns(semidigested)	P	P	P	P	P
Rotifers	P	P	P	P	P
Others	P	P	P	P	P

A-absent, P-present

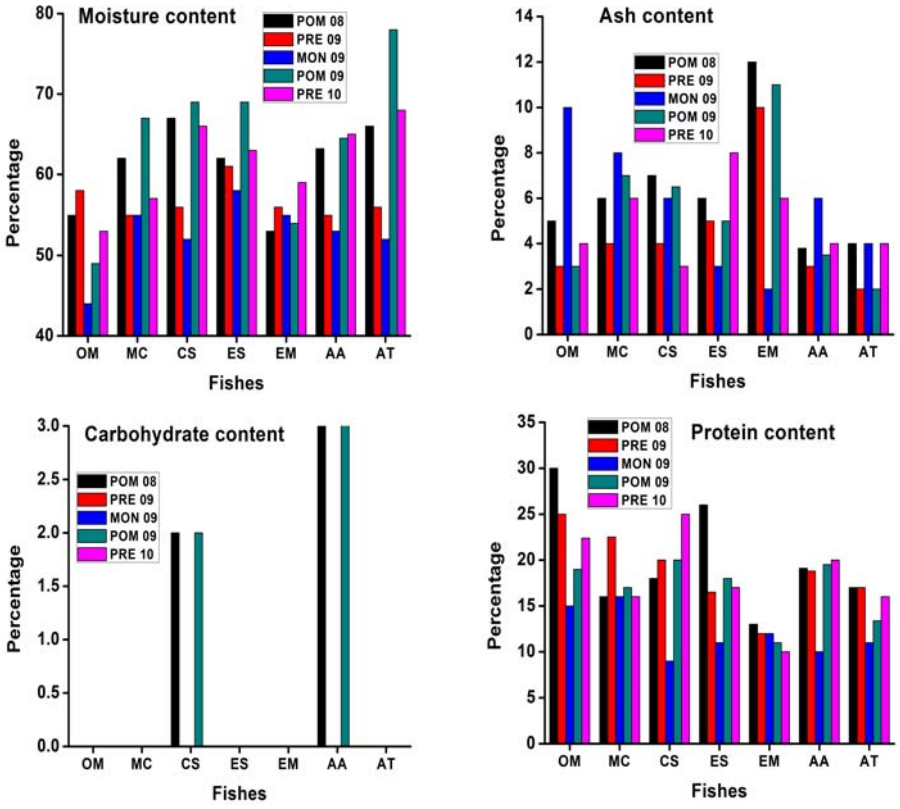
4.1.3. c Proximate composition of selected food fishes

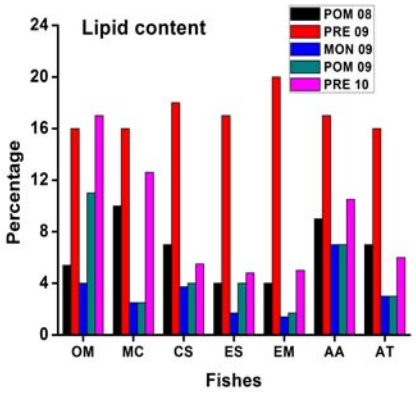
Concentration of protein, carbohydrate and lipid which form the major biochemical constituents of major fishes from Cochin Back waters were estimated. In the present study, the fish species analysed individually were rich in protein (12 to 19.87%) and lipid (3.3 to 17.14%). Figure 4.5 represent the proximate composition of selected species of fishes in the study area.

Moisture Content

During POM 08, *Channa striatus* exhibited maximum moisture content (67%) (table 4.88). Minimum value was obtained from *Etroplus maculeatus* (55%). It was found that during PRE 09 maximum moisture content was exhibited by *Etroplus suratensis* (61%), and minimum was shown by two fishes viz., *Mugil cephalus* and *Arius arius* (55%). The present study revealed that *Oreochromis mossambicus* showed the minimum value (44%) and *Etroplus suratensis* exhibited the maximum (58%) in the MON 09. In POM 09, minimum moisture content was recorded by *Oreochromis mossambicus*

(49%) and the maximum was observed in *Anabas testudineus* (78%). During PRE 10, minimum moisture content observed was (53%) in the case of *Oreochromis mossambicus* and maximum (68%) in the case of *Anabas testudineus*. Moisture content during POM 08 varied from 53% to 67% (average: 61.17±5.29%), 55% to 61% (average: 56.71±2.14%) during PRE 09, from 44% to 58% (average: 52.71±4.39%) during MON 09, from 49% to 78% (average: 64.36±9.83%) during POM 09, and from 53% to 68% (average: 61.57±5.41%) during PRE 10.





OM= *Oreochromis mossambicus* , MC= *Mugil cephalus* , CS= *Channa striatus*,
ES= *Etroplus suratensis*, EM= *Etroplus maculeatus* , AA= *Arius arius*, AT= *Anabas testudineus*

Figure. 4.5 Proximate composition of selected species of fishes in the study area

Table 4.87 Moisture content in fish samplesin the study area (%)

FISH SPECIES	POM08	PRE09	MON09	POM09	PRE10
Oreochromis mossambicus	55	58	44	49	53
Mugil cephalus	62	55	55	67	57
Channa striatus	67	56	52	69	66
Etroplus suratensis	62	61	58	69	63
Etroplus maculeatus	53	56	55	54	59
Arius arius	63.2	55	53	64.5	65
Anabas testudineus	66	56	52	78	68
Minimum	53	55	44	49	53
Maximum	67	61	58	78	68
Average	61.17±5.29	56.71±2.14	52.71±4.39	64.36±9.83	61.57±5.41
ANOVA					
Species wise	0.22				
Seasonal	0.0005				

Ash Content

The content of ash ranged from 3.8 to 12 % (average: 6.26 ±2.78%) during POM 08 (table 4.89). The maximum value recorded during PRE 09 was 10 % and minimum was 2% (average: 4.43± 2.64%) in PRE09. Ash exhibited variation from 2 to 10% (average: 5.57 ±2.81%) during MON 09. The minimum value recorded during POM 09 was 2% and the maximum was found to be 11% (average: 5.43±3.06%). During PRE 10, ash percentage varied from 3 to 8% (average: 5±1.73%).

During POM 08, lowest value was showed by *Arius arius* (3.8%) and highest was that of *Etroplus maculeatus* (12%). But in PRE09 minimum ash percentage was recorded by *Anabas testudineus* (2%) and recorded highest value was 10% in the case of *Etroplus maculeatus.* In MON 09, minimum ash content was exhibited by *Etroplus maculeatus* (2%) and maximum by *Oreochromis mossambicus* (10%). While in POM 09 minimum value (2%) was showed by *Anabas testudineus* and maximum value was 11% in the case of *E.maculeatus.* Meanwhile during PRE 10, minimum content (3%) was recorded by *Channa striatus* and the maximum ash content was recorded by *Etroplus suratensis* (8%).

Table 4.89 Ash content in fish samples in the study area (%)

FISH SPECIES	POM08	PRE09	MON09	POM09	PRE10
Oreochromis mossambicus	5	3	10	3	4
Mugil cephalus	6	4	8	7	6
Channa striatus	7	4	6	6.5	3
Etroplus suratensis	6	5	3	5	8
Etroplus maculeatus	12	10	2	11	6
Arius arius	3.8	3	6	3.5	4
Anabas testudineus	4	2	4	2	4
Minimum	3.8	2	2	2	3
Maximum	12	10	10	11	8
Average	6.26±2.78	4.43±2.64	5.57±2.82	5.43±3.06	5.00±1.73
ANOVA					
Species wise	0.22				
Seasonal	0.84				

Carbohydrate Content

Carbohydrate occurs in minute quantity in the fish tissues. During PRE 09, MON 09 and PRE 10 non detectable levels were found (table 4.90). During POM 08 and POM 09, *Channa striatus* and *Arius arius* showed a concentration of 2% and 3 % respectively (average: 0.62±1.18%).

Table 4.90 Carbohydrate content in fish samples in the study area (%)

FISH SPECIES	POM 08	PRE 09	MON 09	POM 09	PRE10
Oreochromis mossambicus	ND	ND	ND	ND	ND
Mugil cephalus	ND	ND	ND	ND	ND
Channa striatus	2	ND	ND	ND	ND
Etroplus suratensis	ND	ND	ND	ND	ND
Etroplus maculeatus	ND	ND	ND	ND	ND
Arius arius	3	ND	ND	3	ND
Anabas testudineus	ND	ND	ND	ND	ND
Minimum	ND	ND	ND	ND	ND
Maximum	3	ND	ND	3	ND
Average	0.62±1.18	ND	ND	0.62±1.18	ND
ANOVA					
Species wise	0.0397				
Seasonal	0.091				

Lipid Content

Mugil cephalus exhibited maximum lipid content (10%) and the minimum concentration was exhibited in two species *Etroplus maculeatus* and *Etroplus suratensis* (4%) during POM 08 (table 4.91). *Anabas testudineus*, *Oreochromis mossambicus* and *Mugil Cephalus* recorded minimum content (16%) and *Etroplus maculeatus* exhibited the maximum (20%) in the PRE 09. In MON 09, minimum lipid content was recorded by *E.maculeatus* (1.4 %) and maximum was shown by *Arius arius* (7%). During POM 09, minimum content ranged from 1.7% (*Etroplus maculeatus*) to 11% (*Oreochromis mossambicus*). But in PRE 10, minimum lipid content (4.8%) was observed in the case of *Etroplus suratensis* and maximum (17%) in the case of *Oreochromis mossambicus*.

During POM 08, it ranged from 4 to 10 % with an average of 6.62±2.33%. Lipid content varied from 16 to 20 % and estimated average was found to be 17.14±1.46% (during PRE 09). The range of lipid ranged from 1.4 to 7% and recorded average was 3.33±1.8% (MON 09). But in

POM 09 minimum content observed was 1.7 and the maximum was found to be 11 % (average: 4.74±3.23%). In the present study, minimum lipid content was found to be 4.8% (*Etroplus suratensis*) and maximum was 17% (*Oreochromis mossambicus*) (average: 8.77±4.72%) in PRE 10.

Table 4.91 Lipid content in fish samples in the study area (%)

FISH SPECIES	POM08	PRE09	MON09	POM09	PRE10
Oreochromis mossambicus	5.4	16	4	11	17
Mugil cephalus	10	16	2.5	2.5	12.6
Channa striatus	7	18	3.73	4	5.5
Etroplus suratensis	4	17	1.7	4	4.8
Etroplus maculeatus	4	20	1.4	1.7	5
Arius arius	9	17	7	7	10.5
Anabas testudineus	7	16	3	3	6
Minimum	4	16	1.4	1.7	4.8
Maximum	10	20	7	11	17
Average	6.63±2.33	17.14±1.46	3.33±1.88	4.74±3.23	8.77±4.72
ANOVA					
Species wise	0.22				
Seasonal	1.96903E-08				

Protein Content

During POM 08, it was observed that protein content varied from 13 (*Etroplus maculatus*) to 30% (*Oreochromis mossambicus*) with an average of 19.87±5.98% (table 4.92). It was found that PRE 09 recorded a minimum of 12% (*Etroplus maculeatus*) and maximum of 25% (*Oreochromis mossambicus*) and exhibited an average concentration of 18.83±4.25%. The minimum protein content was 9% (*Channa striatus*) and maximum of 16% for *Mugil cephalus* (average: 12±2.58%) during the MON 09 period. However, during POM 09 exhibited a minimum value of 11% (*E.maculeatus*) and maximum of 20% represented by *Channa striatus*. (average: 16.84±3.39). It was observed that during PRE 10, minimum

protein content was 10% (*Etroplus maculeatus*) and maximum content of 25% was estimated for *Channa striatus* (average: 18.06±4.92%).

Table 4.92 Protien content in fish samplesin the study area (%)

FISH SPECIES	POM08	PRE09	MON09	POM09	PRE10
Oreochromis mossambicus	30	25	15	19	22.4
Mugil cephalus	16	22.5	16	17	16
Channa striatus	18	20	9	20	25
Etroplus suratensis	26	16.5	11	18	17
Etroplus maculeatus	13	12	12	11	10
Arius arius	19.1	18.8	10	19.5	20
Anabas testudineus	17	17	11	13.4	16
Minimum	13	12	9	11	10
Maximum	30	25	16	20	25
Average	19.87±5.98	18.83±4.25	12.00±2.58	16.84±3.39	18.06±4.92
ANOVA					
Species wise	0.0373				
Seasonal	0.00896				

4.2 Discussion

Cochin backwater system is a tropical estuary influenced by various stressors. The wind brings cool, oxygen deficient and nutrient rich waters towards the SW coast of India. The varying physico-chemical conditions makes the coastal waters highly fertile (Habeebrehman et al., 2008) and enhances primary production several fold higher than the offshore waters (Ryther,1963). Considering the significant role of plankton in the productivity of tropical and coastal ecosystems the present study has been undertaken to extend the knowledge on systematics, species composition, distribution, abundance and ecology of the phytoplankton, zooplankton and fishes in the

study area. In recent times it is increasingly evident that CBW faces pollution because of excessive use of pesticides, effluents, and sewage. Over the seasons, the ecosystem experiences extensive droughts in the pre-monsoon to flooding in the monsoon. Physico-chemical properties of water vary daily, seasonally, and yearly because of natural seasonal cycles. Daily fluctuations in the near shore physical environment are mainly due to tides, and biological processes like excretion. All these processes significantly affect near shore distributions and concentrations of phytoplankton.

Phytoplankton in the estuarine environments utilizes carbon dioxide for photosynthesis thereby play an important role in maintaining carbon dioxide budget of the atmosphere. The food chain of this ecosystem is drawn from primary producers through zooplankton to omnivorous and carnivorous fishes. The fishes caught from the aquatic environment are consumed by human beings thereby reducing protein deficiency. Indiscriminate exploitation of marine food source has resulted in depletion andso there should be judicious and sustainable fishing is necessary. This could be possible by quantifying the biomass of plankton, from which the fish population will be produced and calculated and finally the catchable amount per year could be predicted. Major and minor phytoplanktons identified in the study area during different seasons are furnished in tables 4.93 to 4.98.

Table 4.93 Major and minor phytoplanktons identified in the study area during POM 08

SEASON	MAJOR SPECIES	MINOR SPECIES
Chlorophyceae	*Closterium* sp., *Pediastrum* sp. *Staurastrum* sp.	*Volvox* sp., *Tetraspora* sp., *Pledorina* sp.,*Microspora* sp. *Chlorococcum* sp.
Bacillariophyceae	*Asterionella japonica, Aulacoseira granulata,Cerataulina bergonii, Coscinodiscus gigas,* ,etc.	*Asteremphalus flabellatus, Bacillaria paradoxa, Bacteriastrum varians, Biddulphia aurita,Chaetoceros* sps. *Coscinodiscus granii,* etc.
Dinophyceae	*Ceratium tripos ,Ceratium macroceros, Goniaulux* sp. *Peridinium claudicans, Prorocentrum micans* etc.	*Phalacroma rotundatus, Peridinium limbatum, Noctiluca milaris, Dinophysis miles,Ceratocorys horrida* etc.
Myxophyceae	*Trichodesmium theibautii*	*Katagnymene spiralis*
Silicoflagellate	*Dictyocha fibula*	*Distephanus speculum*
Cyanobacteria	*Nostoc* colony, *Tolypothrix sp.*	*Merismopedia* sp., *Anabaena* sp.
Zygnematophyceae	*Spirogyra condensata*	-
Desmidaceae	*Desmidium* sp.	-

Table 4.94 Major and minor phytoplanktons identified in the study area during PRE 09

SEASON	MAJOR SPECIES	MINOR SPECIES
Chlorophyceae	*Chlorella sp,* Chlorococcum sp. *Pledorina* sp., *Staurastrum* sp.	*Tetraspora* sp. *Arthrodesmus* sp.
Bacillariophyceae	*Asterionella japonica, Biddulphia aurita, Chaetoceros sps. Climacodium sp. Cerataulina bergonii, Coscinodiscus centrales Aulacoseira granulata*	*Asteremphalus flabellatus, Amphiprora sp., Bacteriastrum* sp., *Bellerochea malleus, Biddulphia heteroceros, Coscinodiscus granii,* etc.
Dinophyceae	*Ceratium tripos ,Ceratium macroceros, Goniaulux* sp. *Prorocentrum micans Ceratium lineatum.*	*Amphisolenia bidentata, Phalacroma rotundatus, Peridinium* sp. *Dinophysis miles.*
Myxophyceae	*Trichodesmium theibautii, Katagnymene spiralis,*	*Oscillatoria* sps.
Silicoflagellate	*Dictyocha fibula*	*Distephanus speculum*
Cyanobacteria	*Nostoc* colony, *Anabaena* sp.	*Merismopedia* sp.
Zygnematophyceae	*Spirogyra condensata, Zygnema* sp.	*Cosmarium* sp.
Desmidaceae	-	*Desmidium* sp.

Table 4.95 Major and minor phytoplanktons identified in the study area during MON 09

SEASON	MAJOR SPECIES	MINOR SPECIES
Chlorophyceae	*Arthrodesmus* sp., *Chlorella* sp., *Closterium* sp.	---
Bacillariophyceae	*Asteremphalus flabellatus ,Biddulphia aurita, Cerataulina bergonii, Asterionella japonica, Chaetoceros lorenzianus, etc. ….*	Amphiprora sp., Coscinodiscus sp. *Pleurosigma normanii, Rhizosolenia* sp. *Climacodium* sp., *Lithodesmium* sp. etc
Dinophyceae	*Dinophysis caudata, Prorocentrum micans*	*Pyrophacus* sp., *Pyrocystis* sp. *Ceratium lineatum , Podolampus bipes, Peridinium* sp. *Gymnodinium* sp.
Myxophyceae	*Oscillatoria* sp.	-
Silicoflagellate	-	*Distephanus speculum, Dictyocha fibula*
Cyanobacteria	-	*Anabaena* sp
Zygnematophyceae	*Spirogyra condensata*	-
Desmidaceae	-	-

Table 4.96 Major and minor phytoplanktons identified in the study area during POM 09

SEASON	MAJOR SPECIES	MINOR SPECIES
Chlorophyceae	*Volvox., Ulothrix . Pledorina sp., Chlorella sp., Ankistrodesmus falcans, Chlorococcum sp., Closterium sp., etc. …*	*Arthrodesmus sp., Micrasterias sp., Microspora sp., Pediastrum sp. , etc*
Bacillariophyceae	*Asterionella sp., Aulacoseira granulata, Ceratualina bergonii, Coscinodiscus sp., Cyclotella menegjiniana, Hyalodiscus etc.*	*Amphiprora* sp., *Asteromphalus* sp. *Bacillaria paradoxa, Biddulphia heteroceros .,Chaetoceros* sp.
Dinophyceae	*Ceratium breve, Ceratium fusus, Gonialux* sp. *Podolampas bipes, Prorocentrum micans.*	*Ceratium lineatum, Ceratium macroceros,*
Myxophyceae	*Katagnymene spiralis*	*Trichodesmium theibautii*
Silicoflagellate	-	*Dictyocha fibula*
Cyanobacteria	*Merismopedia* sp., *Nostoc colony*	*Anabaena* sp.
Zygnematophyceae	*Spirogyra condensata, Zygnema, Cosmarium*	-
Desmidaceae	*Desmidium* sp.	-

Table 4.97 Major and minor phytoplanktons identified in the study area during PRE 10

SEASON	MAJOR SPECIES	MINOR SPECIES
Chlorophyceae	*Closterium* sp., *Pediastrum* sp., *Sturastrum* sp. *Microspora sp. etc*	*Chlorella* sp. , *Pledorina sp. Scenedesmus quadricauda*
Bacillariophyceae	*Asterionella sp. Aulacoseira granulata, Biddulphia aurita Cerataulina* sp. *Chaetoceros* sp., *Coscinodiscus* sp.,*Nitzschia longissima,Thalassiosira* sp. *etc..*	*Amphiprora* sp. , *Asteremphaus flabellatus, Bacteriastrum* sp. *Bellerochea malleus, Melosira sulcata*, etc…
Dinophyceae	*Ceratium fusus, Peridinium sp.Prorocentrum micans, Ceratium lineatum pyrocystis* sp. *etc*	*Ceratium macroceros,Ceratium breve etc*
Myxophyceae	*Trichodesmium theibautii*	-
Silicoflagellate	*Dictyocha fibula*	-
Cyanobacteria	*Anabaena* sp., *Nostoc colony*	-
Zygnematophyceae	*Zygnema* sp., *Spirogyra condensata, Cosmarium* sp.	
Desmidaceae	-	-

Phytoplanktons are the assemblages of particulate plants making up the first trophic level of pelagic food chains. Phytoplankton forms the primary source of energy for all organisms from zooplankton and upto large fishes and even birds. Phytoplankton, Chlorophyll a and primary production are important determinants of the standing stock and organic productivity of a water body. These variables have often been utilized to evaluate the overall health of any particular water body (Menon et al., 2000). Diatoms are often the dominant algal group in most fresh water systems, often contributing more than half of the overall primary production. Species assemblage can be effectively used to infer past environmental changes. Phytoplankton, the basis of food chain, forms the chief index of utilisation of abiotic factors and the net productivity of the ecosystem, ultimately the extent of utilisation on these recourses at secondary and tertiary levels can be interpreted. The present study aims at obtaining more basic knowledge on distribution of pigments, describing relative contributions of phytoplankton, zooplankton and fishes in Cochin Backwaters. It would help in understanding ecological changes and

formulation of effective management strategies for the sensitive marine habitats. Enrichment of the organic matter in sediment observed in the Cochin estuary is a sign of environmental degradation. As a consequence, there has been considerable reduction in the diversity of zooplankton.

Table 4.98 Previous studies on phytoplankton abundance in CBW

Phytoplankton group	No.of species	Year of sampling	Reference
Bacillariophyceae,Dinphyceae, Cyanobacteria, Chlorophyceae	194	1958-75	George 1958 a, b; Devassy and Bhattathiri, 1974; Gopinathan, 1972 and 1975; Joseph and Pillai, 1975; Kumaran and Rao, 1975.
Bacillariophyceae, Chlorophyceae, Cyanobacteria	76		Sreekumar and Joseph,1995
Bacillariophyceae Dinophyceae Chlorophyceae Cyanobacteria	89 31 2 1	1999	Project Report(2002)
Bacillariophyceae and Dinophyceae	58+2= 60	2001 to 2002	Selvaraj et al., 2003
Bacillariophyceae, Dinophyceae and others	89(PRE)65(MON)	2003	Madhu et al., 2007
Bacillariophyceae, Dinophyceae,Chlorophyceae	28+9+2=39 54+19+2=75	2006 to 2007 2007 to 2008	Sanil Kumar, 2009
Bacillariophyceae,Dinophyceae, Chlorophyceae,Cyanobacteria, Zygnematophyceae,Desmidaceae, Myxophyceae	79 (POM08) 86 (PRE09) 75 (MON09) 87 (POM09) 89 (PRE10)	January 2009 to April 2010	Present Study

Phytoplankton diversity was more pronounced during premonsoon season, maximum density was observed during postmonsoon season due to the stable hydrographical conditions and less predation. It was also noticed that species diversity showed the following trend: PRE 10> PRE 09> PRE 09> POM 08> MON 09. *Skeletonema costatum, Cyclotella meneghiniana*

are present which are euryhaline and thus show abundance. Different species belonging to various groups of phytoplankton were observed in the present study. They are Chlorophyceae, Bacillariophyceae, Myxophyceae, Silicoflagellates, Cyanobacteria, Zygnematophyceae and Desmidaceae. During premonsoon, dominant species observed include *Coscinidiscus centralis, Coscinodiscus granii, Chaetoceros lorenzianus, Chaetoceros affinis, Thalssiosira subtilis, Streptotheca indica* and were successfully surviving the saline waters. *Asterionella japonica, Aulacoseira granulata, Cerataulina bergonii, Coscinodiscus centralis, Nitzschia longissima, Nitzschia seriata, Thalssiothrix frauenfeldii* are dominating and it is understood that salinity controls these phytoplankton density and succession. During postmonsoon, gradually the fresh water species disappear coinciding with the predominance of marine forms. *Trichodesmium theibautii* was absent duing rainy season due to the fresh water influx and it could actively grow within optimal salinity range (Sinha et .al., 1996, De et.al 1994, Jyothibabu et al., 2003). The analysis of physicochemical parameters in the water column revealed that the system is oligomesotrophic similar to the earlier reports by Renjith et al., 2012. The results of phytoplankton were comparable with the earlier records (table 4.98). The size structure provides useful insight into the ecosystem functioning as the larger phytoplankton are generally dominant in nutrient-rich, productive waters whereas smaller phytoplankton are abundant under mesotropic conditions (Aneeshkumar, 2009). In the present study, fractionation of P and N in sediments and the elemental ratios estimated as described in Chapter 3, pointed towards the enrichment of P in this estuarine system.

The synthesis of organic compounds from the inorganic constituents of sea water by the photosynthetic activity of green plants is termed as primary production, and traces of organic matter also formed by chemosynthesis. The raw materials are water, CO_2, the nutrients mainly nitrate and phosphate. Plants making use of light energy are able to combine these simple substances to synthesise complex organic molecules. The chief products are the three major categories of food materials namely carbohydrates, proteins and fats. The consumption of plants by herbivorous animals leads to the formation of animal tissue, which in turn becomes the food for the first rank of carnivores and so on. These successive stages of production of living tissue form a series of trophic levels or links in the food chain being interconnected and forming an intricate food web. Eventually as a result of respiration, excretion, death and decomposition, the organic materials undergo break down and are returned to the water as simpler substances which can be utilised by organisms. In this way matter is continually cycled from inorganic to organic forms and back to inorganic state. It is essential to measure the primary production in the aquatic environment to assess the total primary productivity and potential fishery resources.

The rate of PP in an ecosystem is depending on various physical and chemical parameters. The onset of the southwest monsoon varies from year to year and so rainfall contributes to the variability of the estuarine water levels, flow and chemistry. Thereby the water quality plays an important role in selecting the phytoplankton community (Chavez, 1996; Legendre and Le-Fevre, 1989, Moore and Abott, 2000). PP showed significant positive correlation with Chlb, NO_2 and highly significant positive correlation with transparency and Cyanobacteria during PRE 09. In MON

09, primary prodductivity exhibited significant positive correlation with ammonia and pH. The low values of primary productivity during MON 09 is due to freshwater discharges from the rivers, land runoff, leading to turbidity and high value of light extinction coefficient and less availability of light [Kawabata et al., (1993); Godhataraman, (2002); Thillai Rajasegar et al., (2005)]. Primary productivity displayed highly significant positive correlation with pheophytin and iron during POM 09. Two way analysis of variance (ANOVA) revealed that there was high spatial and seasonal variation ($p<0.01$) in surface waters. In bottom waters two way ANOVA showed highly significant seasonal variation ($p<0.05$). The currently recorded high PP during POM 09 and PRE 09 could be attributed to high light intensity, clear water condition and nutrient availability as stated in the earlier reports (Gopinathan et al., 1994), Thillai Rajasegar et al., (2005). In the present study the observed low value during POM 09, could be due to the uptake of silicates by planktonic organisms (Mishra et al., 1993; Ramakrishnan et al., 1999). The recorded lower primary productivity during MON 09 could be due to the wash out of phytoplankton by the monsoonal floods, thereby reduction in salinity which could affected the phytoplankton population and lowering of PP during MON 09 and these findings are in concordance with the earlier reports (Rajasegar et al., 2000, Gowda et al 2001, Thillai Rajasekar et al., 2005).

In estuaries, quantitatively phytoplankton are the second source of particulate organic matter after terrestrial inputs from soil erosion which supply the highest quality food source and constitutes premier basis of the estuarine food web (Gasparini et al., 1999; Burdloff et al., 2000). The phytoplankton biomass contains: chlorophyll a, b and its degradation products, pheophytin. It is a marker of organic carbon (Bianchi et al.,

1995) and is present in all phytoplankton species; it can serve, as a measure of changes in their biomass. Pigments like Chl a, Chl b and pheophytin in seawater are good markers of different processes taking place in the water column, principally grazing by heterotrophic organisms (Welschmeyer and Lorenzen, 1985). Chlorophyll a derivatives, especially of pheophorbides a, are indicators of intensive activity of these organisms (Bianchi et al., 2002). Chloropyll a (Chl a) can be used as a global algal biomass indicator. Chl a is present in all groups of photosynthetic organisms except some bacteria (Moss, 1968). Cermeno et al., (2006) suggested that large-sized phytoplankton have greater potential to export organic matter through a short classical food chain, whereas the small-sized phytoplanktons are utilized by complex microbial food webs that favour the recycling of organic matter. Many studies have confirmed that small sized phytoplankton is an integral component in environmental monitoring assessment of the plankton community. Their relative contribution to the total community varies with the abundance of large-sized phytoplankton (Raimbault et al. 1988). Increase of diversity and evenness in offshore communities of low biomass is common (Madhupratap, 1987). According to Madhupratap et al., (1990) the occurrence of increased biological productivity during monsoon season could be due to river run off. Generally, nutrient enrichment favours the growth of large phytoplankton, while the production of small phytoplankton is mainly controlled by microzooplankton (cilites and flagellates) grazing (Jyothibabu et al., 2006).

Pigments are bound in pigment-protein complexes as part of the light harvesting complexes of reaction centres in autotrophs (Porra et al., 1997). Chemical structures of pigments and properties have been extensively reviewed (Young and Britton, 1993; Scheer, 2003), as have

their metabolism (Porra et al., 1997) and applications in oceanography (Jeffrey, 1997). Comprehensive data and graphic sheets were compiled for most important chlorophylls and carotenoids present in marine algae (Jeffrey and Vesk, 1997). Chlorophylls are more susceptible to biological breakdown than the carotenoids (Porra et al., 1997) and are explained by many workers (Brown et al., 1981, Scheer, 1991 and Kowalewska et al., 2004) and most of these breakdown products are easily detectable by regular pigment analysis. Chlorophyll a is a ubiquitous pigment and can be used as a global algal biomass indicator. It is present in all groups of photosynthetic organisms except some bacteria (Moss, 1968). Chl b was the next important pigment detected in low concentration.

In the present study, Chl a value was maximum during the POM 09 at S11 (39.62µg/L) which is a thickly populated semi urban area having sewage disposal and waste dumping taking place and it lead to eutrophication and lowest value was 0.20µg/L at S1 during PRE 09 which is a fresh water zone (riverine area). The variation in concentration of this pigment in the present study was generally associated with environmental factors, especially inflow of freshwater during rainy season, light and nutrient availability. Earlier studies revealed that mean Chl a concentration in the estuarine and coastal waters vary with respect to other aspects (Selveraj et al., 2003; Renjith, 2006). In the Cochin estuary, the Chl a content have been reported as 2 to 21µg/L (Nair et al., 1975), 4.93 to 8.93 µg/L (Selveraj et al., 2003) and 1 to 34.61 µg/L (Renjith et al, 2006), 2.75 to 17.97 µg/L (Aneeshkumar, 2009). The estimated Chl a value recorded in the present study showed comparatively lower values with the earlier reports (table 4.99). Observation of higher Chl content during premonsoon and postmonsoon seasons in the present study agree with the earlier

observations by Gopinathan (1972), Devessy and Bhattathiri, (1974) in Cochin estuary. Estimation of photosynthetic pigments of plankton of the Cochin backwaters has brought out contrasting results. Nair et al., (1975) have estimated an overall range of 1.5–18 mg m-3 for Chl a. The findings of Joseph and Pillai (1975) indicated that maximum Chl a concentration for pelagic flora occurs during monsoon, whereas for benthic microflora, the maximum were reported during premonsoon and monsoon (Sivadasan & Joseph, 1995). In this study, transparency and CO_2 showed highly significant positive correlation with Chl a supporting the highly productive nature of the system due to these factors during POM 08. Chl a showed significant negative correlation with Desmidaceae. The estimated average Chl a content was in good agreement with the previously reported works (Martin et al., 2012). The high biomass of Chl a in the study area are possibly due to the enrichment of nutrients by industrial and domestic activities (Jyothibabu et al. 2006; Madhu et al., 2007). The anthropogenic activities have lead to an increased production of chlorophyll a in the estuary. Moreover, the high organic productions are not transferred to the higher tropic level due to the lack of effective grazers, which leads to settling of the excess chlorophyll to the sediment (Jyothibabu et al., 2006).

Table 4.99 Previous studies on Chlorophyll a in Cochin backwater system.

Area	Chl a µg/L	Reference
Cochin	1.5 to 18	Nair et al., 1975
Surf Zone Cochin	8.35 to 15.64	Selveraj et al., 2003
Cochin estuary	4.93 to 8.85	Selveraj et al., 2003
Off Cochin	1.0 to 5.0	Gopinathan et al., 2001
Cochin Back water	1 to 34.6	Renjith et al., 2006
Cochin Back water	1.7 to 47.0	Madhu et al., 2007
Cochin Back water	2.75 to 17.97	Aneeshkumar, 2009
Cochin Back water	5 to 49	Martin et al., 2012
Cochin Back water	1.53 to 9.74	In the present study

Chlorophyll b, also exhibited the same trend, in the entire sampling sites with slight variations in some stations. Moderately higher concentration was observed at all stations in all seasons under study.

The environmental factors that strongly influence pigmental composition of phytoplankton are irradiance (Schlüter et al., 2000., Henriksen, 2002), Spectral distribution of light (Partensky et al., 1993), day length (Sakshang et al., 1986), diurnal cycle (Tukaj et al., 2003), nutrient status (Henriksen et al., 2002), iron concentration (Van Leeuwe et al., 1998), growth phase (Schlüter et al., 2000 and strain differences (Stolte et al., 2000; Zapata et al., 2000).

The amount of pigments and nutrients in the water column are the key factors for determining the biological productivity and potential resources. The transparency and the nutrients indicate the fertility of the water body for the enhancement of primary productivity and the availability of the photosynthetic pigments and phytoplankton. The peak production was coinciding with the periods of low nutrient concentration have been observed by Qasim, (1980) and Jagadeeshan, (1986) in Cochin back waters, Cuddalore, Uppanan back waters and Coleroon estuary and the same trend could be observed in the present study. Insignificant correlation between nutrients and primary production pointed out the fact that in spite of the higher concentration of available nutrients in water column; the productivity was restricted by factors like transparency and meteorological factors. Moreover nutrients available in the water column are not fully utilized by the phytoplankton.

Plankton particularly has been used as indicators of water quality (Palmer 1969; Stoermer and Yang, 1969). Copepods and other zooplankton groups and the larval forms of many bottom living and pelagic marine

animals appear to be herbivorous grazing on phytoplankton. Through all these ways plankton are very much beneficial but some of them cause deleterious effects on the ecosystem due to algal bloom (Martin et al., 2011).

Variability in plankton is enormous and is dependent on the changes in the environment. Thus with the changing environment it is only natural to expect the variations in the composition of plankton and this variability provides the only source of information about the dynamics of natural population of plankton. The numerical abundance of a species at a given locality in the ocean is the result of interaction between a number of factors like water transport, change in temperature, availability of food, diurnal vertical migration, rate of production, age of the ecosystem and the survival.

The study of the zooplankton biomass is helpful to determine the potential fishery resource of a nation and the relative fertility of the water bodies. So regular monitoring of plankton is necessary to know the fishery potential. Because of their worldwide distribution, abundance and dominance, copepods are most significant secondary producers (Gaonkar et al., 2010). The zooplanktons are considered to be the cattles of the sea. They are the grazers feeding either on the phytoplanktons (herbivorous) or on other zooplanktons (carnivorous). In that way they actually contribute to the transfer of energy to other organisms in the oceans. Being the primary consumer, they have a key role in the sustenance of higher forms of life in the oceans. In many cases the plankton serves as indicator organisms for water quality, temperature profile and nutrient richness of the water column.

The ecological role of an organism is largely determined by its position and significance in the food web. The zooplanktons are important in marine food chain as it plays a dual role as phytoplankton consumers and contributors to the higher tropic level. Primary trophic level can be directly connected to the next level or through the animal plankton or zooplankton. Zooplanktons are primary consumers, simply the grazers on phytoplankton in pelagic ecosystem models. Zooplanktons are secondary producers, so to assess the biomass at this trophic level to determine the rates of secondary production.

The potential cause of higher production of fishes is basically due to the higher plankton abundance which is determined by many other factors such as physical and chemical parameters of the marine environment. Species diversity can be defined as the effective number of different species that are represented in a collection of individuals (a dataset). Species diversity consists of two components, species richness and species evenness. Species richness is a simple count of species, whereas species evenness quantifies how equal the abundances of the species. The species diversity is the total number of species present at a time in an ecosystem in the same time. In the environment which is having normal ecological condition will have more species diversity than that in extreme climatic condition. The species diversity of holoplankton mainly depends on temperature, salinity, DO and water currents and other hydrographical parameters. Thus the highest diversity is found in tropical and subtropical regions and the lowest in the extreme environment such as polar zones and brackish water areas.

Majority of the aquatic feeds constitutes plankton community. Zooplankton serves as the primary source of food for the larval stages as

well as adults of many fishes and aquatic organisms of economic importance. Study of species composition is important or some species are useful indicators of the health of the environment. Presence of certain zooplanktons indicates the water quality or degradation of the environment. The fishery production of any aquatic system mainly depends on the magnitude of phytoplankton as well as zooplankton production and their interrelationship (Prasad, 1969). The secondary production in an area can be calculated by analyzing the zooplankton production. A gradual increase in the total density of zooplankton population played significant role in the trophic food web observed during PRE 09 and PRE 10. Copepods were found to be the predominant groups showed strong seasonality in abundance and diversity suggesting their dominant role in all seasons which is in accordance with the earlier studies (Madhupratap,1978, Madhu et al., 2006). Zooplanktons were abundant during high saline premonsoon period and was supported by Silas and Pillai, 1975. The salinity acts as a limiting factor in the distribution of living organisms and its variation caused by dilution and evaporation which influence the faunal composition and distribution of the coastal ecosystems (Chandramohan and Sreenivas, 1998). Experimental studies in CBW by Jyothibabu et al., (2006) have revealed that approximately 43% of phytoplankton biomass was consumed by microzooplankton per day. The increased grazing of phytoplankton by microzooplankton could be one of the reasons for a relatively low level of Chl a during PRE 09 eventhough the environmental conditions remained favourable for phytoplankton growth.

In the present investigation, copepods were present throughout year in the plankton samples and formed the dominant component of the crustacean holoplankton. Copepods like *Acartia centura, Acartia spinicauda,*

Acartia bowmani, Acartia southwelli, Acartia pacifica, Acartia plumosa are present during all seasons and disappear during rainy season.The intimate relationships of Cladocera with fisheries were reported by Yahia et al., (2004). It was observed that the percentage incidence of cladocerans was 0.09 to 4.92%. The dominance of cladocerans were in the order POM 09>POM 08>MON 09>PRE 10>PRE 09. The dominance of cladocerans during postmonsoon period was reported earlier (Bhat 1979, Patil, 1987) in Nethravathi-Gurupur estuary. The percentage incidence of copepods, which are vital components of secondary producers, was between 79.38 to 97.30% and the percentage was maximum during PRE 09.

The maximum percentage incidence of rotifer was during MON 09. Pattil, (2002) attributed the dominance of rotifer to the absence of predator fishes. Unlike crustaceans, rotifers feed on bacteria and detritus, which make them less dependent of autotrophs (Ruttner Kolisko, 1974). Increase in rotifers during MON 09 was noticed in the study eventhough the phytoplankton and primary production was minimum as rotifers are less dependent on phytoplankton (Castro et al., 2005). During PRE 09 and PRE 10 another peak was observed due to the migration of some migrant species to the estuary.

The faunal composition showed fall in density during MON 09 and gradual repopulation leads to another peak during POM 08 and POM 09. The fish eggs were maximum during POM 09 and POM 08. The zooplankton distribution in the back waters suggests that the salinity is the major limiting factior controlling their abundance. All groups showed remarkable seasonal distribution with respect to changes in salinity and other environmental factors. The present investigation is in good agreement with the earlier investigation, which states that the population density of

zooplankton in the estuary is no way limited by primary production, which through out the year far exceeds the consumption by zooplankton (Menon et al., 2000). According to Qasim et al., (1969), the primary production in CBW was maximum at the surface during monsoon and post monsoon seasons, while during premonsoon season, it covers subsurface layers too. It has been reported that the primary production in the estuary exceeds zooplankton several folds (Atkinson and Dhreeve, 1995, Madhu et al., 2007). In the present study, the action of tidal currents and rainfall are most important.

Fish landing depends on environmental and the socioeconomic factors and fishery dependent factors such as fishing effort, type of craft, gear and mesh size. Rapid changes in the environment due to uncontrolled human interventions lead to depletion of the rich fishery resources of Vembanad Lake. The well being of large community depends upon these resources for livelihood and nutritional needs are currently under grave threat. It is necessary to assess the status of fishery with the intention of creating awareness about this situation.

Algal production acts as a biostimulation for the enhancement of fish production. Aquatic systems, especially the backwaters, are storehouses of cheap protein rich diet. Aquatic life is continuously under the threat of various stressors of environment which include exposure to contaminants, unfavourable temperatures, water velocities, sediment loads, hypoxia, reduced food availability etc. These factors individually or collectively, can impose considerable stress on the physiological system of the aquatic organisms and can lead to reduced growth, impaired reproduction and susceptibility to diseases and reduce capacity to tolerate subsequent stress. Study of fish fauna helps us to obtain a deeper insight

into casual relationship between stress and its effects at the community levels. Fishes are affected by these toxic substances which lead to biomagnification. The effluents discharged from industries resulted in mass destruction of aquatic organisms in many coastal environments (Cognetti, 1999, Benovic et al., 2000). Seven landing centres adjacent to sampling sites were studied and monthly data were collected for seasonal comparison for fishes.

Some fishes are extensively zooplankton feeders and therefore the abundance is directly linked to the presence of secondary producers. The success and failure of fishery particularly, pelagic fishes depends on the availability of plankton. The overall niches are governed by the feeding spectrum and feeding types among the zooplankton, some are detritivorous some are filter feeders feeding in different size spectrum of phytoplankton organic detritus as well as on nano and micro zooplankton. The functioning of the food webs depends on the balance between bottom up and top down control. Bottom up is the resource driver control. The top down control is the predator control.

The temperature fluctuations from premonsoon to monsoon are significant and it exerts some effects on the seasonal distribution and abundance of stenohaline fishes which migrate completely from the estuary during south west monsoon (Menon et al., (2000), Kurup and Samuel, (1985a). Annual landings (1988-1989) of fishery resources form Vembanad lake was 7200 tonnes of which fishes constituted 3297 tonnes, marine prawns 3499 tonnes, freshwater prawns 118 tonnes and crab 284 tones (KSSP, 1992). Kurup and Samuel, (1987) reported that among 115 species of fishes recorded in the Vembanad lake, 77 preferred high saline areas, but during 1987 these autors recorded 103 species associated with salinity.

According to Pramodbabu(2007) the total landings of crustaceans was 42762 kg from Thanneermukkom to Thottappally. The present study was carried out from Karippadom to Kalamassery (near FACT) and the yield of fish from the entire study area was 260816 kg and crustaceans were 50816 kg. The study of fishes from the different areas of the CBW explained that high landings were always recorded from high saline regions.

The present study revealed that there is the decline in fish species that might be due to destructive methods of fishing that lead to the destruction of breeding grounds (KSSP, 1992). Pollution due to the dumping of waste water form industries and domestic sewage situated on the banks of CBW (KWBSP, 1989), dredging of lime shells, lack of salinity intrusion and disease outbreak etc. are responsible for the reduction in fishery potential. This study was helpful to reveal the present status of this ecosystem which has become extremely crucial for exploiting the brackish water fishery resources. The annual production of fishes in Kerala is unsatisfactory and the current landings from waterbodies are below the protein requirements of people in Kerala. So under these circumstances, the judicious exploitation of water resources in a scientific manner is a necessity to tackle the deficit food situation in the country.

With the onset of south west monsoon, salinity gets reduced drastically in most of the stations. This will leads to the reduction in the distribution and occurrence of fishes from the study area during MON 09 (Kurup and Samuel, 1987). Another possible reason for the decline in fishery resources is due to loss of nursery grounds of the area. The anthropogenic stress and pollution to the water bodies are causing decline in fishery. The abundance and distribution of fishes in the CBW is based on the prevailing salinity and annual rainfall (Kurup and Samuel, 1985).

The maximum landings recorded in the present study were obtained during POM 08 and POM 09 the landings were 65903 kg and 67256 kg respectively.

Gut content analysis imparts important insight into fish feeding patterns and quantitative assessment of food habits. Accurate description of fish diets and feeding habits also provide the basis for understanding trophic interactions in aquatic food webs. Diets of fishes provide a combination of many important ecological components that included habitat use, energy intake, inter and intra specific interactions (Bindu and Padmakumar, 2008). Assessment of food and feeding habits of the fish helps us to determine its niche in the ecosystem and its preferred food items. It tells us how much the food spectrum of a fish overlaps with that of the coexisting fishes. The analysis of food components in the gut of a species from different ecosystem provides the information that how much that fish is flexible in feeding on different types of food items. Feeding habit is one of the primary criteria in deciding on transplantation of species to new ecosystems with least possible damage or competition to the native fauna, or its utility in overall production enhancement. In the present study, relative length of gut ranged between 1.16 and 6.87cm indicating omnivorous feeding (Bindu and Padmakumar, 2008).

Chlorophyceae which formed the primary food of *Etroplus suratensis* were represented by *Spirogyra, Oscillatoria, Lyngbia and Fragillaria*. Diatoms, *Nitzschia, Pleurosigma* and *Navicula* were observed in the gut contents during PRE 09. Detritus, filamentous algae and semidigested materials were present as a major food constituent throughout the year. The large quantities of detritus in the diet of *E. suratensis* in the CBW, was observed in the study, pointed out the feeding behaviour of this

fish which includes detritus. In freshwater systems, detritus play a significant role in the diet of fishes (Bowen, 1981; Keshava et al., 1988). The seasonal change in the abundance of food items of *E. suratensis* is a reflection of the availability of food in the environment (Bindu and Padmakumar, 2008). During PRE 09 and PRE 10 Chlorophyceae dominated the food items, whereas detritus comprising of decayed vegetable matter formed the major item during POM 08 and POM 09. Low utilisation of planktonic food during MON 09 may be due to its poor availability owing to high turbidity resulting in low phytoplankton production. The present results agreed with the findings of Kurup, (1993) who reported that sizeable reduction in the population of diatoms and algae during monsoon months is a characteristic phenomenon in these backwaters. According to Bhatnagar and Karamchandani, (1970), the feeding intensity and diet composition of fish are apparently linked to the availability of food in the habitat. In the present study along with phytoplankton, the gut contains a variety of food items such as copepods, cladocerans, insects and worms during POM 09 (Jhingran and Natarajan, 1969)

In *Oreochromis mossambicus* the percentage occurrence of *Lyngbya* spp. *Anabaena* spp, and *Merismopedia* sp. show an increase in percentage occurrence with *Navicula sp., Melosira* sp., *Nirzschia* sp., *Anabaena sp., Microcystis sp., Merismopedia* sp., *Pediastrum* sp., *Oscillatoria* sp., *Scenedesmus* sp., *Lyngbya* sp., *Saurastrum* sp., *Cymbella* sp., *Synedra* sp., *Ceratium* sp., *Chlorella* sp., were observed in the gut contents during POM 09 and POM 10. In the case of *Oreochromis mossambicus* the most preferred food items observed during PRE 10 were *Nitzschia, Lyngbya, Microcystis aeruginosa* and *Pediastrum simplex, Melosira* sp, *Navicula* sp.

Among the zooplankton, the Cladocera and the Rotifera had low to moderate percentage in the gut. Some of the food items consumed showed an increasing trend with fish size.

Fishes of all size categories were found to be phytoplanktivores. A total of 26 microphytoplankton species were observed in the stomach contents (15 species of Chlorophyceae, 11 species of Bacillariophyceae, together with a few rotifers and some organic material). In terms of cell numbers, the overall composition of the diet was 70% Chlorophyceae, 21% Bacillariophyceae, 6% organic matter and semidigested small fishes. Neither diet composition nor stomach fullness varied with fish size. However, fish had relatively gorged stomachs, with higher proportions of Chlorophyceae, Bacillariophyceae, during MON 09. Long coiled intestine suggest the species is largely herbivorous, consuming planktonic algae and aquatic plants (Hensley and Courtenay 1980; Gonzales and Moran, 2005). Most of the fish species can be placed in the opportunistic omnivore category (Boschung and Mayden, 2004).

Proximate composition, were determined in some widely consumed fish species obtained from the CBW. The results obtained in the present study indicated that biological differences existing in fish species can influence the values to be set for the standards and composition (Guner et al., 1999). The data on proximate composition help the nutritionist, dieticians and consumers to estimate the intake of the principal nutrient in the human diet, to calculate energy values, contents of the diet and was useful to determine the difference in the nutrient value seasonally. The variation was observed from species to species. Increase in the moisture content during seasons other than MON 09 was coincided with increase in salinity. Shekhar et al., (2004) reported that moisture content differ according to season when

other constituents were low. The low values of carbohydrates recorded in the present study could be because glycogens in many marine animals do not contribute much to the reserves in the body (Jayasree et al., 1994). Ramaiyan et al., (1976) reported similar findings in 11 species of Clupeids. Phillips et al., (1967) reported that carbohydrates are utilized for energy in trout, thus sparing protein for building of the body.

The average lipid content in the fishes taken for study was maximum during PRE 09 (average: 17.14±1.46%) ie. during spawning season. Depending upon the level of lipids in the fish muscles, they are classified into three categories eg. fat fish with more than 8 % average fat content, average fat fish with fat content range between 1 % and 8 % and lean fish with fat content less than 1 % (Srivastava, 1999). In the present study, all fishes taken were fat fishes during PRE 09. In all other seasons they were included in the category entitled average fat fish. Lowest protein content was recorded during MON 09 and highest value was recorded in an almost steady state during other seasons in the following order, POM 08> PRE 09 > PRE 1O> POM 09 which couples with high feeding intensity observed by the gorged conditions of stomach.

The percentage ash content in the fishes analyzed is an indication of ample mineral content in fish. The proximate composition of a species helps to assess its nutritional and edible value compared to other species. The chemical compositions of marine organisms are quite close to that of land animals. The principal constituents are water (66 to 84 %), protein (15 to 24 %), lipids (0.1 to 22 %), minerals (0.8 to 2 %) and sugar is in very low quantity (0.3%) at maximum value in fishes (FAO, 1998). The importance of the seasonal variation of proximate composition is complex and it is quite difficult to distinguish the effects of factors in the

biochemical composition of fish (Medford and Mackay, 1978). According to Stansby, (1962), the biochemical constituents are influenced by metabolism, mobility of the fish and geographical area. In the present investigation variations were obtained in the biochemical composition of the fish muscles of different fishes under study, which may be the result of the above processes. The present findings describe the major nutritional composition of different fishes.

The range of values for these constituents in the edible portion of common fish species from Indian coastal waters are: moisture (65-90%), protein (10-22%), fat (1-20%), mineral (0.5- 5%) (source: CIFT library)

Minor quantities of carbohydrates, vitamins, nucleotides, other non-protein nitrogenous compounds etc. are also present and these play vital roles in maintaining the system and thus are essential for growth and development of the organisms.

Fishes are very good sources of protein, providing an important complement to the predominantly carbohydrate-based staple diet of many people in Kerala. The study of the proximate composition of *Oreochromis mossambicus, Mugil cephalus, Channa maruleus, Etroplus suratensis, Etroplus maculeatus, Arius arius, Anabas testudineus* revealed that they are rich in protein and have average to high lipid contents. The present investigation revealed that these fish species are good sources of minerals. It could also be inferred that the mineral elemental levels of each species is a function of the availability and preferential accumulation. Differences in biochemical composition of fish may also occur within the same species depending upon the fishing ground, fishing season, age and sex of the

individual and reproductive status. Spawning cycle and food supplies are the main factors responsible for this variation (Love, 1980).

Statistical Analysis

Correlation

The correlation matrix for the various parameters estimated in water coloumn and phytoplankton are depicted in tables 4.100 to 4.104. In the present study during POM 08, DO showed highly significant negative correlation with Chlorophyceae due to less abundance of this species, while CO_2 exhibited significant negative correlation pointing towards its decrease in concentration caused by photosynthetic uptake. NO_2^- showed highly significant negative correlation with Chlorophyceae while salinity displayed significant positive correlation with Chlorophyceae which inferred the fact that these species flourish in optimum saline habitats. Chlorophyceae exhibited significant negative correlation with transparency and salinity (POM 09). Chlorophyceae showed significant negative correlation with Bacillariophyceae, Myxophyceae and iron (POM 09). The negative correlation with iron implied the uptake of this nutrient metal. Chlorophyceae recorded highly significant negative correlation with ammonia, signaling to the increased uptake of uptake of ammonia from water column for protein synthesis. In the present study, Chlorophyceae showed highly significant negative correlation with Dinophyceae and Myxophyceae and significant negative correlation with Cyanobacteria. Chlorophyceae showed significant positive correlation with silicate (PRE 10).

For Convenience the following abbreviations are used for phytoplankton groups in correlation tables. CP- Chlorophyceae, BP-Bacillariophyceae, DP-Dinophyceae, MP-Myxophyceae, SF-Silicoflagellates, CB-Cyanobacteria, ZP – Zygnematophyceae, DD-Desmidaceae

Table 4.100 Correlation matrix for variables estimated during POM 08

POM08	DO	CO2	NO3	NO2	PO4	SiO4	Alk	Trans	Temp	pH	Salinity	NH4	Iron	BOD	PP	Chl a	Chlb	Pheo	CP	BP	DP	MP	SF	CB	ZP	DD
DO	1	0.36 (*)	0.20	0.44 (*)	-0.15	0.65 (**)	-0.62 (**)	0.38 (*)	0.43 (*)	-0.60 (**)	-0.76 (**)	0.02	-0.02	0.06	0.14	0.26	0.23	0.27	-0.55 (**)	-0.29	0.13	0.2	-0.04	0.57 (**)	0.49 (**)	-0.3
CO2	0.36 (*)	1	0.15	0.35	-0.01	0.25	-0.24	0.5 2(**)	0.23	-0.02	-0.33	-0.03	0.26	0.59 (**)	0.36	0.48 (**)	0.14	0.21	-0.40 (*)	-0.28	-0.34	0.33	-0.11	0.16	-0.13	-0.21
NO3	0.20	0.15	1	0.23	-0.13	0.01	-0.10	0.09	0.39 (*)	-0.16	-0.22	-0.09	0.36 (*)	0.04	-0.34	-0.21	0.07	0.84 (**)	-0.15	-0.13	0.04	-0.03	-0.16	-0.14	0.21	-0.01
NO2	0.44 (*)	0.35	0.23	1	0.22	0.26	-0.21	0.40 (*)	0.16	-0.32	-0.40 (*)	0.41 (*)	0.13	0.22	0.07	0.45 (*)	0.16	0.35	-0.47 (**)	-0.28	-0.17	0.14	0.06	-0.01	0.28	-0.13
PO4	-0.15	-0.01	-0.13	0.22	1	-0.05	0.20	-0.13	-0.27	0.05	0.09	0.46 (*)	0.07	0.03	0.02	0.04	0.14	0.10	-0.02	-0.19	-0.30	0.04	-0.14	-0.31	-0.16	-0.08
SiO4	0.65 (**)	0.25	0.01	0.26	-0.05	1	-0.79 (**)	0.11	0.51 (**)	-0.75 (**)	-0.84 (**)	0.28	0.09	0.05	-0.06	0.13	0.18	0.07	-0.24	-0.52 (**)	0.24	0.22	-0.32	0.40 (*)	0.52 (**)	0.04
Alk	-0.62 (**)	-0.24	-0.10	-0.21	0.20	-0.79 (**)	1	-0.03	-0.45 (*)	0.64 (**)	0.89 (**)	-0.16	0.00	0.06	0.04	-0.15	-0.14	-0.11	0.20	0.55 (**)	-0.40 (*)	0.10	0.26	-0.45 (*)	-0.63 (**)	0.21
Trans	0.38 (*)	0.52 (**)	0.09	0.41 (*)	-0.14	0.12	-0.03	1	0.28	0.04	-0.27	-0.10	0.05	0.65 (**)	0.37 (*)	0.50 (**)	0.29	0.26	-0.20	0.05	-0.17	0.30	0.10	0.40 (*)	0.04	-0.48 (**)
Temp	0.43 (*)	0.23	0.39 (*)	0.16	-0.27	0.51 (**)	-0.45 (*)	0.28	1	-0.31	-0.59 (**)	0.02	0.21	0.181	-0.06	-0.12	0.40 (*)	0.38 (*)	-0.27	-0.39 (*)	0.34	0.23	-0.12	0.39 (*)	0.35	0.10
pH	-0.60 (**)	-0.02	-0.16	-0.32	0.05	-0.75 (**)	0.64 (**)	0.04	-0.31	1	0.70 (**)	-0.28	-0.10	0.11	0.05	0.04	-0.16	-0.20	0.21	0.26	-0.15	-0.21	0.14	-0.26	-0.61 (**)	-0.09
Salinity	-0.76 (**)	-0.33	-0.22	-0.40 (*)	0.09	-0.84 (**)	0.89 (**)	-0.27	-0.59 (**)	0.70 (**)	1	-0.26	-0.13	-0.13	0.08	-0.14	-0.33	-0.31	0.38 (*)	0.52 (**)	-0.29	-0.07	0.31	-0.53 (**)	-0.68 (**)	0.28
NH4	0.02	-0.03	-0.09	0.41 (*)	0.46 (*)	0.28	-0.16	-0.10	0.02	-0.28	-0.26	1	-0.01	0.06	-0.19	0.00	0.43 (*)	0.31	-0.21	-0.46 (*)	-0.24	-0.10	-0.24	-0.14	-0.07	0.0
Iron	-0.02	0.26	0.36 (*)	0.13	0.07	0.09	0.00	0.05	0.21	-0.10	-0.13	-0.01	1	0.09	-0.26	-0.12	0.145	0.35	-0.21	-0.16	0.02	0.02	-0.14	-0.25	0.13	0.11
BOD	0.06	0.59 (**)	0.04	0.22	0.03	0.05	0.06	0.65 (**)	0.18	0.11	-0.13	0.06	0.09	1	0.31	0.36	0.38 (*)	0.23	-0.26	-0.09	0.42 (*)	0.31	-0.15	0.19	-0.33	-0.3
PP	0.14	0.36	-0.34	0.07	0.02	-0.06	0.04	0.37 (*)	-0.07	0.05	0.08	-0.19	-0.26	0.31	1	0.51 (**)	0.07	-0.27	0.06	0.11	-0.28	0.35	0.42 (*)	0.24	-0.25	-0.14
Chl a	0.26	0.48 (**)	-0.21	0.45 (*)	0.04	0.13	-0.15	0.50 (**)	-0.12	0.04	-0.14	0.00	-0.12	0.36	0.51 (**)	1	-0.07	-0.16	-0.12	-0.10	-0.05	0.08	0.15	0.25	0.01	-0.43 (*)
Chlb	0.23	0.14	0.07	0.16	0.14	0.18	-0.14	0.29	0.40 (*)	-0.16	-0.33	0.43 (*)	0.15	0.38 (*)	0.07	-0.07	1	0.38 (*)	-0.47 (**)	-0.24	-0.15	-0.08	-0.09	0.22	-0.13	-0.21
Pheo	0.27	0.21	0.84(**)	0.35	0.10	0.07	-0.11	0.26	0.38 (*)	-0.20	-0.31	0.31	0.35	0.23	-0.27	-0.16	0.38 (*)	1	-0.27	-0.31	-0.13	-0.01	-0.26	-0.06	0.07	-0.17
CP	-0.55 (**)	-0.40 (*)	-0.15	-0.47 (**)	-0.02	-0.24	0.20	-0.20	-0.27	0.21	0.38 (*)	-0.21	-0.21	-0.26	0.06	-0.12	-0.47 (**)	-0.27	1.00	0.29	0.08	-0.13	-0.11	-0.12	-0.07	0.04
BP	-0.29	-0.28	-0.13	-0.28	-0.19	-0.52 (**)	0.55 (**)	0.05	-0.39 (*)	0.26	0.52 (**)	-0.46 (*)	-0.16	-0.09	0.11	-0.10	-0.24	-0.31	0.29	1	-0.07	-0.08	0.28	-0.10	-0.13	-0.11
DP	0.13	-0.34	0.04	-0.17	-0.30	0.24	-0.40 (*)	-0.17	0.34	-0.15	-0.29	-0.24	0.02	-0.42 (*)	-0.28	-0.05	-0.15	-0.13	0.08	-0.07	1	-0.31	0.26	0.39 (*)	0.57 (**)	0.01
MP	0.21	0.33	-0.03	0.14	0.04	0.22	0.10	0.30	0.23	-0.21	-0.07	-0.10	0.02	0.31	0.35	0.08	-0.08	-0.01	-0.13	-0.08	-0.31	1	0.17	0.28	-0.10	0.32
SF	-0.04	-0.11	-0.16	0.06	-0.14	-0.32	0.26	0.10	-0.12	0.14	0.31	-0.24	-0.14	-0.15	0.42 (*)	0.15	-0.09	-0.26	-0.11	0.28	0.26	0.17	1	0.09	-0.07	0.21
CB	0.57 (**)	0.16	-0.14	-0.01	-0.31	0.40 (*)	-0.45 (*)	0.40 (*)	0.40 (*)	-0.26	-0.53 (**)	-0.14	-0.25	0.19	0.24	0.25	0.22	-0.06	-0.12	-0.10	0.39 (*)	0.28	0.09	1	0.28	-0.39 (*)
ZP	0.48 (**)	-0.13	0.21	0.28	-0.16	0.52 (**)	-0.63 (**)	0.04	0.35	-0.61 (**)	-0.68 (**)	-0.07	0.13	-0.33	-0.25	0.01	-0.13	0.07	-0.07	-0.13	0.57 (**)	-0.10	-0.07	0.28	1	-0.19
DD	-0.30	-0.21	-0.01	-0.13	-0.08	0.04	0.21	-0.48 (**)	0.10	-0.09	0.28	0.03	0.11	-0.3	-0.14	-0.43 (*)	-0.21	-0.17	0.04	-0.11	0.01	0.32	0.21	-0.39 (*)	-0.19	1

Table 4.101 Correlation matrix for variables estimated during PRE 09

PRE09	DO	CO2	NO3	NO2	PO4	SiO4	Alk	Trans	Temp	pH	Salinity	NH4	Iron	BOD	PP	Chl a	Chlb	Pheo	CP	BP	DP	MP	SF	CB	ZP	DD
DO	1	0.13	-0.22	0.03	-0.39 (*)	0.26	-0.30	-0.05	-0.27	-0.30	-0.51 (**)	0.27	-0.50 (**)	0.24	0.24	-0.16	-0.04	-0.1	0.32	0.13	-0.37(*)	-0.31	0.13	0.30	-0.26	(o)
CO2	0.13	1	-0.23	-0.29	0.26	-0.19	0.18	-0.11	0.23	-0.37 (*)	0.09	0.28	0.17	0.03	-0.32	-0.17	-0.33	-0.29	0.17	-0.08	0.1	-0.11	0.24	-0.08	-0.07	(o)
NO3	-0.22	-0.23	1	-0.04	-0.06	0.10	-0.10	-0.02	-0.09	-0.09	-0.07	-0.18	-0.39 (*)	0.29	-0.07	0.12	0.11	0.04	0.17	0.53 (**)	0.27	0.65 (**)	-0.46 (*)	-0.06	0.27	(o)
NO2	0.03	-0.29	-0.04	1	0.10	0.04	0.07	0.33	0.02	0.31	0.17	0.02	0.16	-0.08	0.41 (*)	0.14	0.43 (*)	0.28	-0.38 (*)	0.26	0.12	-0.12	-0.19 (**)	0.50 (**)	0.54 (**)	(o)
PO4	-0.39 (*)	0.26	-0.06	0.10	1	-0.28	0.27	0.27	0.09	-0.13	0.48 (**)	-0.13	0.56 (**)	-0.33	-0.17	0.23	-0.03	-0.07	-0.14	-0.05	0.45(*)	0.13	0.42 (*)	-0.19	0.16	(o)
SiO4	0.26	-0.19	0.10	0.04	-0.28	1	0.05	-0.45 (*)	-0.18	0.10	-0.53 (**)	0.26	-0.28	0.17	-0.04	0.07	0.30	0.32	0.27	0.09	-0.05	-0.08	-0.08	0.03	-0.17	(o)
Alk	-0.30	0.18	-0.10	0.07	0.27	0.05	1	0.04	0.17	0.19	0.59 (**)	0.00	0.55 (**)	-0.49 (**)	-0.21	0.18	0.10	-0.01	0.15	0.03	0.27	0.00	0.13	-0.02	0.14	(o)
Trans	-0.05	-0.11	-0.02	0.33	0.27	-0.45 (*)	0.04	1	0.01	-0.22	0.64 (**)	-0.24	0.24	-0.19	0.21	0.29	0.01	-0.10	-0.44 (*)	0.23	-0.06	-0.02	0.18	0.04	0.41 (*)	(o)
Temp	-0.27	0.23	-0.09	0.02	0.09	-0.18	0.17	0.01	1	0.11	0.16	-0.03	0.17	0.19	-0.03	-0.23	0.02	-0.02	-0.17	-0.03	-0.12	-0.21	0.00	0.15	0.40 (*)	(o)
pH	-0.30	-0.37(*)	-0.09	0.31	-0.13	0.10	0.19	-0.22	0.11	1	-0.08	-0.16	0.17	-0.31	0.24	-0.08	0.34	0.34	0.09	0.09	0.08	-0.08	-0.27	0.25	0.28	(o)
Salinity	-0.51 (**)	0.09	-0.07	0.17	0.48 (**)	-0.53 (**)	0.59 (**)	0.64 (**)	0.16	-0.08	1	-0.23 (**)	0.65 (**)	-0.53 (**)	-0.03 (**)	0.36 (*)	-0.06	-0.14 (*)	-0.41 (*)	0.05	0.26	0.11	0.14	-0.18	0.36	(o)
NH4	0.27	0.28	-0.18	0.02	-0.13 (**)	0.26	0.00	-0.24 (**)	-0.03	-0.16	-0.23	1	-0.12	0.20	-0.21	-0.17	-0.07	-0.06	0.103	-0.21	-0.35	-0.25	0.04	0.13	-0.20	(o)
Iron	-0.50 (**)	0.17	-0.38(*)	0.16	0.56 (**)	-0.28	0.55 (**)	0.24	0.17	0.17	0.65 (**)	-0.12	1	-0.61 (**)	-0.14	0.05	-0.09	-0.14	-0.20	-0.39	0.42 (*)	-0.16	0.29	-0.14	0.19	(o)
BOD	0.24	0.03	0.29	-0.08	-0.33	0.17	-0.49 (**)	-0.19	0.19	-0.31	-0.53 (**)	0.20	-0.61 (**)	1	0.10	-0.28	0.10	0.20	-0.02	0.03	-0.28	0.05	-0.27	0.08	-0.05	(o)
PP	0.24	-0.32	-0.07	0.41 (*)	-0.17	-0.04	-0.21	0.21	0.29	0.24	-0.03	-0.21	-0.14	0.10	1	0.29	0.37 (*)	0.32	-0.08	0.28	-0.04	-0.09	-0.30	0.51 (**)	0.33	(o)
Chl a	-0.16	-0.17	0.12	0.14	0.23	0.07	0.18	0.29	0.17	-0.08	0.36 (*)	-0.17	0.05	-0.28	0.29	1	0.35	0.35	-0.14	0.25	0.37 (*)	0.04	-0.06	-0.01	0.30	(o)
Chlb	-0.04	-0.33	0.11	0.43 (*)	-0.03	0.30	0.10	0.01	0.02	0.34	-0.06	-0.07	-0.09	0.10	0.37 (*)	0.35	1	0.91 (**)	-0.08	0.28	0.19	0.02	-0.25	0.1	0.37 (*)	(o)
Pheo	-0.10	-0.29	0.04	0.28	-0.07	0.32	-0.01	-0.10	-0.02	0.34	-0.14	-0.06	-0.14	0.20	0.32	0.35	0.91 (**)	1	-0.10	0.17	0.12	0.00	-0.35	-0.03	0.21	(o)
CP	0.32	0.17	0.17	-0.38 (*)	-0.14	0.27	0.15	-0.44 (*)	-0.17	0.09	-0.41 (*)	0.10	-0.20	-0.02	-0.08	-0.14	-0.08	-0.10	1	0.29	-0.02	0.12	0.02	0.11	-0.31	(o)
BP	0.13	-0.08	0.53(**)	0.26	-0.05	0.09	0.03	0.23	-0.03	0.09	0.05	-0.21	-0.30	0.03	0.28	0.25	0.28	0.17	0.20	1	0.22	0.57 (**)	-0.49 (**)	0.17	0.44 (*)	(o)
DP	-0.37 (*)	0.1	0.27	0.12	0.45 (*)	-0.05	0.27	-0.06	-0.12	0.08	0.26	-0.35	0.42 (*)	-0.28	-0.04	0.37 (*)	0.19	0.12	-0.02	0.22	1	0.29	-0.07	-0.12	0.35	(o)
MP	-0.31	-0.11	0.65(**)	-0.12	0.13	-0.08	0.00	-0.02	-0.21	-0.08	0.11	-0.25	-0.16	0.05	-0.09	0.04	0.02	0.00	0.12	0.57 (**)	0.29	1	-0.34	-0.33	-0.10	(o)
SF	0.13	0.24	-0.46(*)	-0.19	0.42 (*)	-0.08	0.13	0.18	0.00	-0.27	0.14	0.04	0.29	-0.27	-0.30	-0.06	-0.25	-0.35	0.02	-0.49 (**)	-0.07	-0.34	1	-0.07	-0.29	(o)
CB	0.30	-0.08	-0.06	0.50 (**)	-0.19	0.03	-0.02	0.04	0.15	0.25	-0.18	0.13	-0.14	0.08	0.51 (**)	-0.01	0.1	-0.03	0.11	0.17	-0.12	-0.33	-0.07	1	0.40 (*)	(o)
ZP	-0.26	-0.07	0.27	0.54 (**)	0.16	-0.17	0.14	0.41 (*)	0.40 (*)	0.28	0.36	-0.20	0.19	-0.05	0.33	0.30	0.37 (*)	0.21	-0.31	0.44 (*)	0.35	-0.10	-0.29	0.40 (*)	1	(o)
DD	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)

Table 4.102 Correlation matrix for variables estimated during MON 09

MON09	DO	CO2	NO3	NO2	PO4	SiO4	Alk	Trans	Temp	pH	Salinity	NH4	Iron	BOD	PP	Chl a	Chlb	Pheo	CP	BP	DP	MP	SF	CB	ZP	DD
DO	1.00	0.26	0.11	-0.32	-0.27	-0.17	0.07	0.08	0.45 (*)	0.00	-0.21	-0.16	-0.70 (**)	-0.35	-0.11	0.24	-0.12	-0.05	-0.06	-0.09	0.38 (*)	0.41 (*)	0.19	-0.13	-0.36	.(a)
CO2	0.26	1.00	0.02	0.23	0.07	-0.01	0.07	-0.47 (**)	-0.22	0.22	-0.26	-0.15	-0.18	-0.15	0.12	-0.17	-0.07	-0.10	0.04	0.23	-0.02	0.02	0.08	0.15	0.04	.(a)
NO3	0.11	0.02	1.00	-0.24	-0.22	-0.28	-0.06	-0.39 (*)	0.25	-0.01	-0.09	-0.22	-0.25	-0.22	-0.24	-0.10	-0.12	-0.16	-0.03	-0.17	0.10	0.17	-0.01	-0.07	-0.08	.(a)
NO2	-0.32	0.23	-0.24	1.00	0.40 (*)	-0.03	0.50 (**)	0.20	-0.31	-0.12	0.28	0.46 (*)	0.13	0.06	0.01	-0.19	0.44 (*)	-0.13	-0.12	-0.07	0.10	0.02	-0.12	-0.12	0.00	.(a)
PO4	-0.27	0.07	-0.22	0.40 (*)	1.00	0.31	0.45 (*)	-0.12	0.16	-0.22	0.27	0.28	0.03	-0.18	0.06	-0.28	0.24	0.00	-0.04	0.11	-0.37 (*)	-0.19	0.01	-0.28	0.03	.(a)
SiO4	-0.17	-0.01	-0.28	-0.03	0.31	1.00	-0.15	0.03	-0.20	0.23	-0.12	-0.19	0.23	0.16	0.32	0.11	0.03	0.19	-0.06	-0.05	-0.12	-0.07	-0.28	0.09	0.01	.(a)
Alk	0.07	0.07	-0.06	0.50 (**)	0.45 (*)	-0.15	1.00	-0.24	0.31	-0.41 (*)	0.59 (**)	0.53 (**)	-0.37 (*)	-0.48 (**)	-0.03	-0.15	0.31	-0.24	-0.02	-0.04	-0.06	0.07	-0.03	-0.26	-0.12	.(a)
Trans	-0.37 (*)	-0.47 (**)	-0.39 (*)	0.20	-0.12	0.03	-0.24	1.00	-0.54 (**)	-0.03	0.17	0.30	0.56 (**)	0.75 (**)	-0.06	0.27	0.08	0.33	-0.14	-0.23	0.16	-0.05	-0.07	-0.06	-0.05	.(a)
Temp	0.45 (*)	-0.22	0.25	-0.31	0.16	-0.20	0.31	-0.54 (**)	1.00	-0.47 (**)	0.00	-0.10	-0.56 (**)	-0.70 (**)	-0.29	-0.01	0.10	-0.17	-0.09	-0.11	-0.18	0.05	0.00	-0.22	-0.10	.(a)
pH	0.00	0.22	-0.01	-0.12	-0.22	0.23	-0.41 (*)	-0.03	-0.46 (*)	1.00	-0.29	-0.18	0.14	0.26	0.38 (*)	0.21	-0.23	0.15	0.15	0.13	0.01	-0.02	0.34	0.17	0.21	.(a)
Salinity	-0.21	-0.26	-0.09	0.28	0.27	-0.12	0.59 (**)	0.17	0.00	-0.29	1.00	0.81 (**)	0.02	-0.10	-0.05	0.00	0.31	-0.10	0.06	-0.07	-0.17	-0.12	-0.11	-0.32	0.02	.(a)
NH4	-0.16	-0.15	-0.22	0.46 (*)	0.28	-0.19	0.53 (**)	0.30	-0.10	-0.18	0.81 (**)	1.00	0.07	0.03	-0.01	0.04	0.45 (*)	-0.15	-0.13	0.00	-0.05	-0.15	-0.01	-0.42 (*)	0.05	.(a)
Iron	-0.70 (**)	-0.18	-0.25	0.13	0.03	0.23	-0.37 (*)	0.56 (**)	-0.56 (**)	0.14	0.02	0.07	1.00	0.53 (**)	0.00	-0.28	0.14	0.48 (**)	-0.16	-0.08	-0.22	-0.43 (*)	-0.02	0.25	0.31	.(a)
BOD	-0.35	-0.15	-0.22	0.06	-0.18	0.16	-0.48 (**)	0.75 (**)	-0.70 (**)	0.26	-0.10	0.03	0.53 (**)	1.00	-0.06	0.20	-0.09	0.14	0.00	0.06	0.04	-0.12	-0.12	0.05	0.06	.(a)
PP	-0.11	0.12	-0.24	0.01	0.06	0.32	-0.03	-0.06	-0.29	0.38 (*)	-0.05	-0.01	0.00	-0.06	1.00	0.16	-0.17	-0.06	-0.07	0.01	0.00	0.04	0.04	0.11	0.18	.(a)
Chl a	0.24	-0.17	-0.10	-0.19	-0.28	0.11	-0.15	0.27	-0.01	0.21	0.00	0.04	-0.28	0.20	0.16	1.00	0.00	-0.10	0.15	-0.13	0.07	0.25	-0.23	-0.24	-0.23	.(a)
Chlb	-0.12	-0.07	-0.12	0.44 (*)	0.24	0.03	0.31	0.08	0.10	-0.23	0.31	0.45 (*)	0.14	-0.09	-0.17	0.00	1.00	0.07	0.15	-0.14	-0.03	0.07	-0.18	-0.40 (*)	0.02	.(a)
Pheo	-0.05	-0.10	-0.16	-0.13	0.00	0.19	-0.24	0.33	-0.17	0.15	-0.10	-0.15	0.48 (**)	0.14	-0.06	-0.10	0.07	1.00	-0.21	-0.15	-0.10	-0.20	0.11	0.11	0.16	.(a)
CP	-0.06	0.04	-0.03	-0.12	-0.04	-0.06	-0.02	-0.14	-0.09	0.15	0.06	-0.13	-0.16	0.00	-0.07	0.15	0.15	-0.21	1.00	0.35	0.01	0.13	-0.08	-0.10	0.05	.(a)
BP	-0.09	0.23	-0.17	-0.07	0.11	-0.05	-0.04	-0.23	-0.11	0.13	-0.07	0.00	-0.08	0.06	0.01	-0.13	-0.14	-0.15	0.35	1.00	-0.10	-0.20	0.03	-0.01	0.15	.(a)
DP	0.38 (*)	-0.02	0.10	0.10	-0.37 (*)	-0.12	-0.06	0.16	-0.18	0.01	-0.17	-0.05	-0.22	0.04	0.00	0.07	-0.03	-0.10	0.01	-0.10	1.00	0.79 (**)	0.26	0.04	-0.49 (**)	.(a)
MP	0.41 (*)	0.02	0.17	0.02	-0.19	-0.07	0.07	-0.05	0.05	-0.02	-0.12	-0.15	-0.43 (*)	-0.12	0.04	0.25	0.07	-0.20	0.13	-0.20	0.792 (**)	1.00	0.24	-0.20	-0.60 (**)	.(a)
SF	0.19	0.08	-0.01	-0.12	0.01	-0.28	-0.03	-0.07	0.00	0.34	-0.11	-0.01	-0.02	-0.12	0.04	-0.23	-0.18	0.11	-0.08	0.03	0.26	0.24	1.00	0.07	-0.01	.(a)
CB	-0.13	0.15	-0.07	-0.12	-0.28	0.09	-0.26	-0.06	-0.22	0.17	-0.32	-0.42 (*)	0.25	0.05	0.11	-0.24	-0.40 (*)	0.11	-0.10	-0.01	0.04	-0.20	0.07	1.00	0.26	.(a)
ZP	-0.36	0.04	-0.08	0.00	0.03	0.01	-0.12	-0.05	-0.10	0.21	0.02	0.05	0.31	0.06	0.18	-0.23	0.02	0.16	0.05	0.15	-0.48 (**)	-0.59 (**)	-0.01	0.26	1.00	.(a)
DD	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)

Table 4.103 Correlation matrix for variables estimated during POM 09

POM09	DO	CO2	NO3	NO2	PO4	SiO4	Alk	Trans	Temp	pH	Salinity	NH4	Iron	BOD	PP	Chl a	Chlb	Pheo	CP	BP	DP	MP	SF	CB	ZP	DD
DO	1	0.13	-0.22	0.03	-0.39 (*)	0.26	-0.30	-0.05	-0.27	-0.30	-0.51 (**)	0.27	-0.50 (**)	0.24	0.24	-0.16	-0.04	-0.10	0.32	0.13	-0.37 (*)	-0.31	0.13	0.30	-0.26	(o)
CO2	0.13	1	-0.23	-0.29	0.26	-0.19	0.18	-0.11	0.23	-0.37 (*)	0.09	0.28	0.17	0.03	-0.32	-0.17	-0.33	-0.29	0.17	-0.08	0.1	-0.11	0.24	-0.08	-0.07	(o)
NO3	-0.22	-0.23	1	-0.04	-0.06	0.10	-0.10	-0.02	-0.09	-0.09	-0.07	-0.18	-.38 (*)	0.29	-0.07	0.12	0.11	0.04	0.17 (**)	0.53 (**)	0.27	0.65 (**)	-0.46 (*)	-0.06	0.27	(o)
NO2	0.03	-0.29	-0.04	1	0.10	0.04	0.07	0.33	0.02	0.31	0.17	0.02	0.156	-0.08	0.41 (*)	0.14	0.43 (*)	0.28	-0.38 (*)	0.26	0.12	-0.12	-0.19 (**)	0.50 (**)	0.54 (**)	(o)
PO4	-0.39 (*)	0.26	-0.06	0.10	1	-0.28	0.27	0.27	0.09	-0.13	0.48 (**)	-0.13	0.56 (**)	-0.33	-0.17	0.23	-0.03	-0.07	-0.14	-0.05	0.45 (*)	0.13	0.42 (*)	-0.19	0.16	(o)
SiO4	0.26	-0.19	0.10	0.04	-0.28	1	0.05	-0.45 (*)	-0.18	0.10	-0.53 (**)	0.26	-0.28 (**)	0.17	-0.04	0.07	0.30	0.32	0.27	0.09	-0.05	-0.08	-0.08	0.03	-0.17	(o)
Alk	-0.30	0.18	-0.10	0.07	0.27	0.05	1	0.04	0.17	0.19	0.59 (**)	0.00	0.55 (**)	-0.50 (**)	-0.21	0.18	0.10	-0.01	0.15	0.03	0.27	-0.004	0.13	-0.02	0.14	(o)
Trans	-0.05	-0.11	-0.02	0.33	0.27	-0.45 (*)	0.04	1	0.01	-0.22	0.64 (**)	-0.24	0.24	-0.19	0.21	0.29	0.01	-0.10	-0.44 (*)	0.23	-0.06	-0.02	0.18	0.04	0.41 (*)	(o)
Temp	-0.27	0.23	-0.09	0.02	0.09	-0.18	0.17	0.01	1	0.11	0.158	-0.03	0.17	0.19	-0.03	-0.23	0.02	-0.02	-0.17	-0.03	-0.12	-0.21	0.00	0.15	0.40 (*)	(o)
pH	-0.30	-0.40 (*)	-0.09	0.31	-0.13	0.10	0.19	-0.22	0.11	1	-0.08	-0.16	0.17	-0.31	0.24	-0.08	0.34	0.34	0.09	0.09	0.08	-0.08	-0.27	0.25	0.28	(o)
Salinity	-0.51 (**)	0.09	-0.07	0.17	0.48 (**)	-0.53 (**)	.58 (**)	0.64 (**)	0.16	-0.08	1	-0.23	0.65 (**)	-0.53 (**)	-0.03	0.36 (*)	-0.06	-0.14	-0.41 (*)	0.05	0.26	0.11	0.14	-0.18	0.36 (*)	(o)
NH4	0.27	0.28	-0.18	0.02	-0.13	0.26	0.00	-0.24	-0.03	-0.16	-0.23	1	-0.12	0.20	-0.21	-0.17	-0.07	-0.06	0.10	-0.21	-0.35	-0.25	0.04	0.13	-0.20	(o)
Iron	-0.50 (**)	0.17	-0.38 (*)	0.16	0.56 (**)	-0.28	0.55 (**)	0.24	0.17	0.17	0.65 (**)	-0.12	1	-0.61 (**)	-0.14	0.05	-0.09	-0.14	-0.20	-0.30	0.42 (*)	-0.16	0.29	-0.14	0.19	(o)
BOD	0.24	0.03	0.29	-0.08	-0.33	0.17	-0.49 (**)	-0.19	0.19	-0.31	-0.53 (**)	0.20	0.6(**)	1	0.10	-0.28	0.10	0.20	-0.02	0.93	-0.28	0.05	-0.27	0.08	-0.05	(o)
PP	0.24	-0.32	-0.07	0.41 (*)	-0.17	-0.04	-0.21	0.21	-0.03	0.24	-0.03	-0.21	-0.14	0.10	1	0.29	0.37 (*)	0.32	-0.08	0.28	-0.04	-0.09	-0.30	0.51 (**)	0.33	(o)
Chl a	-0.16	-0.17	0.12	0.14	0.23	0.07	0.18	0.29	-0.23	-0.08	0.36 (*)	-0.17	0.05	-0.28	0.29	1	0.35	0.35	-0.14	0.25	0.37 (*)	0.04	-0.06	-0.01	0.30	(o)
Chlb	-0.04	-0.33	0.11	0.43 (*)	-0.03	0.30	0.10	0.01	0.02	0.34	-0.06	-0.07	-0.09	0.10	0.37 (*)	0.35	1	0.91 (**)	-0.08	0.28	0.19	0.02	-0.25	0.10	0.37 (*)	(o)
Pheo	-0.10	-0.29	0.04	0.28	-0.07	0.32	-0.01	-0.10	-0.02	0.34	-0.14	-0.06	-0.14	0.20	0.32	0.35	0.91 (**)	1	-0.10	0.17	0.12	0.00	-0.35	-0.03	0.21	(o)
CP	0.32	0.17	0.17	-0.38 (*)	-0.14	0.27	0.15	-0.44 (*)	-0.17	0.09	-0.41 (*)	0.10	-0.20	-0.02	-0.08	-0.14	-0.08	-0.10	1.00	0.20	-0.02	0.12	0.02	0.11	-0.31	(o)
BP	0.13	-0.08	0.53 (**)	0.26	-0.05	0.09	0.03	0.23	-0.03	0.09	0.05	-0.21	-0.30	0.03	0.28	0.25	0.28	0.17	0.20	1	0.22	0.57 (**)	-0.49 (**)	0.17	0.44 (*)	(o)
DP	-0.36 (*)	0.1	0.27	0.12	0.45 (*)	-0.05	0.27	-0.06	-0.12	0.08	0.26	-0.35	0.42 (*)	-0.28	-0.04	0.37 (*)	0.19	0.12	-0.02	0.22	1	0.29	-0.07	-0.12	0.35	(o)
MP	-0.31	-0.11	0.65 (**)	-0.12	0.13	-0.08	0.00	-0.02	-0.21	-0.08	0.11	-0.25	-0.16	0.05	-0.09	0.04	0.02	0.00	0.12	0.57 (**)	0.29	1	-0.34	-0.33	-0.10	(o)
SF	0.13	0.24	-0.46 (*)	-0.19	0.42 (*)	-0.08	0.13	0.18	0.00	-0.27	0.14	0.04	0.29	-0.27	-0.30	-0.06	-0.25	-0.35	0.02	-0.49 (**)	-0.07	-0.34	1.00	-0.07	-0.29	(o)
CB	0.30	-0.08	-0.06	0.50 (**)	-0.19	0.03	-0.02	0.04	0.15	0.25	-0.18	0.13	-0.14	0.08	0.51 (**)	-0.01	0.1	-0.03	0.11	0.17	-0.12	-0.33	-0.07	1	0.40 (*)	(o)
ZP	-0.26	-0.07	0.27	0.54 (**)	0.16	-0.17	0.14	0.41 (*)	0.40 (*)	0.28	0.36	-0.20	0.19	-0.05	0.33	0.30	0.37 (*)	0.21	-0.31 (*)	0.44 (*)	0.35	-0.10	-0.29	0.40 (*)	1	(o)
DD	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)

Table 4.104 Correlation matrix for variables estimated during PRE 10

PRE10	DO	CO2	NO3	NO2	PO4	SiO4	Alk	Trans	Temp	pH	Salinity	NH4	Iron	BOD	PP	Chl a	Chlb	Pheo	CP	BP	DP	MP	SF	CB	ZP	DD
DO	1	-0.48 (**)	0.37 (*)	-0.46 (*)	-0.31	-0.03	-0.52 (**)	-0.52 (**)	0.35	-0.32	-0.45 (*)	-0.52 (**)	-0.50 (**)	0.47 (**)	-0.25	-0.33	0.13	0.16	0.24	0.02	-0.18	-0.51 (**)	0.3	0.39 (*)	0.08	.(a)
CO2	-0.48 (**)	1	-0.16	-0.04	0.59 (**)	-0.07	0.35	0.35	-0.11	-0.01	0.22	0.52 (**)	0.30	-0.39 (*)	0.09	0.26	-0.16	-0.11	-0.03	-0.36 (*)	0.12	0.29	0.2	-0.25	-0.14	.(a)
NO3	0.37 (*)	-0.16	1	-0.60 (**)	-0.08	-0.43 (*)	-0.61 (**)	-0.47 (**)	0.33	-0.64 (**)	-0.61 (**)	-0.17	-0.31	0.52 (**)	-0.24	-0.49 (**)	0.02	0.31	-0.13	0.06	0.16	-0.21	0.30	0.57 (**)	-0.43 (*)	.(a)
NO2	-0.46 (*)	-0.04	-0.60 (**)	1	0.24	0.32	0.65 (**)	0.60 (**)	-0.34	0.59 (**)	0.607 (**)	0.17	0.32	-0.37 (*)	-0.02	0.30	-0.03	-0.26	-0.10	-0.10	0.06	0.35	-0.24	-0.40 (*)	0.49 (**)	.(a)
PO4	-0.31	0.59 (**)	-0.09	0.24	1	-0.14	0.45 (*)	0.53 (**)	-0.16	-0.11	0.19	0.74(**)	0.245	-0.34	-0.14	0.40 (*)	-0.04	-0.05	-0.17	-0.43 (*)	0.16	0.33	0.29	-0.01	0.14	.(a)
SiO4	-0.03	-0.07	-0.43 (*)	0.32	-0.14	1	0.11	0.18	-0.18	0.29	0.08	-0.15	0.20	-0.19	-0.13	0.13	0.05	-0.15	0.40 (*)	0.15	0.06	-0.07	-0.02	-0.25	0.30	.(a)
Alk	-0.52 (**)	0.35	-0.61 (**)	0.65 (**)	0.45 (*)	0.11	1	0.73 (**)	-0.32	0.61 (**)	0.91 (**)	0.32	0.49 (**)	-0.66 (**)	-0.05	0.24	-0.20	-0.31	-0.28	-0.18	0.09	0.53 (**)	-0.18	-0.52 (**)	0.17	.(a)
Trans	-0.52 (**)	0.35	-0.47 (**)	0.60 (**)	0.53 (**)	0.18	0.73 (**)	1	-0.23	0.38 (*)	0.54 (**)	0.35	0.54 (**)	-0.64 (**)	0.09	0.28	-0.09	-0.26	-0.20	-0.28	0.15	0.61 (**)	0.15	-0.30	0.34	.(a)
Temp	0.35	-0.11	0.33	-0.34	-0.16	-0.18	-0.32	-0.23	1	-0.30	-0.29	-0.26	-0.45 (*)	0.21	-0.06	-0.17	-0.11	-0.01	-0.11	0.00	0.15	0.01	0.17	0.38 (*)	-0.1	.(a)
pH	-0.32	-0.01	-0.64 (**)	0.60 (**)	-0.11	0.29	0.61 (**)	0.38 (*)	-0.30	1	0.62 (**)	-0.02	0.20	-0.41 (*)	0.12	0.23	-0.14	-0.37 (*)	0.07	0.36	-0.15	0.18	-0.52 (**)	-0.62 (**)	0.19	.(a)
Salinity	-0.45 (*)	0.22	-0.61 (**)	0.61 (**)	0.19	0.08	0.91 (**)	0.54 (**)	-0.29	0.62 (**)	1	0.15	0.42 (*)	-0.56 (**)	-0.06	0.17	-0.25	-0.34	-0.35	-0.17	0.08	0.42 (*)	-0.36	-0.48 (**)	0.28	.(a)
NH4	-0.52 (**)	0.52 (**)	-0.17	0.17	0.74 (**)	-0.15	0.32	0.35	-0.26	-0.02	0.15	1	0.08	-0.2	0.12	0.62 (**)	-0.04	-0.09	-0.07	-0.27	0.03	0.22	0	-0.19	0.00	.(a)
Iron	-0.50 (**)	0.30	-0.31	0.32	0.25	0.20	0.49 (**)	0.54 (**)	-0.49 (*)	0.20	0.42 (*)	0.08	1	-0.50 (**)	-0.05	-0.05	-0.09	-0.04	-0.17	-0.16	0.30	0.46 (*)	-0.06	-0.16	0.21	.(a)
BOD	0.47 (**)	-0.39 (*)	0.52 (**)	-.37 (*)	-0.34	-0.19	-0.66 (**)	-0.64 (**)	0.21	-0.41 (*)	-0.56 (**)	-0.20	-0.50 (**)	1	-0.04	-0.15	0.33	0.40 (*)	0.06	0.24	-0.03	-0.56 (**)	0.03	0.34	-0.11	.(a)
PP	-0.25	0.09	-0.24	-0.02	-0.14	-0.13	-0.05	0.09	-0.06	0.12	-0.06	0.12	-0.05	-0.04	1	0.18	-0.10	-0.04	0.21	0.04	-0.05	0.05	0.02	-0.20	-0.10	.(a)
Chl a	-0.33	0.26	-0.49 (**)	0.30	0.40 (*)	0.13	0.24	0.28	-0.17	0.23	0.17	0.62 (**)	-0.05	-0.15	0.18	1	-0.09	-0.40 (*)	0.02	-0.12	-0.01	0.23	-0.15	-0.36	0.36	.(a)
Chlb	0.13	-0.16	0.02	-0.03	-0.04	0.05	-0.20	-0.09	-0.11	-0.14	-0.25	-0.04	-0.09	0.33	-0.10	-0.09	1	0.87 (**)	0.22	0.11	-0.20	-0.26	0.25	-0.06	-0.13	.(a)
Pheo	0.16	-0.11	0.31	-0.26	-0.05	-0.15	-0.31	-0.26	-0.01	-0.37 (*)	-0.34	-0.09	-0.04	0.40 (*)	-0.04	-0.40 (*)	0.87 (**)	1	0.12	0.09	0.00	-0.25	0.34	0.14	-0.31	.(a)
CP	0.24	-0.03	-0.13	-0.10	-0.17	0.40 (*)	-0.28	-0.20	-0.11	0.07	-0.35	-0.07	-0.17	0.06	0.21	0.02	0.22	0.12	1	-0.03	-0.49 (**)	-0.50 (**)	0.28	-0.40 (*)	-0.13	.(a)
BP	0.02	-0.36 (*)	0.06	-0.10	-0.43 (*)	0.15	-0.18	-0.28	0.00	0.36	-0.17	-0.27	-0.16	0.24	0.04	-0.12	0.11	0.09	-0.03	1	0.08	-0.19	-0.56 (**)	0.01	-0.19	.(a)
DP	-0.18	0.12	0.16	0.06	0.16	0.06	0.09	0.15	0.15	-0.15	0.08	0.03	0.30	-0.03	-0.05	-0.01	-0.20	0.00	-0.49(**)	0.08	1	0.59 (**)	0.12	0.30	0.17	.(a)
MP	-0.51 (**)	0.29	-0.21	0.35	0.33	-0.07	0.53 (**)	0.61 (**)	0.01	0.18	0.42 (*)	0.22	0.46 (*)	-0.60 (**)	0.05	0.23	-0.26	-0.25	-0.50 (**)	-0.19	0.59 (**)	1	0.08	-0.21	0.07	.(a)
SF	0.3	0.2	0.30	-0.24	0.29	-0.02	-0.18	0.15	0.17	-0.52 (**)	-0.36	0	-0.06	0.03	0.02	-0.15	0.25	0.34	0.28	-0.56 (**)	0.12	0.08	1	0.15	-0.13	.(a)
CB	0.39 (*)	-0.25	0.57(**)	-0.40 (*)	-0.01	-0.25	-0.52 (**)	-0.30	0.38 (*)	-0.62 (**)	-0.48 (**)	-0.19	-0.16	0.34	-0.20	-0.36	-0.06	0.14	-0.40 (*)	0.01	0.30	-0.21	0.15	1	0.11	.(a)
ZP	0.08	-0.14	-0.43 (*)	0.49 (**)	0.14	0.30	0.17	0.34	-0.1	0.19	0.282	0.00	0.21	-0.11	-0.10	0.36	-0.13	-0.31	-0.13	-0.19	0.17	0.07	-0.13	0.11	1	.(a)
DD	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)

Bacillariophyceae showed highly significant negative correlation with silicate and exhibited strong positive correlation with alkalinity and salinity during POM 08, implying the effect of salinity on its distribution. Bacillariophyceae showed highly significant positive correlation with Myxophyceae, Zygnematophyceae and highly significant negative correlation with silicoflagellates. Bacillariophyceae showed highly significant positive correlation with NO_3^- (PRE 09). During PRE 10, Bacillariophyceae exhibited highly significant negative correlation with Silicoflagellates, CO_2 and phosphate, inferred the process of uptake of this nutrient and CO_2 during photosynthesis. Since diatoms are highly sensitive to changes in environmental variables such as salinity, tidal currents, flooding frequency, pH and salinity plays an important role in the distribution of these organisms. Bacillariophyceae showed highly significant positive correlation with Zygnematophyceae and exhibited highly significant negative correlation with transparency. The standing crop of phytoplankton showed seasonal variation and spatial variation in the CBW and highest peak was observed during POM 09. Bacillariophyceae (diatoms) were dominant which could well thrive in widely varying hydrographical conditions (Tiwari and Nair, 1998; Rajasegar et al., 2000, Gopinathan et al., 2001, Gowda et al., 2001; Senthilkumar et al., 2002). The dominance of Diatoms (Bacillariophyceae) in the present study was supported by earlier reports of pigment characterization by Aneeshkumar and Sujatha, (2012) which explained the abundance of carotenoid pigment fucoxanthin as an indicator of diatoms.

Alkalinity showed significant negative correlation with Dinophyceae. It was recorded that Dinophyceae exhibited highly significant positive correlation with Zygnematophyceae but significant positive correlation with Cyanobacteria (POM 08). During (PRE 09) Dinophyceae revealed significant positive correlation with phosphate. Dinophyceae exhibited

significant negative correlation with phosphate and significant positive correlation with DO implied the uptake of phosphorous and photosynthetic release of oxygen to water column. Dinophyceae had highly significant positive correlation with Myxophyceae and showed highly significant negative correlation with Zygnematophyceae (MON 09). Dinophyceae exhibited significant positive correlation with salinity and alkalinity and highly significant positive correlation with pH and ammonia and significant negative correlation with CO_2 (POM 09). Dinophyceae exhibited highly significant positive correlation with Myxophyceae (PRE 10).

During PRE 09, Myxophyceae displayed highly significant positive correlation with NO_3^- pointing towards the uptake of this nutrient from water column. It exhibited significant negative correlation with iron and Zygnematophyceae and significant positive correlation with DO (MON 09) pointing towards uptake of iron and release of oxygen during photosynthetic activity. Myxophyceae showed significant negative correlation with Silicoflagellates and Cyanobacteria and significant positive correlation with Desmidaceae. Myxophyceae showed significant positive correlation with NO_2 and salinity (POM 09). During (PRE 10) Myxophyceae showed significant positive correlation with salinity, alkalinity, transparency and iron.

Silicoflagellate significant positive correlation with phosphate and significant negative correlation with NO_3 during (PRE 09) pointing towards the uptake of this nutrient. Silicoflagellates exhibited significant positive correlation with Zygnematophyceae and significant negative correlation with Desmidaceae. Silicoflagellates recorded significant negative correlation with iron owing to the uptake of this nutrient. Silicoflagellates recorded significant positive correlation with DO, transparency and

recorded significant negative correlation with phosphate and salinity (POM 09). These relationships implied the uptake of phosphorous from water column, higher solar insolation and the combined effect of both favours photosynthesis and subsequent release of surplus of oxygen. In the present study, highly significant negative correlation was observed between Silicoflagellates and pH (PRE 10).

Dissolved oxygen exhibited highly significant positive correlation with cyanobacteria revealed the fact that enhanced photosynthetic activity increase dissolved oxygen in the water column. Correlation analysis revealed that alkalinity and salinity had significant negative correlation with Cyanobacteria while, transparency exhibited significant positive correlation (POM 08). In the present study Cyanobacteria exhibited significant negative correlation with NO_2^-, alkalinity, salinity and pH. In the present study it was observed that Cyanobacteria showed significant positive correlation with temperature and DO and highly significant positive correlation with NO_3^- (PRE 10). Cyanobacteria displayed significant negative correlation with ammonia during MON 09, which might be due to preferential uptake of this nutrient for protein synthesis.

Zygnematophyceae recorded highly significant positive correlation with NO_2^- and significant positive correlation with temperature (PRE 09). During PRE 10 Zygnematophyceae recorded significant negative correlation with NO_3 inferred to the uptake of nitrate.

Desmidaceae also showed significant negative correlation with NO_3^- (POM 09) pointing towards the uptake from water column. Chl a showed highly significant positive correlation were found with phosphate and ammonia implying the uptake of these nutrients by plankton (PRE 09).

The highly significant negative correlation existing among different groups of phytoplankton pointed out the presence of a particular group inhibit the existence and growth of another set of phytoplankton due to inter/intra specific competition or predation prevailing in the ecological niche.

Community structure

Community composition and community diversity profiles help to assess the seasonal and spatial variation in the occurrence phytoplankton in the study area. Biotic diversity index is used as an indicator of environmental stress (Sheeba et al., 2004). Generally high level of environmental stress will tend to lower biotic diversity. Different diversity indices help to reach different conclusions (Sheeba et al., 2004; Nisha, 2008). Among the various diversity indices Shannon Weiner index was satisfactory with regard to changes in index value with the variation in pollution intensity (Patil and Taille, 1979).

The results of PRIMER analysis are furnished in tables 4.105 to 4.109. During POM 08 maximum species richness was in S2 (6.89) and minimum at S12 (6.01). The species richness varied from 6.01 to 6.89 (average: 6.28±.0.23). During PRE 09 highest species richness was at S5 (7.64) and minimum at S9 (7.33). The species richness varied from 7.33 to 7.64 (average: 7.45±.0.094). During MON 09, highest species richness was at S4 and minimum at S8. The species richness varied from 6.25 to 6.80 (average: 6.46±0.16). During POM 09, species richness was maximum at S11 and minimum at S15. The value was varied from 7.26 to 7.57 (average: 7.42± 0.09). During PRE 10, species richness was maximum at S6 and minimum at S15. The species richness was minimum at S15 (7.01) which is a polluted industrial belt and maximum at S6 (7.85) (average: 7.52± 0.24).

Table 4.105 Showing the results of Primer analysis during POM 08

Stations	S	N	d	J'	H'(Log 2)	Lambda
S1	72	76200	6.31	0.89	5.51	0.03
S2	79	82400	6.89	0.90	5.71	0.02
S3	75	73000	6.60	0.91	5.67	0.02
S4	72	70600	6.35	0.90	5.57	0.02
S5	72	70000	6.36	0.90	5.57	0.02
S6	68	68200	6.02	0.89	5.45	0.03
S7	69	70800	6.08	0.90	5.51	0.03
S8	72	74600	6.32	0.90	5.57	0.02
S9	69	76600	6.04	0.92	5.62	0.02
S10	70	74200	6.15	0.91	5.61	0.02
S11	72	70000	6.36	0.90	5.60	0.02
S12	68	68600	6.01	0.91	5.53	0.02
S13	71	80600	6.19	0.90	5.54	0.02
S14	72	68200	6.37	0.90	5.56	0.02
S15	69	62800	6.15	0.90	5.49	0.02
Maximum	79	82400	6.89	0.92	5.71	0.03
Minimum	68	62800	6.01	0.89	5.45	0.02
Average	71.3± 2.87	72453± 5119	6.28± 0.23	0.90± 0.007	5.57± 0.06	0.028± 0.002

Table 4.106 Showing the results of Primer analysis during PRE 09

Station	S	N	d	J'	H'(Log 2)	Lambda
S1	84	65700	7.48	0.90	5.76	0.02
S2	83	64200	7.40	0.89	5.70	0.02
S3	84	69500	7.44	0.89	5.73	0.02
S4	84	61700	7.52	0.89	5.73	0.02
S5	86	67800	7.64	0.88	5.70	0.02
S6	83	62500	7.42	0.89	5.68	0.03
S7	85	63600	7.59	0.90	5.79	0.02
S8	83	69400	7.35	0.89	5.72	0.02
S9	83	71700	7.33	0.90	5.74	0.02
S10	85	68000	7.54	0.90	5.79	0.02
S11	85	71700	7.51	0.89	5.75	0.02
S12	84	70300	7.43	0.90	5.75	0.02
S13	83	71600	7.33	0.90	5.74	0.02
S14	83	68900	7.36	0.90	5.77	0.02
S15	84	69300	7.44	0.90	5.81	0.02
Maximum	86	71700	7.64	0.90	5.81	0.03
Minimum	83	61700	7.33	0.88	5.68	0.02
Average	83.9± 0.96	67726± 3383	7.45± 0.09	0.89± 0.006	5.74± 0.036	0.02± 0.001

Table 4.107 Showing the results of Primer analysis during MON 09

Stations	S	N	d	J'	H'(Log 2)	Lambda
S1	73	57600	6.56	0.92	5.69	0.02
S2	71	55600	6.40	0.92	5.67	0.02
S3	75	57100	6.75	0.91	5.71	0.02
S4	75	52900	6.80	0.91	5.71	0.02
S5	71	53400	6.43	0.91	5.63	0.02
S6	71	52400	6.44	0.91	5.63	0.02
S7	70	52600	6.34	0.92	5.63	0.02
S8	69	52700	6.25	0.91	5.59	0.02
S9	70	58800	6.28	0.92	5.64	0.02
S10	71	54300	6.42	0.91	5.62	0.02
S11	72	55400	6.50	0.92	5.68	0.02
S12	74	58700	6.64	0.91	5.69	0.02
S13	71	58700	6.37	0.91	5.61	0.02
S14	72	53700	6.51	0.91	5.64	0.02
S15	69	52600	6.25	0.91	5.61	0.02
Maximum	75	58800	6.80	0.92	5.71	0.02
Minimum	69	52400	6.25	0.91	5.59	0.02
Average	71.6± 1.92	55100± 2479	6.46± 0.16	0.91± 0.003	5.65± 0.039	0.02± 0.001

Table 4.108 Showing the results of Primer analysis during POM 09

Stations	S	N	d	J'	H'(Log 2)	Lambda
S1	84	90400	7.27	0.91	5.83	0.02
S2	86	88200	7.46	0.92	5.91	0.02
S3	87	89200	7.54	0.92	5.96	0.02
S4	86	78400	7.54	0.91	5.87	0.02
S5	85	83800	7.41	0.91	5.88	0.02
S6	84	82600	7.33	0.92	5.91	0.02
S7	86	90400	7.44	0.91	5.89	0.02
S8	85	87200	7.38	0.92	5.92	0.02
S9	86	84400	7.49	0.92	5.94	0.02
S10	86	86200	7.47	0.92	5.95	0.02
S11	87	85800	7.57	0.92	5.98	0.02
S12	86	88600	7.46	0.91	5.88	0.02
S13	85	87000	7.38	0.93	6.00	0.02
S14	84	76800	7.37	0.92	5.93	0.02
S15	83	79800	7.26	0.92	5.88	0.02
Maximum	87	90400	7.57	0.93	6.00	0.02
Minimum	83	76800	7.26	0.91	5.83	0.019
Average	85.3±1.18	85253.33± 4263.78	7.42± 0.094	0.92±0.007	5.92±0.047	0.02±0.001

Table 4.109 Showing the results of Primer analysis during PRE 10

Stations	S	N	d	J'	H'(Log 2)	Lambda
S1	83	75400	7.30	0.88	5.64	0.02
S2	84	75200	7.39	0.88	5.68	0.02
S3	88	71600	7.78	0.88	5.73	0.02
S4	83	72400	7.32	0.89	5.72	0.02
S5	88	74400	7.75	0.89	5.75	0.02
S6	89	73200	7.85	0.88	5.75	0.02
S7	88	68400	7.81	0.88	5.73	0.02
S8	88	70200	7.79	0.89	5.77	0.02
S9	84	70400	7.43	0.89	5.70	0.02
S10	87	74200	7.6	0.89	5.75	0.02
S11	84	71400	7.42	0.88	5.64	0.03
S12	85	71800	7.51	0.89	5.72	0.02
S13	85	73400	7.49	0.89	5.72	0.02
S14	83	69000	7.36	0.89	5.68	0.02
S15	79	67800	7.01	0.89	5.62	0.02
Maximum	89	75400	7.85	0.89	5.77	0.03
Minimum	79	67800	7.01	0.88	5.62	0.02
Average	85.2± 2.76	71920± 2417	7.52± 0.24	0.89± 0.004	5.71± 0.04	0.02± 0.001

Species diversity (H' (Log2):

During POM 08, species diversity varied from 5.45 (S6) to 5.71 (S2), (average: 5.57± 0.06). It was found that in PRE 09, value ranged from 5.68 (S6) to 5.81 (S15), (average: 5.74± 0.03). But in MON09, species diversity recorded a minimum of 5.59 (S8) to maximum 5.71 (S4) (average: 5.65± 0.03). During POM 09 value ranged between 5.83 and 6.00 (average: 5.92± 0.04). During PRE 10, species diversity recorded variation between 5.62 (S15) and 5.77 (S8), (average: 5.71± 0.04).

Similarity between stations (Spatial)

Similarity between stations was studied with the help of Bray Curtis similarity index and community coefficient (using only the presence and absence of species). During POM 08, 85% similarity was occurring between S1, S4, S2 and S3; between S5, S6, S7 and S8; and between S15, S14, S13, S12, S11, S10 and S9 using Bray Curtis index. It was recorded that PRE 09 showed 90% similarity occurs between S4, S5, S6, S7 and between S8, S9, S14, S15, S10, S11, S12, S13. 95% similarity occurs between S1, S2 and S3. During MON 09, 90% similarity occurs between stations S4 and S5 and between S6, S7, S8, S9, S10, S11, S12, S13 and S14. 93% similarity occurs between stations S1, S2 between S8 and S14, between S12 and S13; between S10 and S11. Similarity in the species occurrence was highly related to hydrography and sediment characteristics. During monsoon season not much spatial variation was observed compared to other seasons.

During POM 09, 90% similarity occurs between S4, S5, and S6; between S14 and S15; between S12, S11 and S10; between station S7, S8 and S9; between stations S1, S2 and S3. During PRE 10, 90% similarity occurs between 12 stations, except S1, S2 and S15.

Ecologically significant factor groups were presented through cluster analysis by group averaging based on Bray-Curtis similarity index and a comparison was obtained by cluster analysis. Dendrogram constructed for distribution of phytoplankton are depicted in figure 4.6 to 4.10.

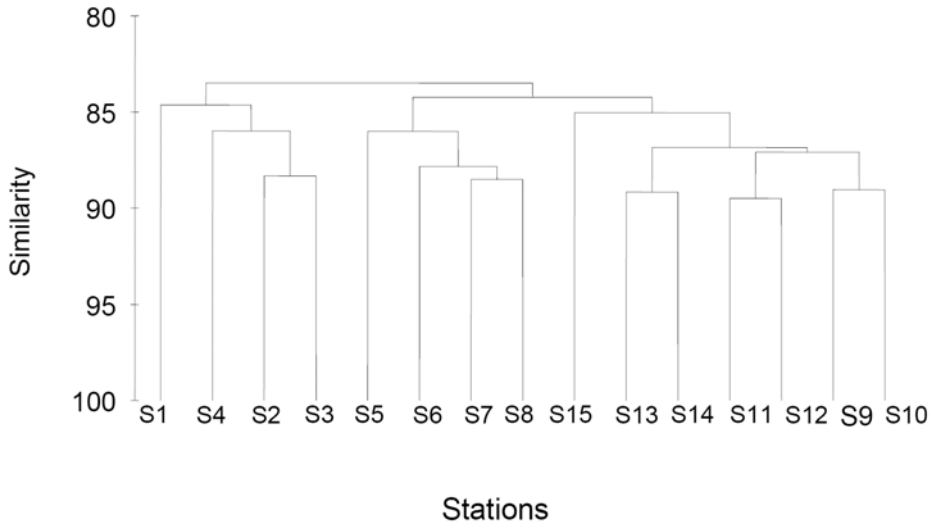


Figure 4.6 Dendrogram showing distribution of phytoplankton (POM 08)

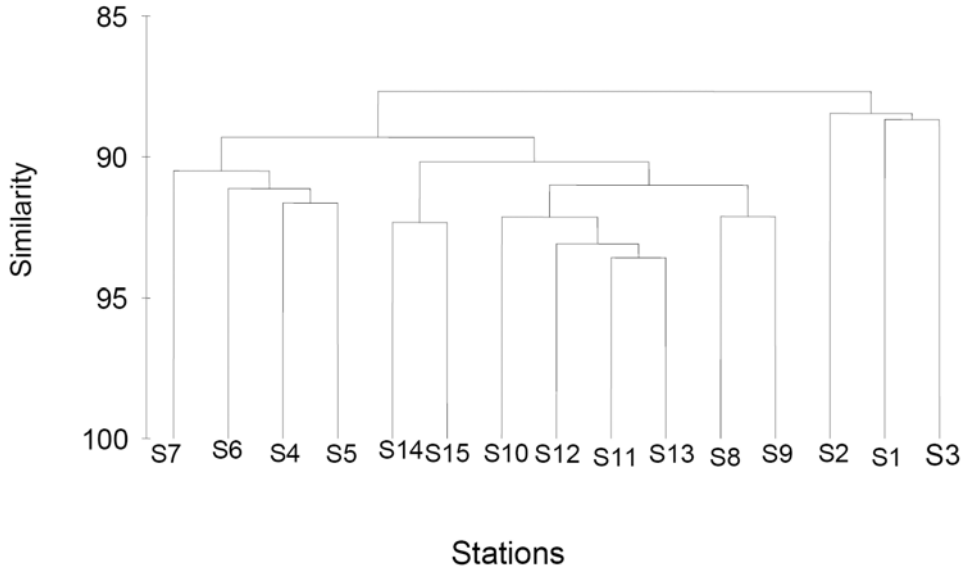


Figure 4.7 Dendrogram showing distribution of phytoplankton (PRE 09)

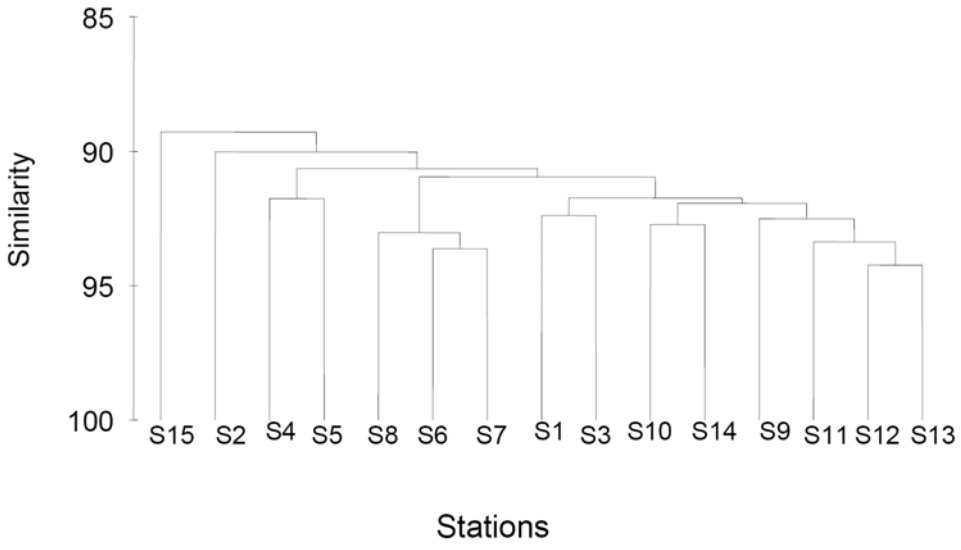


Figure 4.8 Dendrogram showing distribution phytoplankton (MON 09)

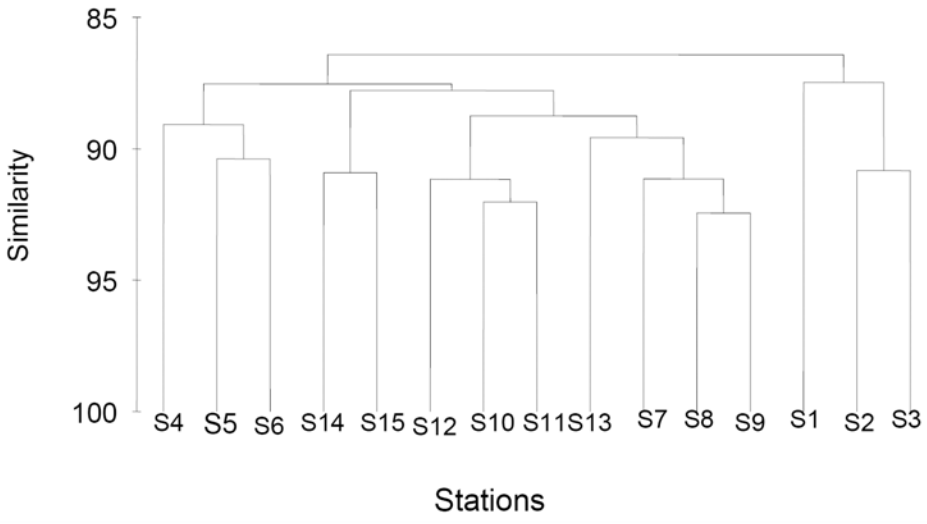


Figure 4.9 Dendrogram showing spatial variation of phytoplankton (POM 09)

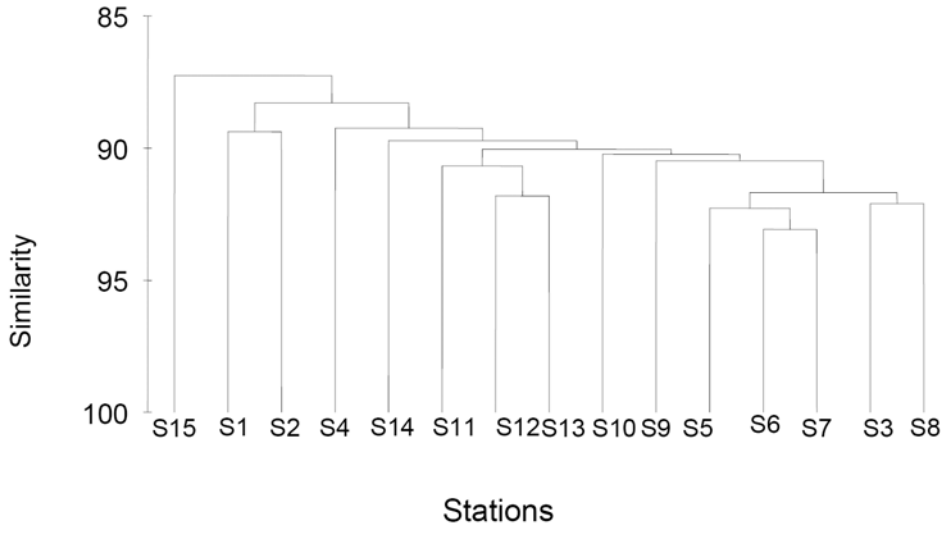


Figure 4.10 Dendrogram showing distribution of phytoplankton (PRE 09)

Species dominance index (Pielou's measure of diversity) ranged between 0.025 (S10) to 0.03 (S1) (average: 0.027±0.001) in the study area during POM 08. During PRE 09, minimum species dominance at S15 and maximum at S6. The value ranged from 0.02 to 0.03 (average: 0.02±0.001). During MON 09, value was ranged between 0.024 (S1) to 0.026 (average: 0.025±0.001). During POM 09, species dominance index of phytoplankton ranged from 0.018 (S13) to 0.022 (S4) (average: 0.02± 0.001). During PRE 10, species dominance index showed uniformity (0.02) (average: 0.02± 0.01). Species dominance index is represented in tables (4.105 to 4.109).

Species evenness in the distribution of phytoplankton species in the study area as measured by Heip's index, a function of Shannon index , showed higher values at S9 (0.92) and lowest value at S6 (0.89) with an average of 0.905± 0.007 during POM 08. It was found that during PRE 09, this value ranged from 0.88 (S5) to 0.90 (S1) and exhibited an average of 0.89±0.006). During MON 09 species evenness exhibited almost same trend in all stations (0.91 and 0.92) (average: 0.91±0.002). During POM 09,

species evenness value showed a common trend in all stations similar to monsoon . During PRE 10 the value varied from 0.88 (S11) to 0.89 (S4), (average: 0.89±0.004). In general higher diversity was followed by lower level of species evenness or equitability in distribution. This leads to the conclusion that existing conditions were favourable for pollution tolerant phytoplankton species. Diversity is important because it is considered as a parameter of a natural or organized community. An inverse relationship between species richness and evenness component of diversity which is mathematically expected can be seen in this study. It can be concluded that the components of diversity viz., richness and evenness are necessary to furnish adequate explanation of species diversity.

According to Kibrige and Perissinotto, (2003) a stress value <0.05 generally represents an excellent similarity. During POM 08 stress was found to be 0.15, low stress value indicates water was less polluted and environmental conditions were favourable for the occurrence of phytoplankton during this season (Nisha, 2008). The stress value during PRE 09 was 0.14 indicated less polluted and favourable environmental conditions. Rainfall was comparatively high during this season.

Figure 4.11 Multi Dimensional Scaling of spatial distribution of phytoplankton (POM 08)

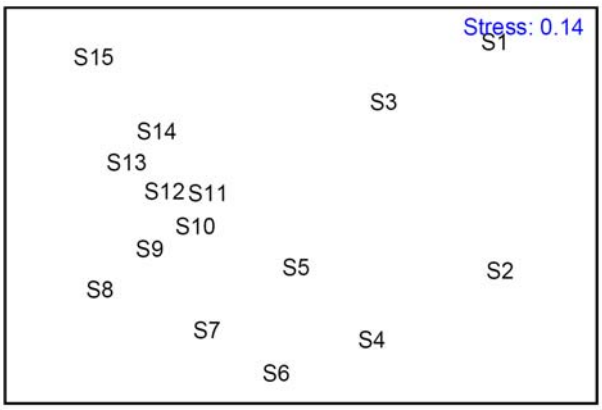


Figure 4.12 Multi Dimensional Scaling of spatial distribution of phytoplankton (PRE 09)

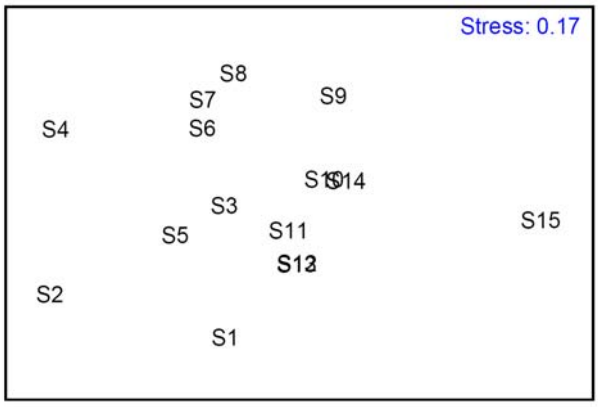


Figure 4.13 Multi Dimensional Scaling of spatial distribution of phytoplankton (MON 09)

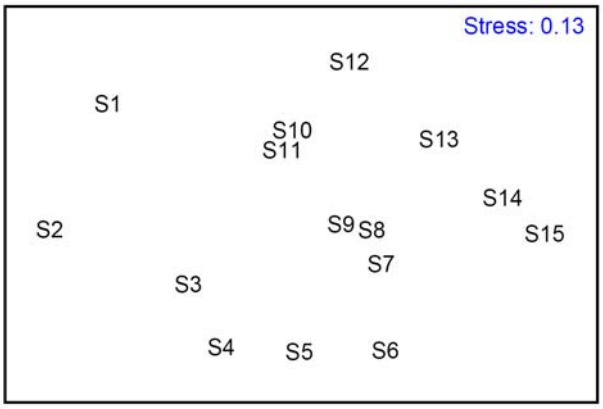


Figure 4.14 Multi Dimensional Scaling of spatial distribution of phytoplankton (POM 09)

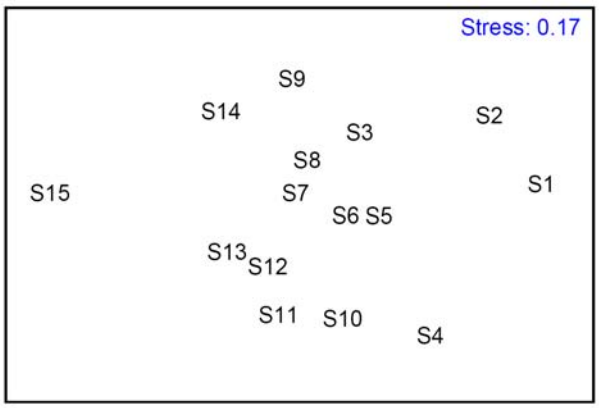


Figure 4.15 Multi Dimensional Scaling of spatial distribution of phytoplankton (PRE 10)

During MON 09, stress value was 0.17 and this indicated the less polluted waters during this season. Compared to other seasons under study, stress value was low (0.13) during POM 09 and this indicated the favourable environmental conditions for the high diversity and richness of phytoplankton during this season. Salinity and other factors were stable during POM 09 the phytoplankton production was more (Nayar and Gowda, 1999; Rajesh et al., 2002) while PRE 10 showed stress value of 0.17 (figures 4.11 to 4.15). In the present study the factors responsible for phytoplankton production vary with the stations in the study area (Joy et al., 1990, Menon et al., 2000). From the study it was observed that generally the nutrients are more enriched at the surface and often these nutrients available in the water column are not fully utilized by the phytoplankton and high concentration were detected in the surface waters. Similar results were also reported by Gopinathan et al (2001).

4.4 Conclusion

The nutrients are more enriched at the surface and often these nutrients available in the water column are not fully utilized by the phytoplankton and high concentrations were detected in the surface waters.

The present study revealed that phytoplankton diversity was more pronounced during premonsoon season, but maximum density was observed during postmonsoon season due to stable hydrographical conditions and less predation. *Skeletonema costatum, Cyclotella meneghiniana* are present which are euryhaline and show abundance. Community composition and community diversity profiles revealed that the seasonal and spatial variation of phytoplankton in the study area. Biotic diversity index is used as an indicator of environmental stress. Generally high level of environmental stress will tend to lower biotic diversity. Different diversity indices help to reach different conclusions. Cyanobacteria displayed significant negative correlation with ammonia during MON 09, which can be attributed to preferential uptake of this nutrient for protein synthesis.

Among the various diversity indices Shanon Weiner index was satisfactory with regard to changes in index value with the variation in pollution intensity. The results showed that production of phytoplankton in the estuary exceeds several times than that of zooplankton. Nitrogen increase in the system is a direct response of human interference. Increase in nitrogen results in excessive growth of phytoplankton. The primary production also presents abundance of phytoplankton which may eventually lead to eutrophication.

It can be concluded that there was insignificant correlation between nutrients and primary production which pointed out the fact that inspite of the higher concentration of available nutrients in the water column, the productivity was restricted by factors like transparency and meteorological factors. The phytoplankton distribution, species composition and dominance are closely associated with the prevailing hydrographic

condition and nutrients. The standing crop of phytoplankton also showed both seasonal and spatial variation in the CBW. Highest peak was observed during POM09. During this peak, Bacillariophyceae (Diatoms) were dominant which could thrive in widely varying hydrographical conditions. Both phytoplankton growth and primary production showed fluctuations according to seasons with respect to annual rain fall. Similarity between stations was studied with the help of Bray Curtis similarity index and community coefficient (using only the presence and absence of species). In general higher diversity was followed by lower level of species evenness or equitability in distribution. It can be concluded that existing environmental conditions were favourable for the growth of pollution tolerant phytoplankton species. Diversity is important because it is considered as a parameter of a natural or organized community. An inverse relationship between species richness and evenness component of diversity which is mathematically expected can be seen in this study. It can be concluded that the components of diversity viz., richness and evenness are necessary to furnish adequate explanation of species diversity. The highly significant negative correlation existing among different groups of phytoplankton explained that the presence of a particular group inhibit the existence and growth of another set of phytoplankton due to inter/intra specific competition or predation prevailing in the ecological niche.

This is an attempt to trace indicators capable of identifying environmental conditions over space and seasons encompassing phytoplankton, zooplankton and fishes, pollution load of CBW ecosystem. The term “shrinking back waters” represent habitat reduction which limits the flushing. Dredging and siltation can result in adverse environment for fishes. Added to these industrial effluents also act as chemical pollutants.

Due to increasing urbanization large volumes of sewage also enters the system. Toxic substances from pesticides and nutrient enrichment from land runoff also contribute adversely. A realistic approach to all these parameters is helpful in assessing the change in the water quality. As shown by Neimi et al., 2004, this study forms a bench mark linking productivity and hydrology in realizing the changes in CBW.

The actual relationship of plankton to fisheries is a subject of intense research and there is the need for further investigation. This is the first step for the detailed classification of phytoplankton, zooplankton and fishes and their distribution in different areas of Cochin back water system. In the present study, seven landing centres adjacent to sampling sites were examined and monthly data were collected for seasonal comparison for fishes captured from the estuary. It was observed that 16 species of major food fishes and 5 crustacean species were abundant and were found to be valued and marketed in the local markets. The decline in the fish production reported from this estuary could also be linked with this observation of a decrease in the meso-zooplankton biomass over the years. The present findings describe the major nutritional composition of different fishes under study. The proximate composition of the commercially important fish species from CBW were studied to assess their nutritional values in order to achieve the knowledge of the risk and benefits associated with the indiscriminate consumption of these species. The fish contains comparatively large amount of protein. These studies warrant that necessary steps should be taken to increase the production and proper management of natural habitat of the species for continued benefits. Data available in literature for proximate composition of individual species will only indicate the range or average and these are not usually taken as

absolute values. Researches on the biochemical (proximate) composition of fish are useful in several ways. Now a day there is an ever-increasing awareness about healthy food and fish is finding more acceptances because of its special nutritional qualities. Proper understanding about the biochemical constituents of fish has become a prime need for the nutritionists and dieticians. The measurement of some proximate profiles such as protein contents, carbohydrates, lipids, moisture contents and ash percentage is often necessary to ensure that they meet the requirements of food.

References

Aneeshkumar, N., 2009 PhD thesis, Cochin University of Science and Technology, Kochi.

Aneeshkumar,N., Sujatha,C.H., 2012. Biomarker pigment signatures inCochin Backwater system- atropical estuary, South West coast of India. *Est, Coast. Shelf Sci.,* (99), 182-190.

APHA, 2005. Standard Methods for the Examination of water and waste water. 21st edition. Andrew. D. Eaton, Lenore S. Clesceri, Eugine W. Rice, Arnold . E.Greenberg., (Eds) Centennial edition.

Atkinson, M, J., Carlson, B and Crow, G, L., 1995. Coral growth in high – nutrient, low pH sea water: a case study of corals cultured at the Waikiki Aquarium, Honolulu , Hawaii. *Coral Reefs*., 14, 215 -223.

Benovi´c A., Lucis, D., Onofri, V., 2000. Does change in an Adriatic hydromedusan fauna indicate an early phase of marine ecosystem destruction? PSZN I: *Mar. Ecol.,* 21,221-231.

Bhat, B.V.,1979. Studies on the meroplankton larvae with reference to the hydrography of Nethravathy-Gurupur estuary, Mangalore (DK). MFSc.Thesis. University of Agriculture Science Bangalore.

Bhatnagar, G.K., Karamchandani, B.J., 1970. Food and feeding habits of *Labeo fimbriatus* (Bloch) in river Narbada near Hoshangabad. *J. Inland. Fish. Soc.,* India. 2, 30-40.

Bianchi, T.S., Lambert, C., Santschi, P.H., Baskaran, M., Guo, L., 1995. Plant pigments as biomarkers of high molecular weight dissolved organic carbon. *Limnol. Oceanogr.,*40 (2), 422-428.

Bianchi, T.S., Rolff, C., Widbom, B., Elmgren, R., 2002. Phytoplankton pigments in Baltic Sea seston and sediments: seasonal variability, fluxes and transformations. *Est. Coast. Shelf Sci.,* 55, 369-383.

Bindu.L. K.G. Padmakumar. 2008. Food and feeding of the Pearlspot, *Etroplus suratensis* (Bloch) from the Vembanad Lake, Kerala. *J. Mar. Biol. Assoc. India.,* 50(2):156-160.

Brown, L. M., Hargrave, B. T., MacKinnon, M. D., 1981. Analysis of chlorophyll a in sediments by high-pressure liquid chromatography. *Can. J. Fish. Aquat. Sci*., 38, 205-214

Burdloff, D., Gasparini, S., Sautour, B., Etcheber, H., Castel, J., 2000. Is the copepod egg production in a highly turbid estuary (the Gironde, France) a function of the biochemical composition of seston. *Aquat. Ecol.,* 34, 165-175.

Castro, B.B., Antunes, S.C., Pereira, R., Soares, A.M.V.M., Gonçalves, F., 2005. Rotifer community structure in three shallow lakes: seasonal fluctuations and explanatory factors. *Hydrobiologia.,* 543, 221-232.

Cermeno, P., Maranon, E., Perez, V., Serret, P., Fernandez, E., Castr,C. G., 2006). Phytoplankton size structure and primary production in highly dynamic coastal ecosystem (Ria de Vigo,NW-Spain): Seasonal and short - time scale variability. *Est. Coast. Shelf Sci.*, 67, 251-266.

Chandra Shekhar, A., Rao P. and Abidi, A. B. 2004. Changes in muscle biochemical composition of Labeo rohita (Ham) in relation to season. *Indian J. Fish*., 51(3): 319-323.

Chandramohan, P., Sreenivas, N., 1998. Diel variations in zooplankton populations in mangrove ecosystem at Gaderu canal, Southwest coast of India, *Indian J. Mar. Sci.,* 22, 232-234.

Chavez FP (1996) Forcing and biological impact of onset of the 1992 El Niño in central California.*Geophy. Res. Lett.,* 33: 265-268.

Cognetti, G., 1999. Aquatic Conservation: Marine and Freshwater Ecosystems Special Issue: Issues in Aquatic Conservation: Past, Present, and Future, 9(6), 509-515.

De, T.K., Ghosh, S.K., and Jana, T.K., 1994, Phytoplankton community organization and species diversity in the Hooghly estuary, northeast coast of India. *Indian J. Mar. Sci.*, 23,152-156.

Devassy, V.P., Battathiri, P.M.A., 1974. Phytoplankton ecology of the Cochin backwaters. *Indian J. Mar. Sci.*, 3, 46-50.

FAO., 1998. Body Characteristic, Yield Indices and Proximate Composition of Commercial Fish Speciesof Lake Nubia. Foran J.A, Carpenter D.O, Hamilton M.C.

Gaonkar, C. A., Krishnamurthy, V., Anil, A. C., 2010. Changes in the abundance and composition of zooplankton from the ports of Mumbai, India , *Environ. Monit. Assess*., 168, 179-194.

Gasparini, S., Castel, J., Irigoien, X., 1999. Impact of suspended particulate matter on egg production of the estuarine copepod, *Eurytemora affinis*. *J. Mar. Syst,* 22: 195–205.

George, M, J., 1958. Observations on the plankton of Cochin back waters. *Indian J. Fish.*, 5, 373-401.

Godhantaraman, N., 2002. Seasonal variations in species composition, abundance, biomass and estimated production rates of tintinnids at tropical estuarine and mangrove waters, Parangipettai, Southeast coast of India. *J. Mar. Syst*., 36, 161-171.

Gonzales, M., Moran, E., 2005. An inventory of fish species within the San Antonio Missions National Historical Park. San Antonio River Authority, Final Report. Boschung, H.T., Jr., and R.L Mayden. 2004. Fishes of Alabama. Smithsonian Books, Washington, D.C. pp. 736

Gopinathan, C. P. 1972. Seasonal abundance of phytoplankton in the Cochin backwater. J.*Mar. Biol. Ass. India,* 14(2), 568-577.

Gopinathan, C. P., 1975. On new distributional records of plankton diatoms from the Indian Seas. *J. Mar. Biol. Ass. India*, 17 (1), 223-240.

Gopinathan, C.P., Gireesh, R., Smitha K.S., 2001. Distribution of chlorophyll 'a' and 'b' in the eastern Arabian sea (West coast of India) in relation to nutrients during post monsoon. *J. Mar. Biol. Ass. India*, 43, 21-30

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.

Gowda, G., Gupta, T, R, C., Rajesh, K,M., Gowda , H., Lingadhal, C., Ramesh, A, M., 2001. Seasonal distribution of phytoplankton in Nethravathi estuary. *J.Mar.Biol.Ass.India*, 43, 31-40.

Guner, S., Dincer, B., Alemdag, N., Colak, A. and Tufekci, M. 1998. Proximate composition and selected mineral content of commercially important fish species from the Black Sea. *J. Sci. Food and Agr*., 78, 337-342.

Habeebrehman, H., Prabhakaran, M. P., Jacob, J., Sabu, P., Jayalakshmi, K.J., Achuthankutty, C. T., Revichandran, C., 2008. Variability in biological responses influenced by upwelling events in the Eastern Arabian Sea. *J. Mar. Sys*., 74, 545-560.

Henriksen P., Riemann, B., Kaas, H., Sorensen, H.M., Sorensen, H.L., 2002. Effects of nutrient-limitation and irradiance on marine phytoplankton pigments, *J. Plankton Res*., 24: 835-858.

Hensley, D.A. and W.R. Courtenay, Jr. 1980. *Tilapia mossambica* (Peters) Mozambique tilapia pp. 774 in: D.S. Lee et al. Atlas of North American Freshwater fishes. N.C. *State Mus. Nat. Hist*., Raleigh, 854.

Hyslop, E, J., 1980. Stomach content analysis-a review of methods and their applications. *J. Fish. Biol*., 17, 411-429.

Jagadeesan, P. 1986. Studies on the environmental invertory of the marine zone of Coleroon estuary and inshore waters of Pazhayaree. PhD. thesis, Annamalai Univ.

Jayasree V, Parulekar, A.H, Wahidulla, S, Kamat, S.Y., 1994. Seasonal changes in biochemical composition of Holothuria vleucospilota (Echinodermata). *Indian J. Mar. Sci*., 23, 17-119.

Jeffrey, S.W., 1997. Application of pigment methods to oceanography. In: Jeffrey, S.W., Mantoura, R.F.C., Wright, S.W., (eds) Phytoplankton pigments in oceanography: Guidelines to modern methods. UNESCO, Paris, p 127.

Jeffrey, S.W., Vesk, M., 1997. Introduction to marine phytoplankton and their pigment signatures. In: Jeffrey, S.W., Mantoura, R.F.C. and Wright, S.W. (eds), Phytoplankton Pigments in Oceanography: A Guide to Advanced Methods. SCOR-UNESCO, Paris, pp 37–84.

Jhingran, V, G., 1975. Fish and Fisheries of India, Hindusthan Publ.corp., Delhi. 954.

Joseph, K, J., Pillai, V, K., 1975. Seasonal and spatial distribution of phytoplankters in Cochin Backwaters. *Bull.Dept.Mar.Sci.Univ.*, Cochin., 7, 171-180.

Joy, C.M., Balakrishnan, K.P., Joseph, A., 1990. Effect of industrial discharges in the ecology of phytoplankton production in the river Periyar(India)., *Wat.Res.*, 24, 787-796.

Jyothibabu, R., Madhu, N.V., Nuncio, M., Haridas, P.C., Nair, K.K.C., and Venugopal.P,2003. Intense blooms of *Trichodesmium erythreum*(Cyanophyta) in the open waters along the east coast of India. *Indian J. Mar. Sci.*, 32,165-167.

Jyothybabu, R.,Madhu , N.V., Jayalakshmi , K.V., Balachandran , K.K., Shiyas , C.A., Martin, G.D ., Nair , K.K.C., 2006. Impact of Freshwater influx on microzooplankton mediated foodweb in a tropical estuary (Cochin backwaters-India) *Est.Coast.Shelf.Sci.*, 69, 505-518.

Kawabata, Z., Magendran., A., Palanichamy. S., Venugopalan V.K., Tatsukawa, R., 1993. Phytoplankton biomass and productivity of different size fractions in the Vellar estuarine system, southeast coast of India. *Indian J. Mar. Sci*., 22,294-296.

Kibirige,I., Perissinotto, R., 2003. In situ feeding rates and grazing impact of zooplankton in a South African temporarily open estuary. *Mar.Biol.,* 142,357 doi: 10. 1007/s00227-002-0963-x.

Kowalewska, G., Wawrzyniak-Wydrowska, B., Szymczak-Zyła, M. 2004. A Chlorophyll a and its derivatives in sediments of the Odra estuary as a measure of its eutrophication. *Mar. Poll. Bull.,* 49: 148–153

KSSP, 1992. Kuttanad: facts and Fallacy, Kerala Sastra Sahitya Parishat, pp 168.

Kumaran, S., 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.

Kurup, B.M., Samuel, C.T., 1985. Fish and fishery resources of the Vembanad lake. In: Proc. Harvest and Post-harvest Technology of Fish. *Soc. Fish. Technol.*, 77-82.

Kurup B.M. Samuel, C.T., 1987. Length-weightRelationship and Relative Condition Factor in Daysciaena albida (Cuv.) and Gerres filamentosus (Cuv.) *Fish. Technol.,* 24: 88-92.

Kurup, B. M., 1993. Food and feeding habits of *Labeo dussumieri* (Val) of the river Pampa. *Indian J. Fish*. 40, 234-241.

KWBSP, 1989. Exploited fishery resources of Vemband Lake. Final report presented to Kuttanad water balance study project, Indo Dutch co-operation programme, Kuttanad water balance study project, 12, pp143.

Legendre, L., Lefevre J. 1989. Hydrodynamical singularities as controls of recycled versus export production in oceans, 49-63. In W. H. Berger et al. [eds.], Productivity of the ocean: Present and past. Wiley.

Love, R.M., 1980. The Chemical Biology of Fishes. Academic Press, London.

Madhu, N.V., Jyothibabu, R., Maheswaran, P.A., Gerson, V.J., Gopalakrishnan, T.C., 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.

Madhu, N. V., Jyothibabu, R., Balachandran, K. K.,Honey, U. K., Martin, G. D., Vijay, J. G., 2007. Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters-India), *Est. Coast. Shelf Sci,* 73, 54-64.

Madhupratap, M., 1978. Studies on the ecology of zooplankton of Cochin backwates, Mahasagar. *Bull.Natn.Inst.Oceanogr.II*: 45-56.

Madhupratap, M., Venugopal, P., Haridas, R., 1979. Biochemical studies on some tropical estuarine zooplankton species. *Indian J. Mar. Sci.* 8, 155-158.

Madhupratap, M., 1987. Status and strategy of zooplankton of tropical Indian estuaries: A review, *Bull. Plankton Soc. Japan,* 34, 65-81.

Madhupratap, M., Nair, S.R.S., Haridas, P., Padmavati, G., 1990. Response of zooplankton to physical changes in the environment: coastal upwelling along central west coast of India, *J. Coast. Res.*, 6, 413 - 426.

Martin, G. D., Jyothibabu, R., Madhu, N. V., Balachandran, K. K., Maheswari Nair., Muraleedharan, K. R., Arun, P. K. , Haridevi, C. K., Revichandran, C., 2012. Impact of eutrophication on the occurrence of Trichodesmium in the Cochin backwaters, the largest estuary along the west coast of India, *Environ. Monit. Assess.*185, 1237–1253.

Medford, B. A., Mackay, W. C., 1978. Protein and lipid content of gonads, liver and muscle of northern pike (*Esox lucius*) in relation to gonad growth. *J. Fish. Res. Board Can*.,35,213-219.

Menon N.N, Balachand, A.N., Menon. N.R, 2000. Hydrobiology of the Cochin back water system- a review. *Hydrobiologia*., 430: 149-183.

Mishra, Sujatha, D., Panda, R.C., 1993. Panigrahy: Physico-chemical characteristics of the Bahuda estuary (Orissa), East coast of India. *Ind. J. Mar. Sci*., 22, 75-77.

Moore, J.K., Abbott, M.R., 2000. Phytoplankton chlorophyll distributions and primary production in the Southern Ocean. *J. Geophys. Res*., 105, 28709-28722.

Moss, B., 1968. Studies on the degradation of chlorophyll a and carotenoids in freshwaters. *New Phytol,* 67, 49-59.

Nair, P. V. R., Joseph, K. J., Balachandran, V. K., Pillai, V. K., 1975. A study on the primary production in the Vembanad Lake. Third all India symposium on the estuarine ecology, Cochin. *Bull. Dept. Mar. Sci. Univ.,* Cochin. 7, 161-170.

Nargis, A. and Hossain M. A., 1987. Food and feeding habit of Koi fish *(Anabas testudineus* Bloch. Anabantidae: Perciformes). Bangladesh J. Agri. 12(2), 121-127.

Nayar, S., Gowda, G., 1999. Studies on phytoplankton pigments in a tropical coastal lagoon. *Ind. J. Fish*., 46, 215-220.

Niemi, G.J., and Mc Donald. M., 2004. Application of ecological Indicators. *Annu. Rev. Ecol. Evol. Syst.* 35,89–111.

Nisha.P.Aravind, 2008. Ph.D thesis, Cochin Univeristy of Science and Technology, Kochi.

Padmakumar K.G., L. Bindu., P.S Sreerekha Nitta Joseph. 2009. Food and Feeding of the Golden catfish, *Horabagrus brachysoma* (Gunther). *Indian J. Fisheries.* 56(2): 139-142.

Palmer, C, M., 1969. A Composite rating of algae tolerating Organic pollution. *J. Phycol*. 5, 78.

Pandey, A., Srnastava, P. K., Adirkari, S. and Singh, D.K. 1992. pH Profile of Gut as an Index of Food and Feeding Habits of Fishes. J. *Freshwat. Biol.*, 4(2),75-79 .

Pandey, B.N., Mishra, A.K., Das, P.K.L, Jha, A.K .,1995. Studies on Hydrological conditions of River Saura in relation to its impact on biological health. Recent research in aquatic environment. Daya publishing House, New Delhi, India. 57-65.

Partensky F, Hoepffner N, Li WKW, Ulloa, Vaulot D., 1993. *Plant. Physiol*., 10-1,285

Patil, G.P., Rosenzweig, M. (eds) 1979. Contemporary Quantitative Ecology and Related Ecometrics, Fairland (Maryland), International Co-operative Publishing House.

Patil, S.G., 1987.Studies on plankton in relation to hydrography of Nethravathy-Gurupur estuary, Mangalore (DK). MFSc.Thesis. University of Agriculture Science, Bangalore.

Patil, S.G., 2002. Limnological investigations-Biotic factors. Zoological Survey of India. Wetland ecosystem series No.3 Fauna of Ujani. 27-61.

Phillips AM Jr., Poston HA, Livingston DL. 1967. Theeffect of caloric sources and water temperature up ontrout growth and body chemistry. *Fish. Res. Bull*., 30, 25-34.

Porra, R.J., Pfündel, E.E., Engel, N., 1997. Metabolism and function of photosynthetic pigments. In: Jeffrey SW, Mantoura RFC, Wright SW (eds) Phytoplankton pigments in oceanography: Guidelines to modern methods. UNESCO, Paris, pp 85.

Potogkam, K. 1972. Experiment on feeding climbing perch, *Anabas testudenius* (Bloch) with ground trash fish and pellets. Department of Fisheries Annual Report, Bangkok, Thailand.

Pramodbabu, K.R, 2007, Ph.D thesis, M.G.University.

Prasad, R, R., 1969. Zooplankton biomass in the Arabian Sea and the Bay of Bengal with a discussion on the fisheries on the region. *Proc. Natl.Inst.Sci*.India, 35, 389-437.

Project report, 2002. Department of Ocean Development.Govt. of India.

Qasim, S. Z., Wellershaus, S., Battathiri, P. M. A., Abidi, S. A. H. 1969. Organic production in a tropical estuary. *Proc. Indian Acad. Sci.,* 69B (2), 51-94.

Qasim, S.Z., 1980. Adaptation in phytoplankton to changing condition in tropical estuaries. *Mahasagar*.,13 (2), 117-124.

Qasim , S, Z., Sen Gupta , R., 1981. Environmental characteristics of the Mandovi-Zuari estuarine system in Goa. Est. Coast. Shelf Sci.,13, 557-578.

Raimbault, P., Rodier, M., Taupier-Letage, I., 1988. Size fraction of phytoplankton in the Ligurian Sea and the Algerian Basin (Mediterranean Sea): size distribution versus total concentration. *Mar. Microb. Food Webs.,* 3, l-7.

Rajasegar, M., M. Srinivasan and R. Rajaram, 2000. Phytoplankton diversity associated with the shrimp farm development in Vellar estuary, South India. *Seaweed Res. Utilization.*, 22, 125-131.

Rajesh, K.M., Gowda G., Mridula, R., Mendon, 2002. Primary productivity of the brackishwater impoundments along Nethravathi estuary, Mangalore in relation to some physico-chemical parameters. *Fish.Technol*., 39, 85-87.

Ramaiyan V, Paul, A. L., Pandian, T.J., 1976. Biochemical studies on the fishes of the order clupeiformes. *J. Mar.Biol. Ass.,* India, 18(3), 516-524

Ramakrishnan, R., Perumal, P., Santhanam, P., 1999. Spatiotemporal variations of hydrographical features in tha Pichavaram mangroves and Mohl aqua farm, South east coast of India. In: *Proc. Intl. Sem. Appl.Hydrogeochem*., Annamalai University, Annamalai Nagar, India, Published by Dept. of Geology, Annamalai University, Annamalai Nagar, India.197-203.

Renjith, K. R., Manju Mary Joseph, Prosenjit Ghosh, Habeeb Rahman, K., Ratheesh Kumar, C. S., Chandramohanakumar N., 2012. Biogeochemical. Facsimile of the organic matter quality and trophic status of a micro-tidal tropical estuary, *Environ. Earth. Sci*., DOI 10.1007/s12665-012-2159-0.

Renjith, K.R., 2006. PhD thesis. Cochin University of Science and Technology.

Riley, J.P., Chester, R., 1971. Introduction to marine chemistry, London, Academic Press.

Ruttner-Kolisko, A., 1974. Plankton Rotifers. E.Schweizerbart'sche, Stuttgart. 146

Ryther, J, H., 1963. Geographical Variations in productivity in the Sea, Ed. M.N. Hill, Interscience publ; London, 347-380.

Sanilkumar, 2009. PhD Thesis. Cochin university of science and Technology.

Scheer, H., 1991. Chlorophylls. CRC Press, Boca Raton, Ann Arbour, Boston, London.

Scheer, H., 2003. The pigments. In: Green, B.R., Parsons, W.E., (eds) Light-harvesting antennas in photosynthesis. Advances in Photosynthesis and Respiration, Vol 13. Kluwer Academic Publishers, Dordrecht, 29.

Schlüter L, Mohlenberg, F., Havskum, H, Larsen, S., 2000. The use of phytoplankton pigments for identifying and quantifying phytoplankton groups in coastal areas: testing the influence of light and nutrients on pigment/chlorophyll a ratios. *Mar. Ecol. Prog. Ser.,* 192, 49-63.

Selvaraj, G, S, D., Thomas, V.J., Khambadkar, L.R. 2003. Seasonal variation of phytoplankton and productivity in the surf zone and Backwaters at Cochin. *J.Mar.biol.Ass.*India., 45, 9-19.

Senthilkumar, S., Santhanam, P., Perumal, P., 2002. Diversity of phytoplankton in Vellar estuary, Southeast coast of India. The 5th Indian Fisheries Forum Proceedings (Eds.: S. Ayyappan, J.K. Jena and m. Mohan Joseph). Published by AFSIB, Mangalore and AeA, Bhubanewar, India. 245-248.

Sheeba, P Jayalakshmi, K.V and Saraladevi, K. 2004. Bottom fauna of dredging and dredge soil and disposal sites of a tropical estuary, *J.Ecol.Envt.Sci.*, (30), 225-238.

Silas, E.G., Parameswaran Pillai, 1975. Dynamics of Zooplankton in a tropical estuary (Cochin Backwater). With a review on the plankton

fauna of the environment. *Bull. Dept. Mari. Sci*., Univ. Cochin, VII,2, 329-355.

Sinha, M., Mukhopadhyay,M.K., Mitra, P.M, Bagchi, M.M Karamkar,H.C. 1996. Impact of Farakha Barrage on the hydrology and fishery of Hooghly estuary, *Estuaries.*, 19,710-722.

Sivadasan, K.K. & Joseph K.J. 1995. Photosynthetic pigments of benthic microalgae in Cochin estuary. *Indian. J. Mar. Sci*., 24:231-232.

Sreekumar, R., Joseph, K.J., 1995. Periphytic algae of Cochin estuary. *Phytos.,* 34, 83-89

Srivastava, C.B.L., 1999. Fishery Science and Indian fisheries, Ketab Mahal, Allahabad, 527.

Stansby, M. E.1962. Proximate composition of fish. In Heen, E., and R. Kreuzer (eds .), Fish in nutrition, 55-60. Fish News (Books) Ltd., London.

Stoermer, E, F., Yang, J, J., 1969. Plankton Diatom Assemblages in Lake Michigan Ann Arbor.

Stolte, W., Kraay, G.W., Noordeloos, A. A. M., Ricgman, R., 2000. *J .Phycol.,* 36,529.

Thillai Rajsekar, K., Perumal, P., Santhanam, P., 2005. Phytoplankton diversity in the Coleroon estuary, Southeast coast of India. *J. Mar. Biol. Ass India.*, 47, 127-132.

Tiwari, L.R., Vijayalakshmi, R., Nair., 1998. Ecology of the phytoplankton from Dharmatar creek, West coast ofIndia. *Indian. J .Mar .Sci.* Vol. 27. pp. 302-309.

Tukaj, Z., Matusiak-Mikulin, K., Lewandowska, J., Szurkowski, J., 2003. *Plant Physio.Biochem.,* 41, 337.

Van Leeuwen, M., Te Stroet, C., Butler, A. and Tompkins, J. 1998. Stochastic determination of well capture zones. *Water Resour. Res. 34(9): doi: 10.1029/98WR01552. issn: 0043-1397.*

Young, A., Britton, G., 1993. Carotenoids in Photosynthesis- Chapman and Hall, London. pp 498.

Zapata, M., Rodrifuez, P., Garrido, J., 2000. *Mar. Ecol. Prog Ser.,* 195, 29.

Chapter 5

SUMMARY

Cochin backwater system exhibits a unique ecological complex having marine, estuarine and fresh water environments at different zones and a large number of organisms inhabit in these environments. Comprehensive studies covering the combined effects of hydrobiology and nutrient dynamics on trophic structure in this ecosystem is scarce. Present investigation was an attempt to evaluate the implications of the hydrobiology and nutrient dynamics on the trophic relationship and community structure in the Cochin backwaters. An integrated approach relating biological as well as physicochemical aspects of this unique backwater system with respect to seasons was employed.

Seasonal samplings of water, sediments primary producers, secondary producers and fish landings were made from fifteen stations in Cochin backwater system during January 2009 (POM 08), April 2009 (PRE 09), August 2009 (MON 09), January 2010 (POM 09) and April 2010 (PRE 10). Water samples (both surface and bottom layers) were collected using Niskin Sampler and surface sediment samples were taken using Van Veen Grab. Water samples for general hydrography and nutrient analysis was subsampled into high density polyethylene bottles, kept on ice bags, transported to laboratory and analysed without delay. Hydrographic parameters such as pH, dissolved oxygen, BOD, carbon dioxide, temperature, salinity, alkalinity, chlorophyll pigments, productivity, depth and transparency were determined by standard procedures. Nutrients like

nitrite- N, nitrate-N, ammonia-N, phosphate, silicate, iron were also estimated in the water samples by spectrophotometric methods. General sedimentary parameters like pH, redox potential, texture, total organic carbon, total nitrogen, and total sulphur were estimated to assess the general geochemical setting of the sedimentary study area. Fractionation of nitrogen and phosphorous in sediments was also carried out to evaluate the enrichment of these nutrients in the estuarine environment. Primary productivity of the study area was investigated by various tools like phytoplankton (qualitative and quantitative), chlorophyll pigments, light and dark DO bottle method. While secondary production was evaluated by zooplankton abundance and tertiary production by fish landings, gut content analysis and proximate composition. Statistical methods were employed to establish the spatiotemporal variation; interrelationships existed among various estimated parameters and trophic interactions (ANOVA, Pearson correlation and PRIMER).

Values of pH in both surface and bottom waters remained slightly alkaline at all the stations. Higher values for pH might be due to the influence of seawater ingression or increased photosynthetic activity. Discharge of floating sediments carried by land runoff as well as dredging operations in Cochin estuary resulted in wide fluctuations in transparency of water column. Higher concentration of dissolved oxygen recorded during monsoon could be due to the cumulative effect of high wind velocity joined with heavy rainfall and the resultant freshwater mixing. The combined effects of higher biological production coupled with sinking of organic matter, discharge of untreated effluents, wastes from aquaculture fields and agricultural fields into the backwater system have contributed to the increased BOD levels. In the present investigation, no vertical

stratification for salinity was observed and fresh water conditions were prevalent during the monsoon and the estimated higher values during post monsoon season could be due to increased rate of evaporation and sea water ingression. Among nutrients, ammonia displayed a non-uniform distribution throughout the entire study period which indicated an exogenic input in the estuary. The increased nitrate level was due to fresh water inflow, organic decomposition and terrestrial run-off during the monsoon season. The lower contents of nitrite during the premonsoon season were due to less freshwater input, higher salinity, higher pH and also uptake by phytoplankton. The higher phosphate content in the water column could be attributed to regeneration and release of total phosphorus from sediment into the water column by turbulent mixing. Silicate exhibited significant negative correlation with salinity, suggesting its input through land runoff.

Texture analysis provided an insight into the grain size of the sediments in the study area. Higher concentration for organic carbon reported at some stations could be attributed to the settling of the terrigenous organic matter derived from land runoff. During monsoon value observed could be attributed to the dilution effects associated with high river discharge. The average TOC/ TS values indicated the periodic anoxia nature of the system where, the sediments undergo sulphate reduction below an oxygenated water column. Fractionation of nitrogen and phosphorous in sediments were carried out to evaluate their various forms and enrichment character. The lower values for C/P and N/P ratio indicated enrichment of phosphorous in sediments of estuarine system. Phosphorus fractions were analyzed to quantify the different fractions of phosphorus in the estuarine sediments in order to assess the processes leading to the

fractional distribution of phosphorus, its bioavailablity and influence on trophic status. The contribution of labile phosphorous to total P pool was higher indicating that sedimentary P can act as a source for this nutrient to water column.

Biochemical composition of sedimentary organic matter in the study region showed a dominance of lipids followed by proteins and carbohydrates. Higher concentrations of lipids and proteins in sediments reflected the productive nature of the system. The dominance of lipids and protein over carbohydrates indicated the nutritional status of organic matter in the sediments of the study region. PRT/CHO and LPD/CHO ratios were useful to evaluate the quality and quantity of organic matter in the estuarine sediments. Estimated PRT/ CHO ratios having values <1 indicated the presence of aged or less degradable organic matter (refractory organic matter). Lower values of LPD/CHO ratio might be attributed to the higher concentration of carbohydrates derived from allochthonous sources. The higher chlorophyll content in the sediments of the study area pointed towards the higher primary production, settling of the pigments to sediment and their preservation due to anoxic conditions. Biochemical composition of sediment also revealed the fact that the trophic state of the study area can be included under meso-oligotrophic condition. The average values of C/N indicated a mixed origin of organic matter ie., autochthonous as well as terrestrial input. The higher tannin and lignin content in the estuarine sediments could be attributed to the input of terrestrial higher plant debris associated with land runoff.

The present study revealed the fact that phytoplankton diversity was more pronounced during premonsoon season, but maximum density was observed during postmonsoon season due to stable hydrographical

conditions and less predation. *Skeletonema costatum, Cyclotella meneghiniana* etc are present which are euryhaline. Phytoplanktons are classified as abundant, rare, common, few according to biomass. Community composition and community diversity profiles revealed the seasonal and spatial variation of phytoplankton in the study area. Among the various diversity indices Shannon Weiner index was satisfactory with regard to changes in index value with the variation in pollution intensity. Biotic diversity index revealed higher level of environmental stress which will tend to lower biotic diversity.

The results of the present study revealed that production of phytoplankton in the estuary exceeds several times than zooplankton. Increase in nitrogen and phosphorous in the system is a direct response of human interference. The present investigation recorded higher phytoplankton production which may lead to eutrophication. The insignificant correlation between nutrients and primary production pointed out the fact that inspite of the higher concentration of available nutrients in the water column; the productivity was restricted by factors like transparency and meteorological parameters. The phytoplankton distributions, species composition and dominance are closely associated with the prevailing hydrographic condition and nutrients. The standing crop of phytoplankton showed seasonal variation and spatial variation in CBW. Highest peak was observed during POM 09. During this peak Bacillariophyceae (diatoms) were dominant which could well thrive in widely varying hydrographical conditions both phytoplankton growth and primary production and showed fluctuations according to seasons. Similarity between stations was studied with the help of Bray Curtis similarity index and community coefficient (using only the presence and

absence of species). In general, higher diversity was followed by lower level of species evenness or equitability in distribution. The results could be included that the existing conditions were favourable for pollution tolerant phytoplankton species. An inverse relationship between species richness and evenness component of diversity which is mathematically expected can be observed in this study. It can be concluded that the components of diversity viz., richness and evenness are necessary to furnish adequate explanation of species diversity. The highly significant negative correlation existing among different groups of phytoplankton explained the presence of a particular group inhibiting the existence and growth of another set of phytoplankton due to inter/intra specific competition or predation prevailing in the ecological niche.

In the present investigation, copepods were present throughout year in the plankton samples and formed the dominant component of the crustacean holoplankton. Copepods like *Acartia centura*, *Acartia spinicauda*, *Acartia bowmani*, *Acartia southwelli*, *Acartia pacifica* and *Acartia plumosa* were present during all seasons except monsoon. The zooplankton distribution in the back waters suggests that the salinity is the major limiting factor controlling their abundance. All groups showed remarkable seasonal distribution with respect to changes in salinity and other environmental factors. It was found that population density of zooplankton in the estuary was no way limited by primary production, which throughout the year far exceeds the consumption by zooplankton.

Fish stock assessment was made from seven fish landing centres in the study area. Monthly data were collected for seasonal comparison for fishes captured from the estuary. It was observed that 16 species of major food fishes and 5 crustacean species were identified which were found to

be valued and marketed in the local markets. The decline in the fish production was observed during the investigation. The proximate composition of the commercially important fish species from CBW were studied to assess their nutritional values in order to achieve the knowledge of the risk and benefits associated with the indiscriminate consumption of these species. This study would help us for taking necessary steps which should be taken to increase the production and proper management of natural habitat of the species. Differences in biochemical composition of fish may also occur within the same species depending upon the fishing ground, fishing season, age and sex of the individual and reproductive status. The estimation of proximate composition was carried out in the present investigation which revealed seasonal variation. The main causes are spawning cycle and food supplies and are the main factors responsible for this variation. Proper understanding about the biochemical constituents of fish has become a prime need for the nutritionists and dieticians.

The integrated approach involving hydrobiology, nutrient dynamics and productivity and trophic level interactions will be useful to implement corrective measures to restore the health of Cochin backwater system and implementation of sustainable management practices. The present study would serve as a reference for the future investigations in this ecosystem.

..... ൹൹൹.....

LIST OF PUBLICATIONS

1. Padmakumar, K.G., Anuradha Krishnan, **Radhika, R**., Manu, P.S., Shiny, C.K, 2002. Openwater Fishery Interventions in Kuttanad,Kerala,with reference to Fishery decline and ecosystem changes".In: M.r.Bhoopendranath, B.Meenakumari, J.Joseph,T.V.Shankar, P. Praveen and N.Edwin(eds.), Riverine and Reservoir Fishery challenges and strategies, Society of Fishery Technologists (India), CIFT, Cochin, pp.15-24.

2. Padmakumar, K.G., Anuradha Krishnan, Manu, P.S., Shiny, C.K., **Radhika, R**., 2002. Thannermukkom barrage and fishery decline in vembanad wet lands ,Kerala, Wetland conservation and Management in Kerala, 14th Kerala Science congress proceedings of theme topic, M. Jayalakshmi(ed.) Kerala State Committee on Science and Technology and environment . January 29-31., pp 27-36.

3. Rosamma Stephen., **Radhika, R.,** 2002. Mesozooplankton of the mixed layer in the Bay of Bengal antecedent and subsequent to a super cyclone. Presented in GLOBEC Open Science Meeting 15-18 October in Quindao,China

4. Prasannakumar, S., Jayu Narverkar, C., Shaji , P., Anand, P.Sabu, Rejomon, G.,.Josia, J.,.Jayaraj, K.A., **Radhika, R.,** Nair, K.K.C., 2004. Intrusion of the Bay of Bengal water into the Arabian sea during Winter monsoon and associated chemical and biological response Geophysical Research letters., Vol. 31,

5. **Radhika, R,** 2005. Antimicrobial activity of Frog skin", VISTAS, Volume I Number I.
6. Jayu Narvekar., Prasannakumar, S., Sabu P., Anand, P., Rijomon, G., Jayaraj, K.A., Josia, J., **Radhika, R.,** 2010. Wintercooling in the Northern Arabian Sea, 2003. Symposium on Indian Ocean Marine Living Resources, CMLRE, Ministry of Earth Sciences, Kochi. 2- 3 December 2010.
7. Rosamma Stephen., **Radhika, R** , 2011. Key Copepod species of Upwelling reflecting environmental changes in the Eastern Arabian Sea – a Multidecadal Study" presented in EGU, Conference held at Vienna.
8. **Radhika.R.**, Ranjitha Raveendran , Sujatha. C.H., 2011. Role of women in the improvement of Aquatic resources in and around Cochin - an Overview. Presented in the UGC Sponsored seminar, conducted by Department of Economics, Cochin University of Science and Technology,
9. Rosamma Stephen., **Radhika R., 2012**. Decadal changes in Pelagic copepod distribution in the EEZ, West Coast of India". Presented in 2nd Climate Change International Symposium, Effects of Climate Change on the World's Oceans, May 15-19, 2012, Yeosu, Korea.

…… ……