PRODUCTIVITY PATTERN AND ITS DYNAMICS IN A TROPICAL ESTUARY, SOUTHWEST COAST OF INDIA

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Productivity Pattern and its Dynamics in a Tropical Estuary, Southwest Coast of India

Ph.D. Thesis under the Faculty of Marine Sciences

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Certificate

This is to certify that the thesis entitled **"Productivity Pattern and its Dynamics in a Tropical Estuary, Southwest Coast of India"** is an authentic record of research work carried out by Mrs. Thasneem T.A. (Reg. No: 3601), under my supervision and guidance in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Marine Biology, Cochin University of Science and Technology under the faculty of Marine sciences and that no part of this has been presented before for the award of any other degree, diploma or associateship in any university.

Kochi - 682 016
May 2016

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Declaration

I hereby declare that the thesis entitled **“Productivity Pattern and its Dynamics in a Tropical Estuary, Southwest Coast of India** is an authentic record of research work carried out by me under the supervision and guidance of Dr. S. Bijoy Nandan, Professor, Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Marine Biology, Cochin University of Science and Technology under the faculty of Marine sciences and that no part of this has been presented before for the award of any other degree, diploma or associateship in any university.

Kochi - 682 016 **Thasneem T. A.**
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Dedicated to my parents…

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Km	-	Kilometer
ha	-	Hectares
m	-	Meters
Cm	-	Centimeters
mm	-	millimeters
Km^2	-	Square kilometre
%	-	Percentage
Fig.	-	Figure
et al	-	et alli, and others
TDS	-	Total Dissolved Solids
DO	-	Dissolved Oxygen
BOD	-	Biological Oxygen Demand
GPP	-	Gross Primary Productivity
NPP	-	Net Primary Productivity
µ mol	-	Micro mol
L	-	Litres
ml	-	Milliliter
t	-	Tonnes
C	-	Carbon
y^{-1}	-	per year
day^{-1}	-	per day
wt	-	Weight
sp	-	Species
m^{-2}	-	Square meter
m^{-3}	-	Cubic meters
Vis-à-vis	-	in relation to
°C	-	degree Celsius
No:	-	Number
nm	-	Nanometer
N	-	North
v6	-	Version 6

m^3/s - Cubic meter per second

$\leq$ - less than or equal to

$\geq$ - Greater than or equal to

SD - Standard Deviation

ppm - Parts per million

g - gram

mg - Milligram

µm - Micrometer

ind m^{-3} - Individual per cubic meters

……

Chapter 1

GENERAL INTRODUCTION

Wetlands are amongst the most productive ecosystems on earth and deliver many important services to the human society. The importance and usefulness of wetlands was first brought to the notice of the world through a convention on wetlands held at the Iranian city of Ramsar, in the year 1971, which defined wetlands as (Article 1.1) “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters”. In addition, the Convention (Article 2.1) appends that wetlands “may incorporate riparian and coastal zones adjacent to the wetlands, and Islands or bodies of marine water deeper than six meters at low tide lying within the wetlands”. Wetlands are categorized into marine (coastal wetlands), estuarine (including deltas, tidal marshes, and mangrove swamps), lacustarine (lakes), riverine (along rivers and streams), and palustarine (‘marshy’ – marshes, swamps and bogs) based on their hydrological, ecological and geological characteristics (Cowardin et al., 1979). Coastal wetlands occupy an important position in the landscape as they are sinks and sources of organic matter in the trophic system and repositories of unique and specified biotic resources. During the last century, great concern and attention have been given to the impacts of human activities on the integrity and sustainability of coastal ecosystems. The land based anthropogenic activities are strongly reflected in the ecological quality of coastal wetlands.

The coastal zones are the “homes to the ocean’s bounty”. They play a key role in maintaining the ecological balance between marine and inland ecosystems. They are among the most productive ecosystem component in the world which influence the nutrient loadings and serve as regulators of pelagic productivity. The coastal zone, which occupies 8% of the global surface area, accounts for about 25% of global primary production. 90% of the current world fishery production comes from the exclusive economic zone (i.e., from within 200 miles (321.87 km) of the coast), and most of what is caught comes from within 5.59 miles (9 km) of the shore. The loss of coastal wetlands is of particular importance to the fishing industry. Such wetlands are important breeding grounds for coastal fish species but are currently being lost at rates of more than 1% per annum in some areas (Intergovernmental Panel on Climate Change (IPCC), 1994). Bigford, 1991 estimated that a 50% reduction in wetland productivity would lead to a 15-20% loss in estuarine dependant fish harvests.

Coastal wetlands in their natural state provide a wealth of values to the society. The coastal zones provide diverse habitat for fishes, shell fishes, water fowls and other wildlife. Besides providing habitat, coastal zones play an important role in maintaining the environmental quality of the aquatic habitat. They also help to maintain good water quality by storing and recycling nutrients especially nitrogen and phosphorus from flooded waters for plant growth and prevent eutrophication and over enrichment in the water column. They help in removing pollutants from the system, also reducing turbidity and thereby the sediment loads in the water column. Reduction of sediment load is important because the sediments in the water column transport absorbed nutrients, pesticides, heavy metals and other toxins. Coastal wetlands play a key role in nutrient recycling, oxygen production, microclimate regulation and world climate. Many areas in global coastal zones are very rich in biodiversity. Such biologically rich, endangered regions are identified as biodiversity hot spots. Among the 25 biodiversity hot spots of the world, 23 of them are at least partially within coastal zones from which 10.45% of these coastal zones are designated as protected. But high population pressure in and around the coastal systems threaten the biodiversity within the ecosystem (Shi and Singh, 2003). So effective policies are urgently required for the management of these biodiversity hot spots.

The socio-economic values of the coastal zones include protection of shorelines from flood and storm damage, erosion, water supply and ground water recharge, harvest of natural products (timber, peat, fishes etc), livestock grazing, recreation and aesthetics. Coastal zones have been key for transporting goods, people and ideas because sea trade is less costly than land or air based trade. People are attracted to coastal zones for living and work, as well as for leisure, recreational activities and tourism. Since the late 1970s tourism has become the second most important commodity in world trade, surpassed only by oil.

Coastal zones are the most crowded, overdeveloped and overexploited regions of the world. Population density is higher in coastal zones than inlands, with an average of 87 people per km^2 in coastal zones compared to 23 people per km^2 inland in the year 2000.This implies high exposure to hazards and significant human induced changes to range of natural processes (Pernetta and milliman, 1995; Turner et al., 1996). The United Nations in 1992 estimated that more than half of the world population lived within 60km of a shoreline, and this could rise to about 60% by the year 2020. The United Nations Association in Canada in 1991, calculated that 7 out of 10 people in the world lived within 80km of a coast and almost half of the world's cities with populations of over one million people were situated around estuaries. The impact of population explosion was high in the coastal zones of the developing countries in Asia, Africa, and South America, where government regulatory controls are less stringent or lacking compared to those of most developed countries. The population distribution in coastal zones is as follows: 63.7% of the area has low or non-existent population density, 19.2% of the area has medium population density and the remaining 17.1% of the area is under high population pressure. The highest population pressure exists in the coastal zones in Europe and Asia, with 31% of the area having high population density. About 38% of the world's population lives on 7.6% of the total area on earth (Shi and Singh, 2003).

More than 260 cities with populations over 100,000 are located in coastal zones around world, which constitutes of 50% of all cities having over 100,000 people. Among the ten most populous cities in the coastal zone, five are in Asia, three are in South America, one is in North America, and one is in Europe. Out of the five populous cities in Asia, two are in India: Kolkata (Formerly Calcutta) and Mumbai (Formerly Bombay). The average population density in coastal zones was 77 people per km^2 in 1990 and 87 people per km^2 in 2000. This population explosion will continue in a progressive manner such that there will be 99 people per km^2 in 2010, 115 people per km^2 in 2025 and 134 people per km^2 in 2050. The population distribution and pressure is very high in the coastal regions of India, because 50% of the land with high population density is in the coastal zone. About 47.52% of the cultivated land area in India is located in the coastal zone. Thus, coastal zones are bright spots for the current and future population distribution and growth in the world (Shi and Singh, 2003).

In the last few decades, the issues and problems associated with the coastal resources, environment, population and their relationship to sustainable development have continued to receive great attention worldwide. The coastal zones are being exposed to various threats such as sea level rise, coastal erosion and urbanization, changing storm frequency, habitat loss and pollution. The physical and ecological integrity of the coastal systems has been seriously jeopardised due to increasing human population and activities. These environmental stresses affected the coastal zones' ability to provide fishes, protect home and business, reduce pollution and erosion and sustain biodiversity (Shi and Singh, 2003). The

United Nations Agenda 21 from the Earth summit, Rio de Janeiro, 1992, "set forth rights and obligations of the States and provides the international basis upon which to pursue the protection and sustainable development of the marine and coastal environment and its resources. This requires new approaches to marine and coastal areas management and development, at the national, sub-regional, regional and global levels". Unless things change very quickly, world's coastal areas face a grim future (World Resource Institute, 2000-2001).

The coastal zones of the world are vulnerable to global climate change. The possible effects could be increased flooding and inundation of low lying areas, shoreline retreat and loss of land, beach erosion, storm surges, salt water intrusion, siltation, livelihood and wetlands (McLean et al., 2001). During the past century, sea level has risen at a rate of 1-2 mm yr^{-1} (Church and White, 2006).The Intergovernmental Panel on Climate Change (IPCC) has projected that the global sea level will rise 15-95 cm by 2100, principally due to thermal expansion of the ocean and the melting of small mountain glaciers (Watson et al., 1997).Warming of atmosphere and oceans lead to coral bleaching, increased eutrophication in the wetlands and fresh water supplies, as well as damage to coastal structures and agricultural lands to the cyclones. These problems in turn affect the tourism, fishery, agriculture and human life in the coastal zones (Turner et al., 1996). Global sea level rise resulted in the submergence of wetlands and conversion of marsh habitat to an open system which was observed in the northern coast of Gulf of Mexico. The 2015 Conference of the Parties (COP-21) of United Nations Framework Convention on Climate Change

(UNFCCC) set a global agreement on climate, with the aim of limiting global warming below 2°C by 2020.

The vulnerability of Indian coastal region due toestimated sea level rise is alarming. The low lying coral atolls of the Lakshadweep archipelago are highly vulnerable to inundation. Due to a larger frequency of storms and presence of lower continental slopes, the east coast of India is more vulnerable than the west coast to damage from storm surges. The region least vulnerable to coastal erosion lies between approximately 12°N and 18°N on the west coast. However, regions to the south of this belt are likely to experience increased coastal erosion due to the continued rise in sea levels (Shetye et al., 1990). The Vembanad backwater system is one of the most vulnerable coastal ecosystem, many Islands are under the threat of sea level rise. Global warming is also reported to affect the coastal zone of Kochi by probable inundation of low-lying areas, along with accelerated beach erosion and greater frequency of flooding events. Increasing erosion and changes in the sedimentation would cause disturbance in the sandy beaches and sand dunes. Sea level rise would inevitably bring substantial losses from shoreline retreat and associated processes, and the indirect consequences may bring greater damages than the direct ones. The vegetation and life in the coastal environments are expected to be affected with harmful effects for the population in the region (Dinesh Kumar, 2006). According to Emery and Aubrey, 1989, relative sinking of land in the Kochi port continues at a rate of 2.27mm yr^{-1}.

1.1 Coastal zones and Estuaries

Among the most important environments of the coastal zone are the estuaries, which constitute transition zones or ecotones, where fresh water from land drainage mixes with sea water creating some of the most biologically productive areas of earth. In literature, an estuary is defined in a stricter sense. Pritchard, 1967, defined an estuary as a semi enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage. This widely excludes coastal lagoon and many of the tropical estuaries where the boundaries are not well defined. Kjerfve, 1989, gave a more comprehensive definition of estuary, placing it in the context of the entire coastal zone which states that "An estuarine system is a coastal indentation that has restricted connections to the ocean and remains open at least intermittently". The estuarine system can be divided into three regions, a tidal river zone, a mixing zone and a near-shore turbid zone. The tidal river zone is a fluvial zone characterised by lack of ocean salinity, but subject to tidal rise and fall in sea level. The mixing zone is characterized by mixing of water mass as well as existence of strong gradients of physical, chemical, and biotic entities of water masses. It extends from the tidal river zone to the seaward location of a river mouth or ebb-tidal delta. The near-shore turbid zone lies between the mixing zone and seaward edge of the tidal plume at full ebb tide.

Estuaries worldwide are being exposed to an increasingly complex suite of environmental perturbations such as nutrient enrichment, organic carbon loading, chemical contaminants, habitat loss and alterations, overfishing, freshwater diversions and introduced species, originating from overpopulation and uncontrolled development in coastal watersheds, as well as human activities in the estuarine embayment themselves. It is of great concern to detect the human induced alterations of estuaries in order to adopt cost effective remedial measures to improve the viability and health of the valuable coastal ecosystems (Kennish, 2002).

The Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), an international committee sanctioned by the United States, as well as scientific investigators from different countries around the world indicate that there are six primary pathways by which pollutants enter estuarine environments: (1) non-point source run-off from land, (2) direct pipeline discharges, (3) riverine inflow, (4) atmospheric deposition, (5) maritime transportation, and (6) waste dumping at sea (McIntyre,1992 and 1995; Goldberg, 1998; Kennish, 1997). Land-based sources predominate in the estuarine and coastal marine environments, with run-off responsible for an estimated 44% of the pollutant inputs, atmospheric deposition 33%, maritime transportation 12%, waste dumping 10%, and offshore production 1% (GESAMP, 1990). The most conspicuous sources of pollution in estuaries today are the nutrient enrichment, organic carbon loading such as sewage, oil spills, and toxic chemicals such as polycyclic aromatic hydrocarbons (PAH), halogenated hydrocarbons (Organochlorine pesticides) and heavy metals. Influx of pathogens, radioactive materials, thermal loading of natural waters, debris/litter, acid mining wastes, drilling mud and cuttings, pharmaceutical and alkali chemicals, pulp and paper mill effluents, suspended solids and turbidity are the other severe pollution problems in the estuaries.

Anthropogenic nutrient enrichment and organic carbon loading have been linked to the eutrophication of estuarine waters (Cloern, 2001; Paerl et al., 2006; Rabalais et al., 2009). The enhanced eutrophication can cause deleterious changes in ecosystem structure and trophic dynamics in many estuaries. The adverse effects associated with eutrophication are excessive plant growth, hypoxia, anoxia, periodic or toxic algal blooms, shading effects, build-up of toxins, mortality of benthic and pelagic species, reduced biodiversity, diminished secondary production, diminution of recreational and commercial fisheries, as well as altered species composition, abundance and distribution (Kennish, 2000; Howarth et al., 2000).

All heavy metals whether biologically essential (Cu, Co, Fe, Mn, Ni, Se, V and Zn) or not (Ag, Cd, Hg and Pb), can become toxic to estuarine organisms beyond a level of exposure. This can be defined as a threshold bioavailability, which not only depends on the ambient metal concentrations but also vary between metals, between species, and with physicochemical characteristics of area (Marchand et al., 2002) .Toxic chemical contaminants undergo biomagnification in estuarine food chains, posing a potential health threat to humans who consume contaminated sea food. Estuaries exposed to high levels of chemical contaminants experience significant changes such as loss of rare or sensitive species, decreased abundance of species, shifts in the age structure of population, and altered trophic interactions (Howells et al., 1990). Among heavy metals, mercury in particular is a toxic agent that has created problems in estuaries around the world. Anthropogenic sources of heavy metal contamination in estuaries include mining and smelting operations, refining and electroplating, dye and paint manufacture, and fossil fuel burning. The natural sources are river discharges, urban run-off, and atmospheric deposition (Turner, 2000).

Poly aromatic hydrocarbons (PAHs) enter estuarine and marine ecosystems from sewage and industrial effluents, oil spills, fossil fuel combustion and waste incineration. These contaminants have deleterious effects on the structure and function of benthic communities and occurrence of fish immune response. They enter the estuarine system from the industrial and municipal waste water discharge, urban and farmland run-off, as well as through atmospheric deposition (Wania et al., 1998). Sewage impacts are most acute in estuaries of developing countries, where effective sewage treatment and waste disposal programmes as well as government regulatory controls are largely deficient (Kennish, 2002). Additionally, pathogens from sewage pose a serious threat to human health, being responsible for cholera, hepatitis as well as gastro enteric diseases. Overfishing is a major issue in the marine and coastal waters because of the decline in finfish and shell fish resources. Declining fisheries have been reported in many estuaries along the Pacific, Gulf of Mexico, and Atlantic coasts during the past several decades. Introduction of exotic species is another serious problem in the estuarine environment which can lead to reduced species diversity, shifts in trophic organization, infiltration of detrimental pathogens and alteration of habitats. Fresh water diversion for human activities results in decreased river flow in estuaries. The reduced fresh water input into the estuary affects the biological organization and production of an estuary. The most direct physical impacts on estuaries are those associated with shoreline developmental structures (bulkheads, boat ramps, docks and piers) and dredging. Dredging and dredged material disposal in the estuaries has several negative effects, such as destroyed bottom habitats and impaired water quality, as well as direct and indirect impacts on organisms, most conspicuously those inhabiting the benthos (Kennish, 1997).

1.2 Productivity of the Estuarine Systems

Estuaries are one of the most highly productive ecosystems on Earth. The major primary producers in the estuarine system are phytoplankton, benthic micro flora, sea grasses, mangroves and salt marsh plants. The net annual production of phytoplankton ranged from 5-530 gC m^{-2} yr^{-1}. Most of the primary produce passes to the detritus food web, where it is decomposed by bacteria and fungi. Zooplanktons are the principal herbivorous consumers, converting plant to animal matter. They provide food for numerous benthic and nektonic fauna. Estuarine benthic fauna are divided into four major groups based on size: microfauna (<0.1mm), meiofauna (0.04-0.5mm), macrofauna (0.5mm – 20cm), and megafauna (>20cm) (Levinton, 1982). Fishes, marine mammals, marine reptiles, swimming molluscs and crustaceans, together with wading birds and shore birds represent the highest trophic-level organisms. Fishes dominate the nektonic communities in terms of numerical abundance and biomass. They also play a significant role in energy flow of the system. Estimates of annual fish production in temperate range from 5-150 gm^{-2} yr^{-1} where as in the tropics it ranges from 5-125 gm^{-2} yr^{-1} (Day et al., 1989).

Globally, primary productivity generates about 224×10^9 tonnes dry weight of biomass annually. Of this, 59% is produced in the terrestrial ecosystems and rest is produced in aquatic systems (Vitousek et al., 1986). About 2.2% of the world aquatic production is required to sustain the global fisheries industry. The estimated primary production required for the coastal and coral reef ecosystem is 8.3% (Lieth, 1978). The relatively low requirement is due to the higher level of productivity, large catches of low trophic levels (seaweeds, bivalves and other invertebrates) and overfishing which has left the reduced fish biomass unable to use the available production, compared to the upwelling region and continental shelves (Pauly and Christensen, 1995).

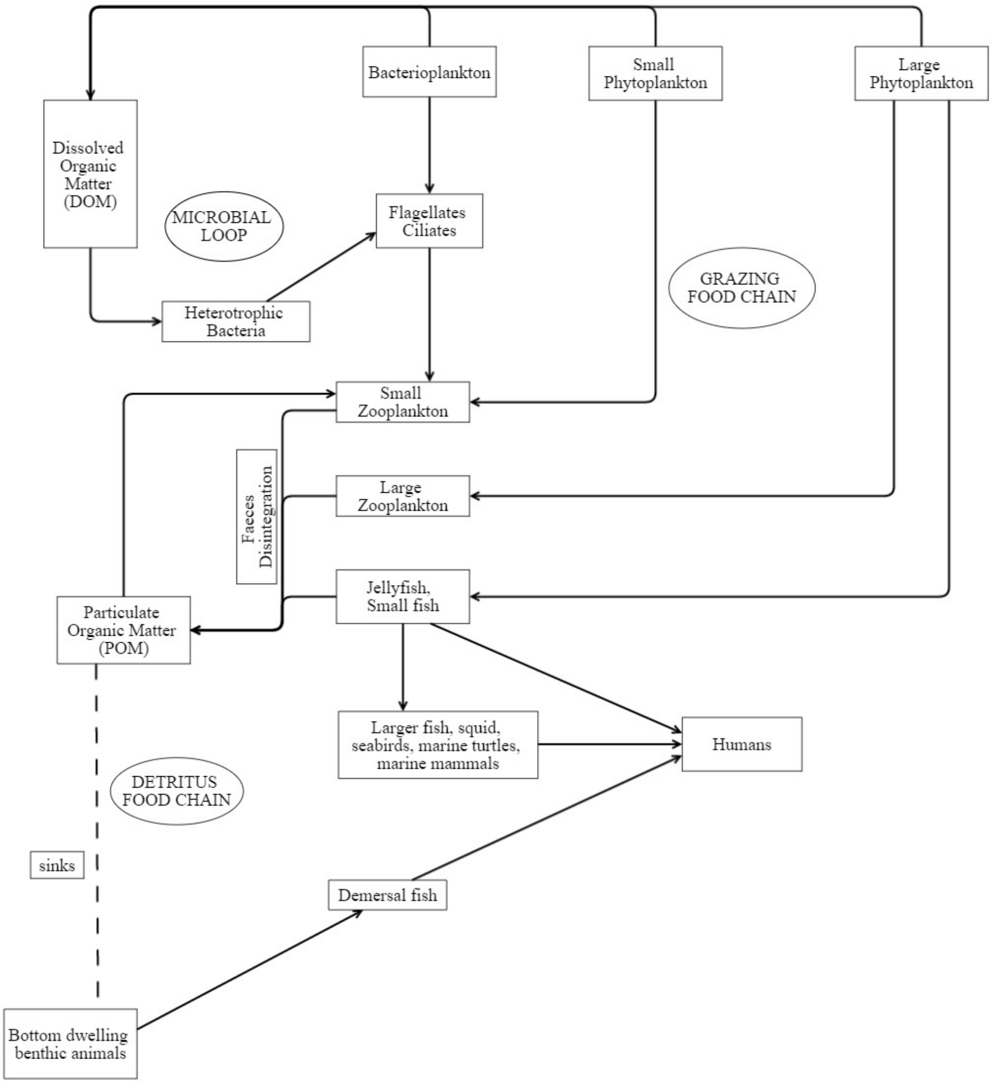
In phytoplankton-generated grazing food webs, phytoplankton such as diatoms, dinoflagellates and other microalgae forms the basis of classic grazing food chain in the oceans. The phytoplankton cells are consumed by the larger herbivorous grazers, in particular the ubiquitous copepods, an important group of zooplanktonic crustaceans. Zooplanktons and are fed upon by the secondary consumers (anchovies, silversides, jelly fishes) which are then consumed by larger predatory and marine animals such as large fishes, marine mammals, marine turtles and seabirds.

A sizeable portion of primary production in the oceans is produced by minute, free floating photosynthetic bacteria known as bacterioplankton. Because of its small size, the bacterioplankton isphagocytosed by heterotrophic flagellates and ciliates and are in turn grazed by the zooplankton and thus coupled with the grazing food chain.

The oceans contain large amounts of dissolved organic matter (DOM) that has been leaked into the seawater from the cells of photosynthetic organisms by the attack of viruses. The dissolved organic carbon is then absorbed directly by non-photosynthetic heterotrophic bacteria that use it as an energy source. These bacteria are inturn consumed by other microorganisms such as flagellates and ciliates, which can then be captured and eaten by larger zooplankters such as copepods. In this way, DOM is recycled back into the grazing food chain. This pathway of energy flow is often referred to as the microbial loop.

The huge mass of tiny faecal pellets produced by zooplankton, together with the disintegrated remains of dead phytoplankton and zooplankton, creates an immense store of particulate organic matter (POM) in the oceans, which form the basis of another important pathway of energy flow- the detritus food chain. Detritivores (benthic organisms) consume detritus, in turn providing food for secondary consumers (larger invertebrates, fishes). These secondary consumers constitute prey for tertiary consumers. Some of this POM is consumed by zooplankton and hence gets recycled back into the grazing food chain.

The separations between grazing and detritus pathways are distinct at the primary producers and primary consumers level (Odum, 1971; Knox, 2001). In both types, transfer efficiencies are relatively low, with an energy loss of about 80-90% (Kennish, 2002). Via these pathways the energy gets ultimately transferred to large marine consumers such as large fish, marine mammals, marine turtles and seabirds. These are all targeted in the end by a distinctly non-marine species, humans for their own needs.



(Source: Mladenov, 2013)

Fig. 1.1. A Schematic picture of food web in the coastal waters

The phytoplankton production in the estuary has been regulated by many factors like light, temperature, salinity, nutrients (N:P), minor nutrients, organic requirements, grazing etc. Several factors have been linked to the limitation of phytoplankton production, but nutrient availability has frequently outweighed all others (Roelke et al., 1999; Domingues et al., 2005). The primary production in estuaries is guided by two principles where it is regulated through both biotic mechanisms (trophic interactions including competition and predation) and abiotic mechanisms (nutrient fluxes, physical variability) (Carpenter et al., 1987). Temporal shifts can occur in the relative importance of biotic and abiotic mechanisms (Bartell et al., 1988), so that "top down" and "bottom up" forces work in concert but at time-varying rates. Alpine and Cloern, 1992, reported that any changes in the population level by abiotic forcing at one trophic level, cascades to the other trophic levels, as observed in the northern San Francisco Bay estuary. The primary and secondary production in estuaries, not only depends on nutrients and sunlight but also on turbidity, ocean exchange, wind energy, inputs of heat and river inflow (Mann and Lazier, 1996, Madhu et al., 2007, Cloern et al., 2014). Nutrient enrichment has altered the phytoplankton species composition in coastal waters (Jickells, 1998). The high potential of estuarine production compared to other ecosystems is not always reached due to its turbidity (Kromkamp and Peene, 1995).

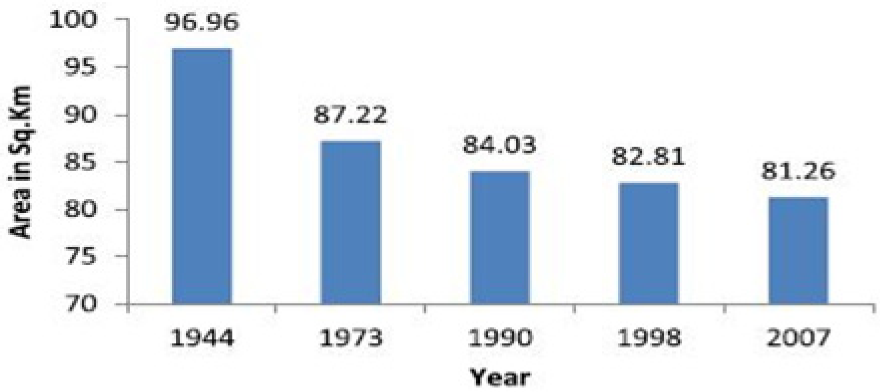
The flow of energy moves along the classical food chain of phytoplankton-zooplankton-fish in mesotrophic and eutrophic systems (Fenchel, 1988). Many studies assume the food web importance of phytoplankton-zooplankton trophic interactions in estuarine systems, but rarely this has been measured at the community level. Phytoplankton community structure determines the efficiency of energy transfer between trophic levels (Mallin and Paerl, 1994). In a planktonic system dominated by easily grazed and assimilated phytoplankton species, trophic efficiency should be high, which should contribute to greater secondary and tertiary production (Ryther, 1969).

1.3 Significance of the Study

As is the case of most developing countries, the nine maritime states of India, which has a combined coastal line of 7516.6km, are under severe stress due to industrialization and urbanisation. Most of the megacities of India, such as Mumbai, Chennai, Calcutta, Kochi and Visakhapatnam, are situated along the coast. Human activities along the coasts, such as port activities, fishing, mining of sand and other minerals, defence operations, research, exploitation of marine reserves, inappropriate land use, pollution and improper development, hascreated problems (Pathak et al., 2004). Over 560 million people living along the coastal zone of India, generate about 6835 million litres waste water every day, out of which only 1492 million litres gets treated in any manner.The indiscriminate release of partially or untreated waste into the coastal environs has resulted in pollution, public health risks and loss of biodiversity. Recent studies showed an increasing abundance of fecal coliform in the estuaries along the west coast (Mandovi-Zuari) and southern coast of Kerala (Ouseph et al., 2009).Discharge of large amounts ofpollutants concentrate heavy metals in marine biota. The coast of

Gujarat recieives around 200 million litres of effluents in a day. It has affected the water quality of the Mindola, Purna, Tapi, Narmada and Mahi estuaries (Zingdae and Desai, 1987). Cargo ships and oil tankers visting Indian ports, cause oil pollution problems in coastal waters due to operational as well as accidental discharges of oil and oily ballast. It is estimated that 0.6 million tonnes of nitrogen and 0.1 million tonnes of phosphorus reach the coastal waters annually.

The city of Kochi, situated along the west coast of India, has expanded rapidly and as a result, has become heavily stressed, from an environmental perspective. The main centre of anthropogenic influence on the Kochi estuary is the Kochi city - the business and industrial hub of Kerala, and a hot spot for coastal pollution. A major portion of the estuary has already been diminished due to uncontrolled reclamation activities for various projects as well as due to illegal encroachment. Dipson et al. (2014) reported that the estuarine area decreased by 81.26% from 1944 to 2007 (Fig.1.2). Most of the estuarine reclamation from 1973 was due to the developmental activities like ICTT (International container transhipment terminal) is container trans-shipment facility, Goshree bridges provide road connectivity to the Islands of Bolgatty, Vallarpadam and Vypin to the city of Kochi, Marine drive extension, extension of Willington Island and public encroachments. Of the 36,500 hectares of backwater that existed in the middle of 19th century, only 12,700 hectares (34.80%) remains as open waters in the present day (Gopalan et al., 1983).



(Source: Dipson et al., 2014)

Fig.1.2. Shrinkage of Cochin estuary during 1944-2007.

The indiscriminate use of fertilizers, insecticides, fungicides and municipal waste has caused considerable damage to the water quality of estuary (Ouseph et al., 2004 a-c).The estuary receives 104×10^3 $m^3$of industrial waste and 260 $m^3 day^{-1}$ of untreated sewage from Kochi city (Martin et al., 2008; Balachandran et al., 2005), besides large quantities of waste from agricultural and aquatic farms (Miranda et al., 2008). According to the study conducted by Central Pollution Control Board (CPCB) and Indian Institute of Technology, New Delhi, in 2012, Kochi was ranked at the 24thposition among the 88 industrial areas of India, where the comprehensive environmental pollution index (CEPI) was calculated for the selected cities. Case studies of eutrophication and hypoxia have been reported from the Kochi estuary (Martin et al., 2010) as well as the Kodungallur-Azhikode estuary(Jayachandran et al., 2012).

Several incidents of fish mortality has been reported in the Cochin estuary, caused by indiscriminate discharges(Bijoy Nandan, 2015; Naqvi et al., 1998; BijoyNandan and Abdul Azis, 1995; Venugopal et al., 1980). This has socio-economical repercussions, as fishing represents one of the main sources of income for the local community. The high influx of tourism in Cochin and the adjoining backwaters has also affected the ecology and the Islands like Vallarpadam, Vypin, Bolgatty and others. Kochi, situated along the west coast is also under the threat of a 2m rise in sea level, caused by climatic changes, which will lead to permanent inundation in the low lying areas. Subsequent damages to the vegetation and life are unpredictable (Mani Murali and Dinesh Kumar, 2015).

The cumulative effects of environmental perturbations as well deleterious changes in the ecosystem structure can potentially alter or compromise the quantity and quality of goods and services provided by estuaries (Wetz and Yoskowitz, 2013). The ultimate challenge of scientists and policy makers is to manage the estuarine systems in order to improve their ecological quality, prevent further deterioration and ensure the progressive reduction of pollution (Cardoso et al., 2011).

Thus it is evident that, the west coast of India is getting seriously affected by various anthropogenic pressures including climate change issues. It has also been established that Cochin and adjoining wetlands and aquatic systems along the west coast have been seriously modified due to impacts from rapid urbanization, water scarcity, sewage disposal problems and pollution from various contaminants and so on. For the Cochin region situated along the Arabian Sea (Lakshadweep sea) is also threatened by possible sea level rise and other climate change issues possibly affecting the livelihood and existence of large populations along the Cochin coastal region.

Under these circumstances, the Department of Environment, Directorate of Environment and Climate Change (DoECC), Govt. of Kerala, initiated a major research project on "*Current status on the biotic potential in relation to environmental quality of the Cochin estuary, India*" from 28-Feb-2009 to 27-Aug-2012 under the project investigator of Dr. S. Bijoy Nandan from the Dept. of Marine Biology, Microbiology and Biochemistry. This Ph.D thesis has been evolved from the results and findings of DoECC project mentioned above.

The objectives of the study are as follows

- Assess the trophic status, *vis-a-vis* the primary and secondary productivity of the Kochi estuary.
- Study the abundance and diversity pattern of phytoplankton and zooplankton and their role in productivity of the system.
- Evaluate the fishery production potential and its relation to the trophodynamics.
- Propose action plans for maintaining the productivity status of the ecosystem while being oriented towards sustainable livelihood.

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Chapter 2

STUDY AREA

Along the coastal region of Kerala, there are several lagoons and backwaters fed by rivers originating from the Western Ghats. These rivers eventually drain into the Arabian Sea (Lakshadweep Sea). The study area is located on the western side of Kerala, near the district of Ernakulam, southern region of the Indian peninsula. After the coastal city of Mumbai, Kochi, formerly known as Cochin is the biggest city along the West coast of India. Kochi also called port city have exerted considerable influence in shaping the history of the region. There has been considerable economic significance in past, as Kochi lies along the route to Australia and the Far East, for travellers from the West. The Kochi estuary is part of the Vembanad wetland system, an important Ramasar site of Kerala. The Kochi estuarine complex, consisting of the Vembanad lake, the rivers flowing into the estuary and the surrounding islands, is a very important estuarine system in Kerala, supporting a rich diversity of flora and fauna.

In recent years, the Kochi estuary has undergone deterioration due to land reclamation, illegal encroachments, dredging, mangrove deforestation, industrialization, urbanization, waste disposal, ballast water discharge, fish processing plants, domestic sewage, coconut husk retting yards etc. The estuarine system is highly sensitive to changing climatic variables, such as river discharge of water and sediments, temperature rise, rainfall, wind and wave climate (Dyer, 1995; Psuty, 1995; Houghton et al., 2001).

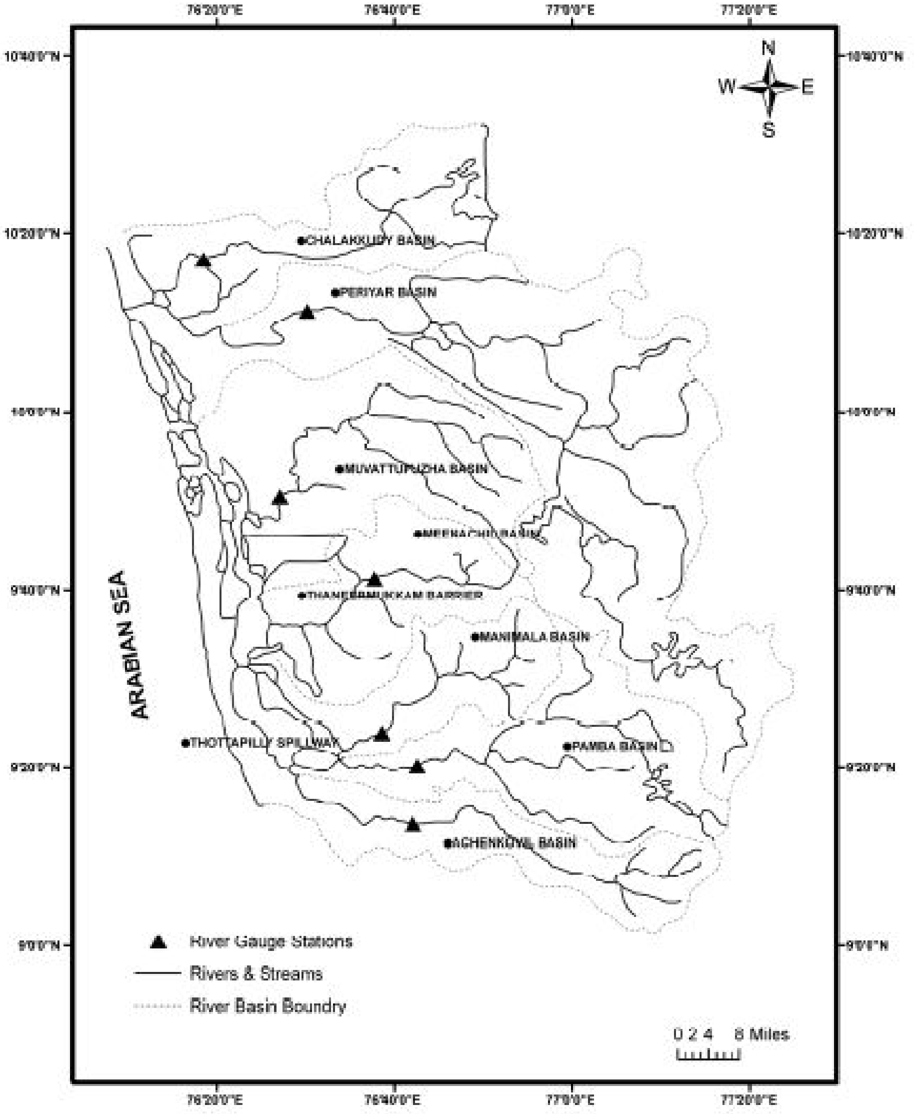
2.1 Geomorphology

The Kochi estuary is characterized by an ox-bow shape running almost parallel to the Arabian Sea, with its northern boundary at Azhikode and southern boundary at Thanneermukkam bund (Soman, 1997). It is located between 76^{o}9'25" E- 76^{o}24'28" E longitudes and 9^{o}47'31" N - 10 ^{o}12'N latitudes. This estuarine area is also known as the Kochi backwaters and is unique in terms of physiography, geology, climate, hydrology, land use, as well as flora and fauna. It is a bar-built, positive and micro tidal estuary. The Kochi estuary (231 km^2 = 23100 ha in area) is a part of the Vembanad-Kol Wetlands, which is the third largest coastal wetland system in India with a total area of 1521.50 km^2 (152150 ha).

The Kochi estuary was previously a marine environment by an alluvial bar parallel to the coastline and interrupted by Arabian Sea at intervals. It attained the present configuration in 4th century A.D. As a result of a catastrophic deluge which took place in 1341 A.D., parts of the Alappuzha and Ernakulam districts including a number of islands arose, thus separating a distinct water body from the sea with connecting channels at Thottappilly, Andhakaranazhi and Cochin. During this period, the river Periyar underwent a diversion through Varapuzha and opened up the Cochin channel, giving rise to a number of islands. These scattered islands were formed by the deposition of alluvium in the course of the river. This transformed the marine system to a typical estuarine system (Gopalan et al., 1983). As part of the establishment of Kochi Port in 1936, the “natural bar” was dredged out while deepening the channel to make the basin accessible to ocean-bound vessels (Strikwerda, 2004).

The tides in the Kochi estuary are of the mixed semi-diurnal type, with an average tidal range of 1m (Qasim and Gopinathan, 1969). The spring phase is dominated by semi-diurnal tides and the neap phase by diurnal tides. There is a rapid decay in the amplitudes of the principal tidal constituents as they propagate upstream. The Kochi estuary is separated from the Arabian Sea by barrier spits interrupted by tidal inlets, one at Fort Kochi and other at Munambam, the former being wider (450m) than the latter (250m). The Kochi Port situated on Willington Island, is near the Kochi Inlet, which provides the main perennial connection to this harbour. The width of the estuary varies from 0.05 km to 4 km, while the depth varies from 0.05 m to 12 m. At the central estuary (from Kochi inlet to 22 km south), strong currents are prevalent. In the northern and southern sections of the estuary, weak currents are more prevalent (Balachandran et. al., 2008).

There are seven main rivers and numerous small streams that flow into this estuary. Periyar and Chalakudy in the north; Achencoil, Pamba, Manimala and Meenachil in the south; and Muvattupuzha midway between the two. These are the main rivers which bring fresh water discharge into the estuary. All of these rivers discharge large quantities of flood waters during the monsoon period, enriched with nutrients as well as considerable quantities of silt.



(Source: Revichandran et al., 2012)

Fig. 2.1. Map of the major river basins which emptying to the Cochin estuary. Doted lines represents river basin boundary, solid line represents rivers and its branches and triangle shows the gauging stations.

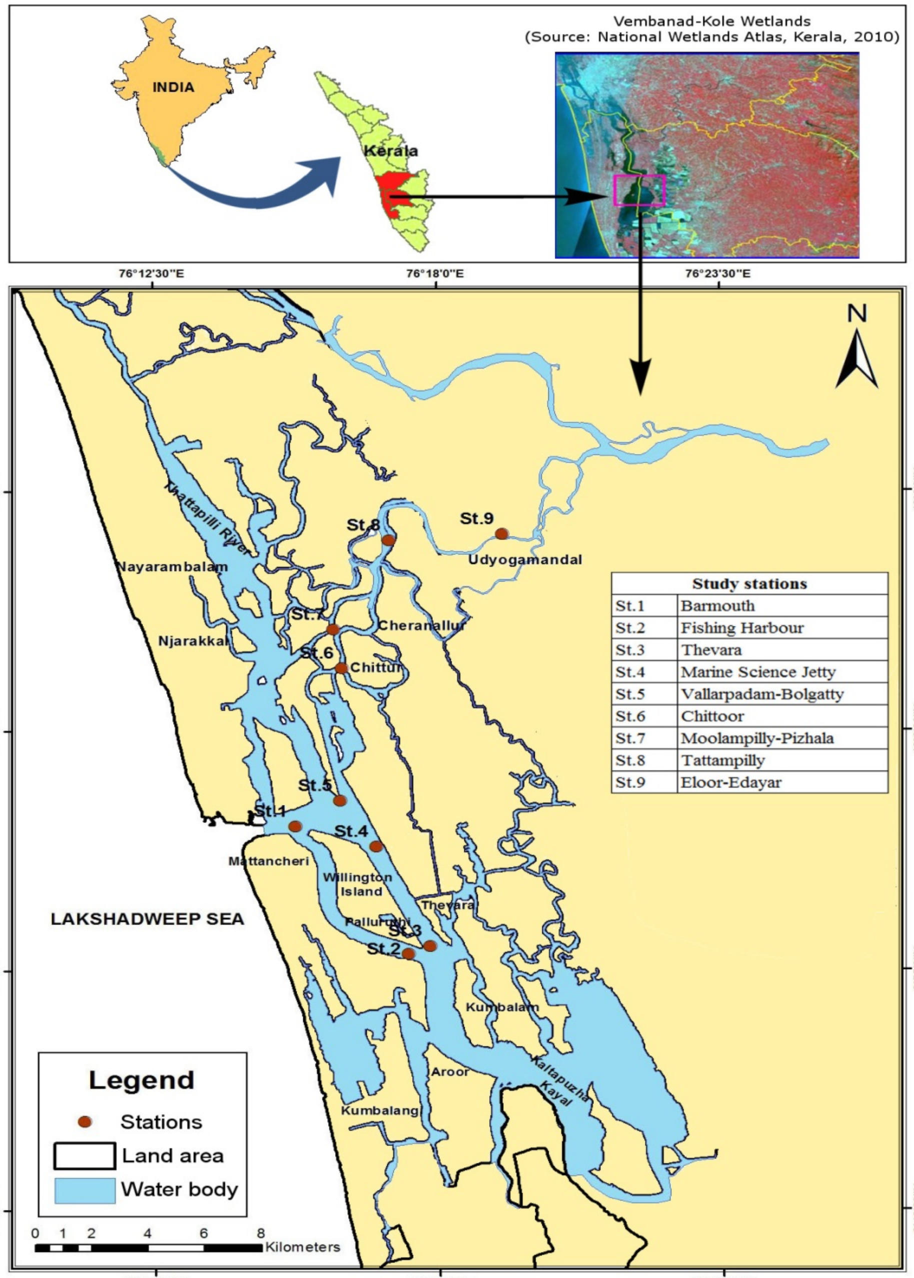
Additionally, Kochi estuary is a monsoonal estuary in which the river discharge exhibits large seasonal variation (Revichandran et al., 2012). About 30% of the discharge from the river Periyar, enters the northern parts of the estuary. The ratio of total annual runoff to the estuarine volume is approximately 42, which indicates that the estuary is flushed 42 times in a year. The Kochi estuary is also influenced by heavy rain and freshwater influx during the monsoon periods. Most of the rain occurs in the summer monsoon from June to September. During the peak of the summer monsoon period, surface salinity reaches near zero values over most of the region (Madhupratap, 1987). Approximately 80% of the total rainfall received is from the Southwest monsoon phase and the remaining 20% is received from the Northeast monsoon period phase.

Shivaprasad et al., 2013a proposed a new nomenclature for this estuary-Cochin Monsoonal Estuarine Bay (CMEB)-which encapsulates the salinity gradient of estuary ranging from completely riverine to completely saline. The term ‘monsoonal’ describes the unsteadiness of salinity of wet season. During the wet season and moderate runoff months, the estuary turning to a river cannot be ruled out. During the peak dry period, the salinity values are high throughout the system with a gradient from mouth to head and the variations in runoff is slow. ‘Bay’ condition is established during peak dry season when the estuary is in a steady state with little constant runoff. During the rest of the year, the system behaves as a true estuary. The nature of the bottom sediment of the Cochin estuary is mostly muddy, with an admixture of fine sand granules in some areas.

From the total area of the Kochi estuary (23100 ha), 6785 ha was demarcated as the study region. From this area, nine sampling stations were fixed, based on a preliminary survey. Monthly field sampling was conducted for 24 months, from June 2009 to May 2011, in nine selected stations of the Kochi estuary.

The tides in the estuary are of mixed semi diurnal tides with two high tides and two low tides occur at each day. Most of the sampling was done during early morning hours in low tide period.

The monthly sampling data were aggregated together based on the rainfall and river runoff of the region to arrive at seasonal trends. Based on the Southwest monsoon and North East monsoon pattern along the west coast of India, there are three well defined seasons, high runoff months characterised by Indian summer monsoon as monsoon period (June-September), moderate runoff months characterised by north-east monsoon as post-monsoon period (October-January) and low runoff months or dry period as pre-monsoon period (February-May).



Study stations	
St.1	Barmouth
St.2	Fishing Harbour
St.3	Thevara
St.4	Marine Science Jetty
St.5	Vallarpadam-Bolgatty
St.6	Chittoor
St.7	Moolampilly-Pizhala
St.8	Tattampilly
St.9	Eloor-Edayar

Fig. 2.2. Map of Cochin estuary showing the study stations

2.2 Study stations

Station 1- Barmouth (BM)

Longitude: 9^{o} 55’ 8.80”
Latitude: 76^{o} 19’ 43.68”
Average Depth: 5.56 m

Barmouth is the permanent wide opening of the estuary to Lakshadweep sea. Strong variations in tidal flux are observed in this area. It is a hub for shipping activities, fishing operations as well as commercial boating. Dredging is frequently done in this area, as part of maintenance of channels required for the passage of international and national shipping vessels. Dredging destroys the much of the habitat heterogeneity supported by the natural water body. Stake nets and Chinese dip nets are widely operated in the area during the high tide phase of the estuary. Kochi Port Trust, International Container Trans-shipment Terminal (ICTT), several boat jetties and the fishing harbour at Kalamukku, are located close to the study area. The boat transports cause noise pollution and acts as potential source of sewage. Large, slow moving animals are vulnerable to propeller damage. The station is located approximately 2.7 km from the mouth of the estuary.

Plate 2.1
Station 1- Barmouth
Chinese dip net operation is widely observed in the region

Plate 2.2

Station 1- Barmouth

Fishing, Shipping and boat transport regularly brings disturbances to this region.

Station 2- Fishing Harbour (FH)

Longitude: 9° 55’ 26.83”
Latitude: 76° 18’ 7.31”
Average Depth: 4.97 m

Thoppumpady fishing harbour is one of the major fishing centres in the state. The high amount of fishing in this area has resulted in an increased deposition of waste from the fishing harbour and several fish processing units in the region. The activities here include docking operations, boating and fishing activities. Gill net fishing is common in the area and the fishes harvested are anchovies, silver bellies, catla, catfishes and prawns.

Plate 2.3
Station 2- Fishing Harbour
Fishing boats anchored in the Thoppumpady harbour

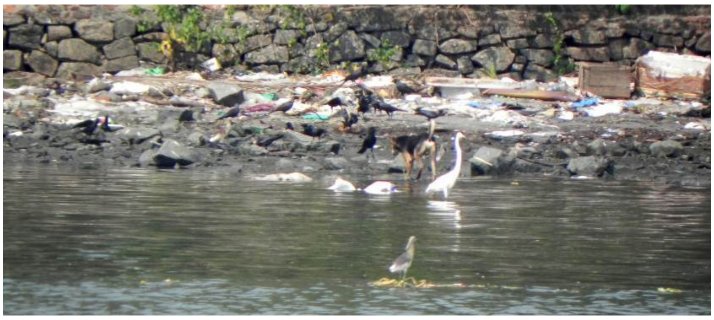


Plate 2.4
Station 2- Fishing Harbour
Waste dumping observed near the sampling station during low tide.

Station 3: Thevara (TA)

Longitude: 9^{o} 55’ 57.72”
Latitude: 76^{o} 16’ 12.22”
Average Depth: 2.73m

This area has heavy fresh water flow during monsoon period and is polluted due to the deposition of domestic sewage discharge from the adjacent residential areas. Around 28 numbers of stake nets are seen here which operate during high tide. The invasive weed species *Eichhornia crassipes* covers the major portion of the station.

Plate 2.5
Station 3- Thevara
Residential complexes constructed near the Thevara study site.

Plate 2.6
Station 3- Thevara
A large number of stake nets are deployed in and around the study station.

Station 4: Marine Science Jetty (MJ)

Longitude: 9° 58’ 9.88”
Latitude: 76° 15’ 21.92”
Average Depth: 3.43 m

Oil and ballast water discharge is of primary concern in this area, as it is a major factor threatening the organism distribution structure in the region. Several oil tankers/ships are observed to be filling or refilling crude oil in the area. Huge pipelines seen in the periphery of this zone are used to transport crude oil to the Kochi crude oil refinery for processing. Oil spillage into the water body occurs during the loading and unloading of crude oil from the ships and vessels in this area. The area is highly infested with different aquatic weeds such as *Eichhornia crassipes* and *Salvinia molesta*. A large number of tourist boats and research vessels are also docked in the jetty.

Plate 2.7
Station 4- Marine science Jetty
Oil Terminal site, where filling and refilling of crude oil into tankers and vessels.

Plate 2.8
Station 4- Marine science Jetty
Construction of apartments near Marine Drive during the sampling period.

Plate 2.9
Station 4- Marine science Jetty
Ballast water discharge was observed in the study station.

Station 5: Vallarpadam–Bolgatty (VB)

Longitude: 9^{o} 33' 29.74"

Latitude: 76^{o} 10' 38.68"

Average Depth: 4.21 m

This area has undergone extensive reclamation and construction activities due to various developmental projects such as the Goshree project opened in 2004, the International Container Trans-shipment Terminal (ICTT) commissioned on 11 February 2011, construction of new residential complexes and other industrial activities. The ICTT port is entirely located on Vallarpadam Island. For all the above mentioned projects as well as their related infrastructure requirements, most of the lands acquired are wetlands. These wetlands are commonly known as Pokkali fields, where paddy and prawn are indigenously grown. To date, approximately 234379 hectares of pokkali fields have been acquired for construction. For the Vallarpadam ICTT project, 0.38km^2 area was utilized for the construction of road and railway track. Kochi international marina started in 2010 is the only marina in India of International standard. The marina provides berthing facility for yachts and also offers services like fuel, water, electricity and sewage pump-outs for boats.

Plate 2.10
Station 5- Vallarpadam-Bolgatty
Kochi International Marina operation near Bolgatty Palace

Plate 2.11
Station 5- Vallarpadam-Bolgatty
Construction phase of Vallarpadam ICTT during the sampling period.

Station 6: Chittoor (CR)

Longitude: 10^{o} 1’ 42.60”
Latitude: 76^{o} 9’ 33.73”
Average Depth: 3.31 m

Due to the presence of a large hospital (Amrita Institute of Medical Sciences) in the area adjacent to this zone, the primary concern is the discharge of hospital waste to the estuary. Fishing is widely prevalent in and around this region. Chinese dip net fishing is one of the types of fishing seen here. Around 30 chinese dip nets are deployed near the sampling site. In addition, integrated fish farming – farming of fishes along with ducks are also seen in this region. Bush park fishing/Padal fishing is an indigenous fishing method seen in this station. An artificial reef made from twigs and leaves of trees is planted in the shallow areas of the estuary. The aim is to harvest fish that find shelter in these structures for the purpose of feeding and breeding. The State Department of Fisheries has banned this method of fishing in the inland waters of Kerala.

Plate 2.12
Station 6- Chittoor
‘Padal’ system

Station 7: Moolampilly-Pizhala (MP)

Longitude: 10^{o} 1’ 8.44”

Latitude: 76^{o} 9’ 40.90”

Average Depth: 3 m

Reclamation of the backwater is evident in this area, with the primary cause being the construction of the Vembanad Railway Bridge which opened in 2011, the longest rail bridge (4.62 Km) in India, connecting Edappally to the International Container Trans-shipment Terminal site. The pillars supporting the bridge have restricted the flow of water through the estuary. Due to mining and dredging activities for the construction of bridge, the water in the region was observed to be turbid.

Plate 2.13
Station 7- Moolampilly- Pizhala
Construction of Vemband Railway Bridge

Station 8: Tattampilly (TP)

Longitude: 10^{o} 3’ 20.09”
Latitude: 76^{o} 10’ 10.60”
Average Depth: 3.48 m

Sand mining is widely prevalent in this area and the water was dark green in colour. The sediment collected from the area appeared black in colour, contained oil residue, as well emitted a pungent odour. This may be attributed to the deposition of wastes from several industries located upstream of the sampling site.

Plate 2.14
Station 8- Tattampilly
Water was turbid may be due to the discharge of industries located in the upstream of the study stations.

Station 9: Eloor- Edayar (EE)

Longitude: 10^{o} 2’ 55.93”

Latitude: 76^{o} 10’ 45.77”

Average Depth: 2.35 m

The factories, FACT (Fertilisers and Chemicals Travancore Ltd), IRE (Indian Rare Earths), Merchem and HIL (Hindustan Insecticides Ltd) are located near to the study station. The effluents possibly from these industries are discharged into the estuary. FACT that manufactures phosphatic and ammonium sulphate fertilizers and is one of the major industries in this region. On observation, the water in the region appears to be dark and turbid, and contains oil residue. The collected sediment had black colour and contained oil as well as salts of sulphur. Fish kills have been known to occur frequently in this zone.

Plate 2.15
Station 9- Eloor- Edayar
FACT- Fertilisers and Chemicals Travancore Ltd, major industry causing pollution in this region

Plate 2.16
Station 9- Eloor- Edayar
Water used for the industrial activities in FACT is discharged into the estuary.

Plate 2.17
Station 9- Eloor- Edayar
Number of drainages from FACT opened to the estuary.

For the purpose of elaborating and discussing water quality parameters the nine study locations were demarcated into three zones. The northern zone of the estuary was represented by stations 6, 7, 8 and 9; stations 2 and 3 were clustered into southern zone while stations 1, 4 and 5 were demarcated as central zone of the estuary. The salinity regime based on the location was the major factor that was followed for demarcating three zones, where the southern zone and central zones were mesohaline (5-18 ppt) and the northern zone was oligohaline (0.5-5 ppt) according to the Venice System of classification (1959).

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Chapter 3

WATER QUALITY OF COCHIN ESTUARY

Contents

3.1 Introduction

Water quality is an aspect vital to the survival and well-being of organisms in the coastal and estuarine areas. To identify and quantify the trends in water quality in a geographical area, monitoring of water quality is necessary. Such monitoring is done to understand the condition of the water, and from there, the various types of problems caused by inferior quality of water. It is also required to track if the problems occur sporadically, seasonally or year round. It is also necessary to identify if the source of the problem is natural or man-made. Such an understanding of relationships between human activities and water chemistry is required to identify and manage sources of anthropogenic stress in Great Lakes and coastal wetlands (Morrice et al., 2008).

Water quality in aquatic systems is facing deterioration due to the high levels of urbanisation, coastal development and industrial expansion taking place today. Such activities have resulted in high levels of nutrient enrichment, depletion of dissolved oxygen, rise in dissolved and particulate organic matter and increased release of carbon dioxide. At the same time, demand for water for varied purposes such as residential usage, agriculture, industrial usage, etc has increased. The environmental effects of these changes are directly reflected in the parameters of water quality. Within the past three decades, many of our estuarine and coastal waters have changed from balanced and productive ecosystems to ones experiencing sudden trophic changes, biogeochemical alterations and deterioration in habitat quality (Pickney et al., 2001)

Deleterious changes in estuarine areas affect the economy of the area as well, primarily on the fishing industry. Optimal primary and secondary production is required for profitable and sustainable fishing practices. The pre-requisite for such optimal production is the prevalence of favourable hydrological conditions. This includes physical factors such as temperature (atmospheric and surface water), salinity, depth, transparency, extinction co-efficient, total dissolved solids, conductivity, turbidity and chemical factors such as dissolved oxygen, pH, free carbon dioxide, total alkalinity, total hardness, biological oxygen demand, nutrients (ammonia, nitrite, nitrate, phosphate and silicate) and hydrogen sulphide.

3.2 Review of Literature

Perusal of the available literature reveals that the water quality of estuaries has been studied by several authors in order to understand the short and long variations of different hydrographic events in estuaries. Ward et al.(1986) determined the seasonal distribution of suspended particulate material and dissolved nutrients in the Choptank River, an estuarine tributary of Chesapeake Bay in the United States. Kuo et al. (1987) reported hypoxia and salinity in estuaries of Virginia, adjacent to the Chesapeake Bay. Marchand (1993) reported that the salinity and turbidity exert maximum influence on the nursery functions as the feeding and breeding ground for fishes of the Loire estuary in France. The water quality assessment of the Humber estuary in Northern England was done by National Rivers Authority of England in 1993.Nienhuis (1993) reviewed the nutrient cycling and food webs in estuaries of Netherlands. Balls et al. (1997) made an attempt to study the influence of rainfall on nutrient distribution in Ythan estuary in Scotland. Breitburg et al. (1997) experimented with the varying effects of low levels of dissolved oxygen on the trophic interactions in an estuarine food web. Changes in predator-prey interactions reflected variation among species in their physiological tolerance to low oxygen and the effects of low oxygen on the escape behaviour of prey, as well as on swimming and feeding behaviours of predators. Because of the variation in the effects of trophic interactions, low dissolved oxygen has the potential to cause major alterations in the relative importance of different path ways of energy flow in the Chesapeake Bay and in other estuarine system. Engle et al. (1999) reported that 5.2 to 29.3% of the total estuarine area in the State of Louisiana, United States, was affected by low dissolved oxygen conditions, which would lead to hypoxia in the immediate future. Eyre and Balls (1999) compared the nutrient behaviour along the salinity gradient of tropical and temperate estuaries. Lane et al. (1999) analysed the water quality of a fresh water diversion at Caernarvon, Louisiana. Strobel et al. (1999) monitored the indicators of the ecological conditions of bays, tidal rivers, and estuaries within the bio-geographic province of Virginia.

Pickney et al. (2001) gave a brief description on nutrient loading and eutrophication in estuarine ecology. Sanderson and Taylor et al. (2003) compared the influence of tides on water quality in two tropical estuaries of central Sumatra, Indonesia. Nutrient cycling in the sub-tropical Brunswick estuary in Australia was studied by Ferguson et al. (2004). Uncles and Smith (2005) compared the turbidity of twenty seven estuaries situated in America. Howarth and Marino (2006) reviewed that nitrogen is the limiting nutrient in eutrophication in coastal marine ecosystems. Acha et al. (2008) described the physical and ecological processes in the Rio de la Plata estuary, situated at the border between Argentina and Uruguay. A case study was carried out in the sewage discharge sites of the Northern Adriatic Sea in Europe, by Mozetic et al. (2008). Pereira et al. (2009) studied the spatial and seasonal variation of water quality in an impacted coastal lagoon in Portugal. Chen et al. (2012) evaluated approximately30 years of temporal and spatial variations of nitrogen and phosphorus nutrients in the Yangtze

River estuary in China. They concluded that the total nitrogen and total phosphorus pollution have risen in the estuary since 2003 with regard to spatial distributions. A case study of estuarine eutrophication in Basque estuaries of Northern Spain was done by Garmendia et al. (2012). Alves et al. (2013) evaluated the eutrophication and water quality status of a tropical Brazilian estuary. Wiegner et al. (2013) compared the water quality between the low and high flow conditions of a river in a tropical estuary of Hawaii.

The Indian subcontinent is bestowed with several estuaries. The hydrography of the Karwar Bay in Karnataka and the Palk Bay in Tamil Nadu was studied by Murty and Varma (1964), and Noble (1980). Vijayalakshmi and Venugopalan (1973) observed that diurnal variations in surface water showed a direct relation with air temperature and tides in Vellar estuary in Tamil Nadu. Venugopalan et al. (1981) studied the relationship between nitrate and phosphate as well as the seasonal variation of nitrogen and phosphorus in different zones of the Vellar estuary, in relation to phytoplankton. Monthly variations of some hydrographic parameters in the Rushikulya estuary in Orissa were studied by Gouda and Panigrahy (1993). Seasonal variation of physico-chemical properties of coastal waters of Kalpakkam, Tamil Nadu was studied by Sathpathy (1996). Swami et al. (1996) reported that the water quality parameters of the Karwar coast revealed a healthy status of the waters of Karwar supporting for the phytoplankton growth. Subramanian and Mahadevan (1999) studied the seasonal and diurnal variation of hydrobiological parameters of the coastal waters of Chennai. The parameters like, current, pH, salinity, dissolved oxygen, biological oxygen demand, inorganic nutrients (NH_4, NO_2, NO_3, PO_4, SiO_2-SiO_3) and heavy metals seasonal variation is influenced by monsoonal rain, littoral drift and land drainage but diurnal variation was influenced by the combination factors like tide, solar radiation, temperature etc.

Nayak et al. (2004) studied the water quality parameters in Chilka lake, Orissa. Mathew (2004) gave a brief account of the marine pollution in the coastal waters of India. Hydrographic parameters of Gulf of Mannar and Palk Bay during a year of abnormal rainfall were studied by Sulochanan and Muniyandi (2005).

Selvaraj (2006) reported that low tide showed more productivity compared to high tide water especially during post-monsoon period in the Chandragiri and Marad estuary along the southwest coast of India. Panigrahi et al. (2007) investigated the spatio-temporal variation of water quality parameters in the Chilka lagoon. The study revealed that northern sector of the lagoon is more impacted than the southern sector by anthropogenic activities. Gupta et al. (2009) studied the variations in water quality of Mumbai coast using the multivariate analysis technique. Kumari and Rao (2009) studied the estuarine characteristics of lower Krishna river, near the coast of Andhra Pradesh. Vijith et al. (2009) pointed out that the salinity field of the estuaries located on the coasts of Indian subcontinent, which come under the influence of the Indian summer monsoon period, is never in a steady state. Sarma et al. (2010) monitored the intra-annual variability of nutrients in the Godavari estuary in Andhra Pradesh. Satpathy et al. (2010) reported that after the 2004 tsunami that struck the coasts of India, a change in coastal biodiversity pattern may be expected, associated with the change in coastal water quality of the Kalpakkam estuary. Deshkar et al. (2012) gave a comparative account on the physico-chemical parameters in the three estuaries of Gulf of Khambhat in the state of Gujarat. Kalpana (2014) studied the effect of sand bar formation on the water quality of the Muttukadu backwaters, on the east coast of Tamil Nadu.

An account of the seasonal and annual variations of chlorinity as well as nitrate, phosphate and silicate in the Korapuzha estuary in Kerala is presented by Rao and George (1959). George and Kartha (1963) investigated the relation between the surface salinity and tidal characteristics in the Cochin backwaters. According to the trend of surface salinity there appears to be three seasons in any year, a season of low salinity from June to September, a post monsoon season with upward trend in salinity from September-October, December-January characterised by rapid fluctuations in salinity values, and January to May when the channel contains water comparable in salinity to the inshore water. Ramamritham and Jayaraman (1963) studied the hydrographical conditions around Willington Island in the Cochin estuary. The hydrography of the Cochin estuary was studied by Sankaranarayanan and Qasim (1969). Tidal cycle and the environmental features of the Cochin backwaters were studied by Qasim and Gopinathan (1969). Nutrient distribution in the

Cochin estuary was studied by Joseph (1974) and Manikoth and Salih (1974). The seasonal changes in physico-chemical parameters of water and nutrients in four estuaries of Kerala namely Kallai, Beypore, Korapuzha and Mahe along the north coast, was studied by Saraladevi et al. (1983). Balchand (1984) studied the dynamics and water quality of the Muvattupuzha River with respect to effluent discharge. Nair et al. (1984) reported that spatial and zonal variation of inorganic nutrients in the Ashtamudi estuary was mainly governed by mixing, nature and intensity of water pollution and other human interferences.

Distribution and variability of nutrients in the Cochin backwaters was investigated by Lakshmanan et al. (1987). The nutrient distribution in the Ashtamudi estuary was carried out by Nair and Abdul Azis(1987) and Olippuramkadavu backwaters by Ramakrishna et al.(1987). Anirudhan (1989) studied the nutrient chemistry of the Cochin estuary. Joseph (1989) investigated on the tidal, seasonal and spatial variations of the hydrographic parameters, circulation as well as the mixing processes of the Cochin estuary. The hydrographic data have been analysed in relation to tide, rainfall and river discharges. From the findings it is seen that at the Cochin inlet, the estuarine features vary annually. Bijoy Nandan and Abdul Azis(1990) studied the BOD_5 and DO in the Kadinamkulam Kayal.

Paul (1992) investigated the trace metal speciation in the Cochin estuary. The chemical effects of sulphur in the Cochin estuary was studied by Jacob (1993). A systematic and comprehensive study on the general hydrography and nutrient chemistry of the Chaliyar river estuary was done by Xavier (1993), together with an attempt to study the fluxes of inorganic nutrients through various cross-sections in the estuary. Bhaskar (1994) studied on the acoustic properties of coastal waters of Kerala in relation to hydrography. Bijoy Nandan and Abdul Azis, (1995a) investigated the changes brought by the retting activities on the environmental parameters and zooplankton of the Kadinamkulam estuary. Bijoy Nandan and Abdul Azis, (1995b) compared the pH and E^h in the retting and non retting zones of Kadinamkulam estuary. The hydrodynamics and metal concentrations in the Beypore estuary were comparable with those reported for Cochin estuary (Nair, 1995; Anilkumar, 1996). Rasheed (1997) assessed the impact of dredging in Cochin harbour. Balchandran et al. (1999) conducted an exclusive study on dissolved silicate and their non-conservative control on its distribution. Jose (1999) examined the nutrient profile of river Chitrapuzha. Kaladharan et al.(1999) reported an oil slick in the inshore waters to the North of the Cochin Port channel. . It was reported from the inshore waters of Narakkal. The intensity of oil deposition in water was estimated as 310.2 mg/l and 268.06 mg/l in the beach sediment.

Mathews (2000) studied the role of sediments on the nutrient dynamics and fertility of Kuttanad backwaters. An attempt has been made by Balachandran (2001) to evaluate linear trends on some of the water quality parameters in the coastal waters of Cochin, for the period 1958 to 1999. The results showed that the influence of the anthropogenic inputs through the Cochin backwaters has not significantly affected the coastal waters, as their behaviours are more or less consistent when compared to the trends observed at the barmouth. The dissolved oxygen concentrations indicate that over the 41 years, there is only a very slight reduction in oxygen levels (< 10 %). The trends for the nutrients are however found to be varying. While silicate shows periodic enrichment in the coastal waters after 1990, phosphate and nitrate seem to deviate slightly from being consistent. Srinivas et al., (2003a), reported that the tides in the Cochin estuary were semi-diurnal tides during the spring phase, while the neap phase was dominated by diurnal tides. An increasing dominance of shallow water tides was seen with increasing distance from the mouth. Modelling the short term and medium term seasonal variation of meteorological and oceaneographic parameters of the Cochin estuary was studied by Srinivas et al., (2003b). Renjith (2006) studied the water chemistry, geochemistry and the nutrient dynamics to the Cochin estuary. Water quality and nutrient characteristics of the Adimathala estuary have been assessed by Anilakumary et al. (2007). Martin et al. (2007) investigated the influence of fresh water on nutrient stoichiometry in the Cochin estuary.

Nitrification rates were measured in Cochin backwaters during three seasons, monsoon period (September), once in mid-dry season (February) and once in peak summer (April) by Miranda et al. (2008). The experimental results suggested that nitrification could be an important mechanism in mitigating ammonium pollution in the estuary. Nandakumar (2008) studied the hydrobiology of coastal waters off Cochin and its influence on selected fishery resources. Balakrishnan (2009) studied the hydro-geological and hydro-chemical aspects of the Periyar river basin. Benny (2009) examined the dynamics of sulphur in the Cochin estuary. Joseph and Ouseph (2009) analysed the nutrient distribution of Cochin backwaters in relation to environmental characteristics. Babu et al. (2010) studied the quality of water and sediment in the Cochin estuary. Balchand et al., 2010 observed that the disruptions in the biodiversity of Cochin backwaters were due to the unscientific closure of Thannermukkam bund as well as the proliferation of floating weed. They suggested that declare the estuary as protected area.

Martin et al., 2010 observed anoxic conditions, 2-6 km away from the barmouth of the Cochin estuary, leading to the formation of hydrogen sulphide. The reduction of nitrate and formation of nitrite within the oxygen deficient waters indicated strong denitrification intensity in the estuary. The expansion of oxygen deficient zone, denitrification and formation of hydrogen sulphide may lead to a destruction of biodiversity and an increase of green house gas emission from this region. In the Cochin inshore waters, cadmium has reached dangerous levels, while copper and lead have reached problematic levels Kaladharan et al., 2011. Jayachandran et al., 2012 examined the variations in water quality in the Kodungallur-Azhikode estuary. Renosh et al., 2012 studied the development of salt silt wedge in the estuarine environment and identified the occurrence of turbidity maxima during pre-monsoon period in the southern arm of the Cochin estuary. Revichandran et al., 2012 reported that the ratio of the total annual runoff to the estuarine volume is ~ 42 that indicate the Cochin estuary will be flushed 42 times in a year.

Amaravayal, 2013 studied the interactions between tides and river runoff in the Cochin estuary. The periodic advance and retreat of the salt wedge is crucial in immunising the system from extended hypoxia/anoxia and thereby maintaining the health of the Cochin estuary (Shivaprasad et al., 2013a). The Cochin estuary is better named as 'Cochin Monsoon periodal Estuarine Bay', embodying the physiographic, hydrographic and biological features of Cochin estuary (Shivaprasad et al., 2013b). Dipson et al., 2014 studied the spatial changes of Cochin estuary for the last seven decades. Remote sensed data showed a progressive decrease in study area, mainly due to reclamation and urbanization. Lallu et al., 2014 observed that the fresh water discharge was high during spring tide. Conversely, the export fluxes of phosphate and ammonia were high during neap tide, due to their input into the Cochin estuary through anthropogenic activities. The export fluxes from the estuary could be a major factor sustaining the monsoon period fishing activities along the southwest coast of India.

3.3 Materials and Methods

3.3.1 Sampling methods

Field sampling was conducted during the early morning hours for 24 months, from June 2009 to May 2011. The CUSAT research vessel, *King Fisher*, was used for the collection of water samples and plankton samples. The rainfall data of the study area during the study period was obtained from the resources of the Hydrometeorology division of the Indian Meteorological Department (www.imd.gov.in). Tide level during the sampling days was obtained using the Indian Tide Tables, published by the Survey of India (www.surveyofindia.gov.in). Daily river discharge during the study period has been obtained from Central Water Commission, Govt. of India (www.india-wris.nrsc.gov.in) from seven standard gauging stations (Arangaly, Kalampur, Kallooppara, Kidangoor, Malakkara, Neelaswaram and Vandiperiyar).

3.3.2 Water quality

The water samples were collected from the study stations in the Cochin estuary, at monthly intervals from June 2009 to May 2011. The surface water samples were collected using a plastic bucket and bottom water samples were collected using a standard Niskin sampler (General Oceanics) of 5L capacity. Samples for the water quality parameters were collected in pre-cleaned acid-washed polythene bottles. The samples for dissolved oxygen, biological oxygen demand and hydrogen sulphide were taken in glass bottles. The dissolved oxygen was fixed using Winkler's reagents and hydrogen sulphide was fixed using zinc acetate solution.

Water samples for the analysis of nutrients were collected in pre-cleaned polythene bottles of 1L capacity and kept in ice boxes. The nutrients were analysed immediately after filtering through Whatman No:1 filter papers, following standard procedures (Strickland and Parsons, 1972 ; Grasshoff et al., 1983) and using a spectrophotometer (Systronics UV-VIS spectrophotometer, Model No.117), after proper calibration. The nutrient values were expressed in the unit of micromole per litre ($\mu M\ L^{-1}$)

3.3.3 Physical parameters

The depth was measured by lowering a graduated weighted rope until it touched the bottom of the estuary. Atmospheric and water temperature were determined on field by standard degree centigrade mercury thermometer with an accuracy of ± 0.01°C. Transparency of water body was measured in the field using a Secchi disc, 20 cm in diameter. The depth of illumination where it disappeared was noted and expressed in meters

(Strickland and Parsons, 1972). Extinction co-efficient was calculated using the formula (Michael, 1984).

Extinction co-efficient = 1.4/ Depth in meters

Salinity was measured by Mohr-Knudsen method (Grasshoff et al., 1983). The halides present in the water samples were treated with standard silver nitrate solution and potassium chromate as indicator. The values were recorded as parts per thousand (ppt). The study stations were separated into zones, based on the Venice system of classification for the brackish waters was given in Table 3.1.

Table 3.1 The Venice system for the classification of brackish waters

Zone	Salinity ‰
Hyperhaline	> ±40
Euhaline	±40-±30
Mixohaline	(±40) ±30-±0.5
Mixoeuhaline	>±30 but < adjacent euhaline sea
(Mixo-) polyhaline	±30-±18
(Mixo-)mesohaline	±18-±5
(Mixo-)oligohaline	±5-±0.5
Limnetic (Fresh water)	<±0.5

(Source: Anon, 1959)

Total dissolved solids (TDS) and conductivity were measured using Systronics water analyser (Model No. 371; accuracy± 0.01) calibrated with standard sea water. The TDS was expressed in parts per million (ppm) and conductivity in milli siemens (mS). Turbidity was measured using Nephelo–Turbidity meter – Systronics model no: 132 (APHA, 2005). The

Nephelometric method is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of the light scattered by a standard reference suspension under the same conditions. Higher intensity of the scattered light implies higher turbidity. Standard turbidity suspension for calibration was prepared using hydrazine sulphate and methylene tetramine. The measured turbidity values were expressed in NTU (Nephelometric Turbidity Unit).

3.3.4 Chemical parameters

Dissolved oxygen was estimated by the modified Winkler method (Strickland and Parsons, 1972, Grasshoff et al., 1983). This method depends on the oxidation of manganese dioxide by the oxygen dissolved in the samples, resulting in the formation of a tetravalent compound, which on acidification liberates iodine equivalent to the dissolved oxygen present in the sample. The quantity of iodine liberated was determined by titration with sodium thiosulphate. The results were expressed in the unit, milligrams per litre (mg L^{-1}).

pH measurements were made using a portable pH meter (Systronics model No: 371; accuracy ± 0.01) having a glass electrode and a calomel electrode as reference. Free carbon dioxide and total alkalinity were analysed using the titrimetric method (Boyd, 1982). It was expressed in milligrams per litre (mg L^{-1}). Total hardness was determined using the EDTA titrimetric method (APHA, 2005; Anon, 1988). EDTA (Ethylenediaminetetraacetic acid) and its sodium salts form a chelated soluble complex when added to a solution of certain metal cations (calcium and magnesium). If a small amount of a dye such as Eriochrome Black T is added to an aqueous solution containing calcium and magnesium ions at a pH of 10.0±0.1, the solution becomes wine red. If EDTA is added as a titrant, calcium and magnesium will form complexes. When this complex formation is completed, the solution turns from wine red to blue, marking the end point of the titration. The result is expressed as milligrams per litre (mg L^{-1}) of $CaCO_3$ and also the concentration of OH^-, CO_3^- and HCO_3^- in the water samples.

Biological oxygen demand (BOD) was determined by APHA, 2005; Kale and Mehotra, 2009.The measurement of oxygen consumed in a three day incubation period was chosen for the present study in order to estimate the environmental effects of waste waters and effluents. The principle is to measure the molecular oxygen utilized during a specified incubation period for the biochemical degradation of organic material and the oxygen used to oxidize inorganic material such as ferrous iron and sulphides. It also measure the amount of oxygen used to oxidize reduced forms of nitrogen (nitrogenous demand) in the presence of an inhibitor. It was expressed in milligrams per litre (mg L^{-1}).

3.3.4.1 Inorganic nutrients

Ammonia-nitrogen was analyzed using the phenate method (Grasshoff et al., 1983). In a moderately alkaline medium, ammonia reacts with hypochlorite to form monochloramine, which forms indophenol blue in the presence of phenol, a catalytic amount of nitroprusside ions and excess hypochlorite. This method estimates the sum of NH_4+ ion and NH_3, and the result is denoted here as NH_4-N.

Nitrite-nitrogen was measured using the diazotised method (Bendschneider and Robinson, 1952; Strickland and Parsons, 1968; Grasshoff et al., 1983). In this method, the nitrite in the water samples, was allowed to react with sulphanilamide. This process is called dizotization. Thereafter, the same sample reacts with N-(1-Naphthyl)ethylenediamine dihydrochloride. The absorbance of the resultant azo dye was measured at 543 nm in a spectrophotometer.

Nitrate-nitrogen was estimated using the resorcinol method (Zhang and Fischer, 2006). The method is based on nitration of resorcinol (Benzene-1,3-diol) in acidified water, resulting in a colour product (Nitrosophenol). The absorption spectrum obtained for the reaction product shows a maximum absorption at 505nm.

Dissolved inorganic phosphate-phosphorus was measured using the ascorbic acid method (Strickland and Parsons, 1972; Grasshoff et al., 1983). In an acid solution containing molybdic acid, ascorbic acid and trivalent antimony, inorganic phosphate forms a reduced phosphomolybdenum complex, which is blue in colour. This technique was used to quantify the amount of phosphate-P in the sample. The absorbance was measured at 882nm.

The dissolved silicate-silicon in the water was estimated using the molybdosilicate method. The determination of dissolved silicate in seawater is based on the formation of a yellow silicomolybdic acid when an acid sample is treated with a molybdate solution (Grasshoff et al., 1983). This is further reduced by ascorbic acid in presence of oxalic acid (to prevent interference from phosphate) to form a blue coloured complex (molybdenum blue). This blue colour is measured at 810 nm.

Sulphide in the water sample was determined as hydrogen sulphide, spectrophotometrically following the Cline method (1969). The samples fixed with zinc acetate solution were treated with N,N-Dimethyl-p-phenylenediaminedihydrochloride and ferric chloride reagents to develop a blue colour. The absorbance was recorded at 630 nm.

3.3.4.2 Nitrogen-Phosphorus ratio (Redfield ratio)

The relative concentrations of N and P have been used to estimate the limiting nutrient on the growth of algae in aquatic systems. The approach is simple and easy to use, provided that data on N and P concentrations are available (Redfield, 1934). Following the observation by Redfield that marine phytoplankton contains a molecular C: N: P ratio of 106:16:1 (50:7:1 by weight), the use of elemental ratios has become widespread in marine and freshwater phytoplankton studies. A departure from this ratio has been assumed to imply nutrient deficiency. In such case, there is not only sub-optimal growth of phytoplankton, but also sub-standard food resources for primary consumers of phytoplankton. For diatoms that need silicate for their frustules an optimal C: Si: N: P ratio of 106:15:16:1 has been suggested. The dissolved silica act as a limiting factor if the Si: N ratio is less than one (Redfield, 1934, Piehler et al., 2004).

Within the framework of protecting water quality of surface water, various ecological classification tools have been proposed to assess eutrophication (Crouzet et al., 1999; Wasmund et al., 2001; Carlson et al., 1977). The EU-Crouzet et al., 1999 method considers the annual mean to nitrate+nitrite and phosphate concentrations and the classification is given in Table 3.2.

Table 3.2 Trophic status of estuarine waters according to the index proposed by Crouzet et al., 1999.

Quality status	Nitrite+nitrate (µmol L^{-1})	Quality status	Phosphate (µmol L^{-1})
Good	< 6.5	Good	< 0.5
Fair	6.5 to 9.0	Fair	0.5 to 0.7
Poor	9.0 to 16.0	Poor	0.7 to 1.1
Bad	>16	Bad	>1.1

3.3.5 Data Analysis

The software programmes SPSS.22 (Statistical Programme for Social Sciences, version 22), PRIMER v6 (Plymouth Routines in Multivariate Ecological Research, version 6.1.9) SURFER.11 and ORIGIN 8.5 were used for data analyses and graphical representation of data.

Statistical analysis two way ANOVA (Analysis of Variance), standard deviation and correlation was done based on SPSS.22 software packages for Windows for testing the presence of significant differences and correlation among the parameters between stations and between seasons.

The PRIMER v 6 (Plymouth Routines in Multivariate Ecological Research, version 6.1.9), was used for univariate and multivariate analyses of data (Clarke and Gorely, 2006).

3.3.5.1 Multivariate methods

Multivariate analysis uses classification and ordination methods to compare communities on the basis of the identity of the component species and relative importance in terms of abundance or biomass. Classification analyses assign entities to groups, whereas ordinations place them spatially so that similar entities are close and dissimilar ones are distant.

3.3.5.2 Cluster analysis

Cluster analysis is indicative of the degree of similarity in species, composition either between stations or at the same station over time. Sites that are grouped into the same cluster are more similar in species composition. The most commonly used clustering technique is the hierarchical agglomerative method. It produces a hierarchy of clusters, ranging from small clusters of very similar items to larger clusters of increasingly dissimilar items. Hierarchical methods produce a graph known as a dendrogram or tree that shows the hierarchical clustering structure in which x- axis represents the full set of samples and the y axis defines the similarity level at which the samples or groups are fused. The dendrogram was produced using the Bray-Curtis coefficient (Bray and Curtis 1957).

$$S_{jk} = 100\left\{1 - \frac{\sum_{i=1}^{p}\left|y_{ij} - y_{ik}\right|}{\sum_{i=1}^{p}(y_{ij} + y_{ik})}\right\}$$

$$=100\ \frac{\sum_{i}^{p}=1\ \ 2\min\ \ (y_{ij,}y_{ik})}{\sum_{i}^{p}=1(y_{ij}+y_{ik})}$$

Where

y_{ij}represents the entry in the i th row and j th column of the data matrix i.e. the abundance or biomass for the i th species in the j th sample;

y_{ik} is the count for the i th species in the k th sample;

| … | represents the absolute value of the difference;

'min' stands for, the minimum of the two counts and

Σ represents the overall rows in the matrix.

SIMPROF Test was used to test the significance of the groups.

SIMPROF Test: The significance of the cluster groups created was tested by Similarity profile (SIMPROF) test.

3.4 Results

3.4.1 Meteorological Parameters

3.4.1.1 Rainfall

The Cochin estuary, being a tropical area, has a climate with two peaks of heavy rainfall during the southwest and northeast monsoon period. The rainfall data showed a clear seasonal variation. The 2010 monsoon period had a combined mean rainfall of 2353.80 mm from the southwest monsoon period. During October and November 2010, the mean rainfall was 1142.20 mm from the northeast monsoon period. The highest mean monthly rainfall of 849.9 mm was recorded in June 2010 and absolutely no rain fall was recorded in February 2010 (Fig.3.1). The combined annual average rainfall was higher during the 2010-11 period (4109.10mm) compared to the previous year (3314.20 mm).

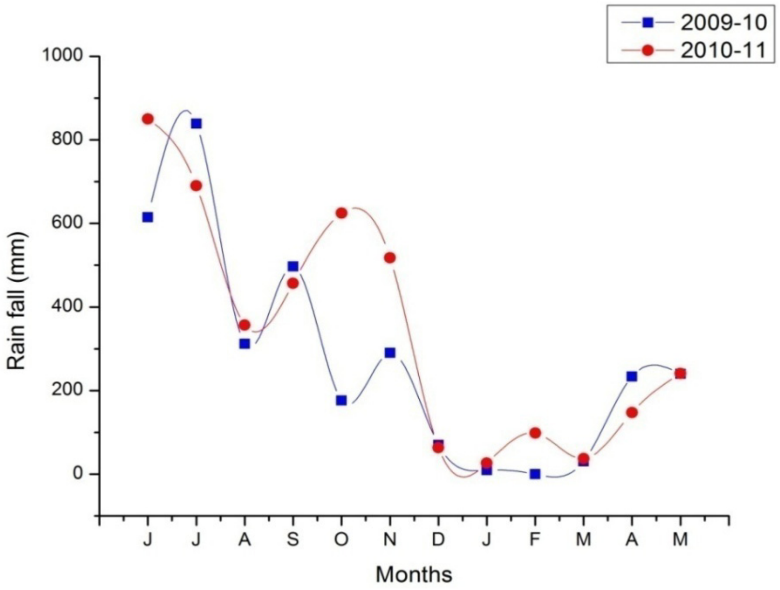


Fig. 3.1. Mean monthly variation of rain fall in Ernakulam district during 2009-11 period

3.4.1.2 River discharge

Monthly river discharge data showed that the river discharge was higher during the monsoon season; approximately 60-70% discharge occurs during this season. The mean monthly variation of river discharge in Cochin estuary during 2009-11 period is given in Fig.3.2 The maximum river discharge was observed during July for both the years; 67712.03 m^3s^{-1} during 2009-10 period and 51754.061 m^3s^{-1} during 2010-11 period. The maximum annual net discharge was recorded for the river Periyar during 2010-11 period (68995.20 m^3s^{-1}). The total discharge was higher during the 2010-11 period (285050.517 m^3 s^{-1}) compared to 2009-10 period (217606.792 m^3s^{-1}), similar to that of the annual rainfall pattern for the period.

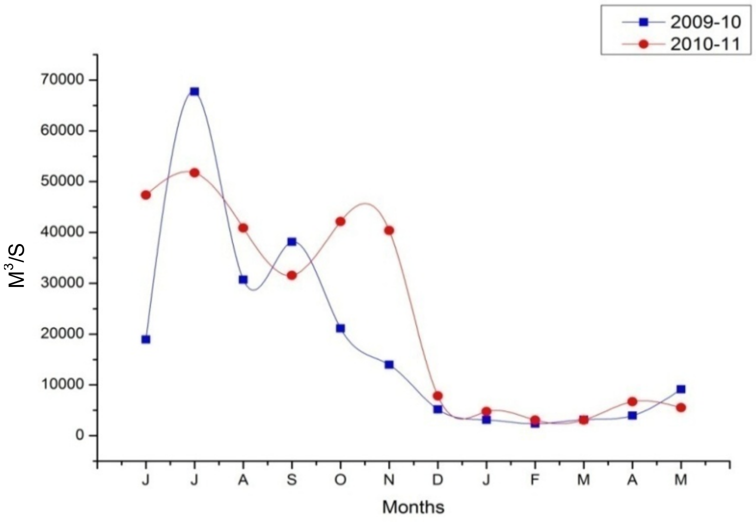


Fig.3.2. **Mean monthly variation of river discharge in Cochin estuary during 2009-11 period**

3.4.2 Physical parameters

3.4.2.1 Tides

The tidal amplitude of the Cochin estuary ranged from 0.2m to 0.9m. The highest tidal amplitude of 0.9m was observed during February 2010.

3.4.2.2 Depth

The entire estuary was shallow in nature, with an average depth of 3.70 ± 0.39 m. In the present study, the average monthly depth of the estuary ranged from 0.10 m at station 9 to 8.50 m at station 1 (Table 3.3.1).

The station wise variation of depth in Cochin estuary during the study period is presented in Table 3.3.3.The central zone of the estuary was found to be deeper compared to the other zones, which may be due to the dredging activities in the area. The southern zone, station 2 (4.97 m) was deeper than station 3 (2.73 m). In the northern zone, the depth ranged from 2.35 m at station 9 to 3.48 m at station 8.

During the monsoon period, the highest depth (6.50 m) was recorded in August 2009 and July and September 2010 and the lowest in July 2009 (0.10 m). In the post-monsoon period, the lowest depth was recorded in November 2009 at station 9 (1.10 m) and the highest was observed in December 2009 at station 1 (6.50 m). During the pre-monsoon period, the depth was minimum in February 2010 at station 8 and 9 (1.50 m) and maximum in April 2010 at station 1.

The variation of depth in the annual range was 0.10 to 8.50 m during the period 2009-10 period and 0.80 m to 7 m during 2010-11 period. Mean monthly variation of depth showed the minimum (0.10 m) in July 2009 and maximum (8.50 m) in December 2009.

ANOVA result of depth showed that it was significant at 1% level between seasons ($p \leq 0.05$), between stations ($p \leq 0.001$), between seasons and stations ($p \leq 0.05$) (Table 3.3.4).

Table 3.3.1 Mean monthly variation of depth in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	4.00	4.63	2.54	3.50	4.18	2.72	2.38	3.97	0.83	3.19
J	4.50	5.10	2.00	3.10	3.75	2.75	2.90	4.40	0.10	3.18
A	6.50	5.00	1.82	3.90	4.50	3.10	2.48	4.00	1.10	3.60
S	7.00	3.80	3.80	3.50	4.30	2.30	1.75	3.50	1.30	3.47
O	5.00	5.20	3.60	3.50	4.40	3.40	4.90	5.40	1.50	4.10
N	4.40	4.60	3.50	3.60	4.40	3.25	5.00	3.75	1.10	3.73
D'09	8.50	5.40	4.00	3.50	4.25	4.10	2.50	3.50	2.25	4.22
J'10	7.00	5.50	3.50	4.00	4.50	3.10	4.50	3.50	2.50	4.23
F	7.50	5.70	3.50	4.00	4.50	3.50	4.50	1.50	1.50	4.02
M	3.50	4.45	3.00	2.45	4.00	2.90	2.45	4.50	3.00	3.36
A	8.00	5.00	3.00	4.00	5.00	2.45	2.25	1.50	3.50	3.86
M	5.00	5.10	3.00	3.50	4.40	2.70	3.50	3.00	2.50	3.63
J	6.50	5.50	3.10	3.50	3.90	3.70	3.50	3.50	3.50	4.08
J	4.50	5.10	2.00	3.10	3.80	2.80	2.90	4.40	0.80	3.27
A	4.80	5.40	2.20	3.50	4.50	3.50	3.50	4.00	3.00	3.82
S	6.50	4.50	2.00	3.80	4.40	3.00	2.50	3.50	3.00	3.69
O	6.23	5.18	3.65	3.65	4.39	3.46	4.23	4.04	1.84	4.07
N	6.08	5.33	2.52	2.95	4.43	2.99	3.84	3.05	2.88	3.79
D'10	6.50	5.00	2.30	3.50	4.40	2.30	4.30	3.50	3.30	3.90
J'11	5.50	5.80	1.60	1.70	4.50	3.20	3.00	1.60	3.50	3.38
F	6.00	5.06	3.13	3.49	4.48	2.89	3.18	2.63	2.63	3.72
M	5.50	4.52	2.19	3.50	3.64	2.70	3.14	3.38	3.38	3.55
A	3.50	4.00	1.90	3.00	3.00	3.20	2.25	3.50	3.00	3.04
M'11	7.00	4.50	1.55	4.00	3.45	2.00	4.00	4.00	4.50	3.89

Table 3.3.2 Mean season wise variation of depth in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	4.00 ± 2.27	5.58 ± 1.08	6.23 ± 1.88	6.08 ± 0.42	6.00 ± 2.12	5.50 ± 1.47
2	4.63 ± 0.59	5.13 ± 0.45	5.18 ± 0.40	5.33 ± 0.34	5.06 ± 0.51	4.52 ± 0.43
3	2.54 ± 0.89	2.33 ± 0.53	3.65 ± 0.24	2.52 ± 0.85	3.13 ± 0.25	2.19 ± 0.68
4	3.50 ± 0.33	3.48 ± 0.29	3.65 ± 0.24	2.95 ± 0.89	3.49 ± 0.73	3.50 ± 0.41
5	4.18 ± 0.32	4.15 ± 0.35	4.39 ± 0.10	4.43 ± 0.05	4.48 ± 0.41	3.64 ± 0.62
6	2.72 ± 0.33	3.25 ± 0.42	3.46 ± 0.44	2.99 ± 0.50	2.89 ± 0.45	2.70 ± 0.51
7	2.38 ± 0.48	3.10 ± 0.49	4.23 ± 1.17	3.84 ± 0.60	3.18 ± 1.04	3.14 ± 0.71
8	3.97 ± 0.37	3.85 ± 0.44	4.04 ± 0.92	3.05 ± 1.05	2.63 ± 1.44	3.38 ± 0.57
9	0.83 ± 0.52	2.58 ± 1.21	1.84 ± 0.65	2.88 ± 0.74	2.63 ± 0.85	3.38 ± 0.81

Table 3.3.3 Mean station wise variation of depth (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface	
	Min	Max
1	3.50	8.50
2	3.80	5.80
3	1.55	4.00
4	1.70	4.00
5	3.00	5.00
6	2.00	4.10
7	1.75	5.00
8	1.50	5.40
9	0.10	4.50

Table 3.3.4 ANOVA of depth in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	26	9.306	12.740
Season	2	4.126	5.648**
Station	8	26.612	36.431**
Season * Station	16	1.301	1.782**
Error	189	0.730	
Total	216		
R^2= 0.637			

** Variation is significant at 1% level

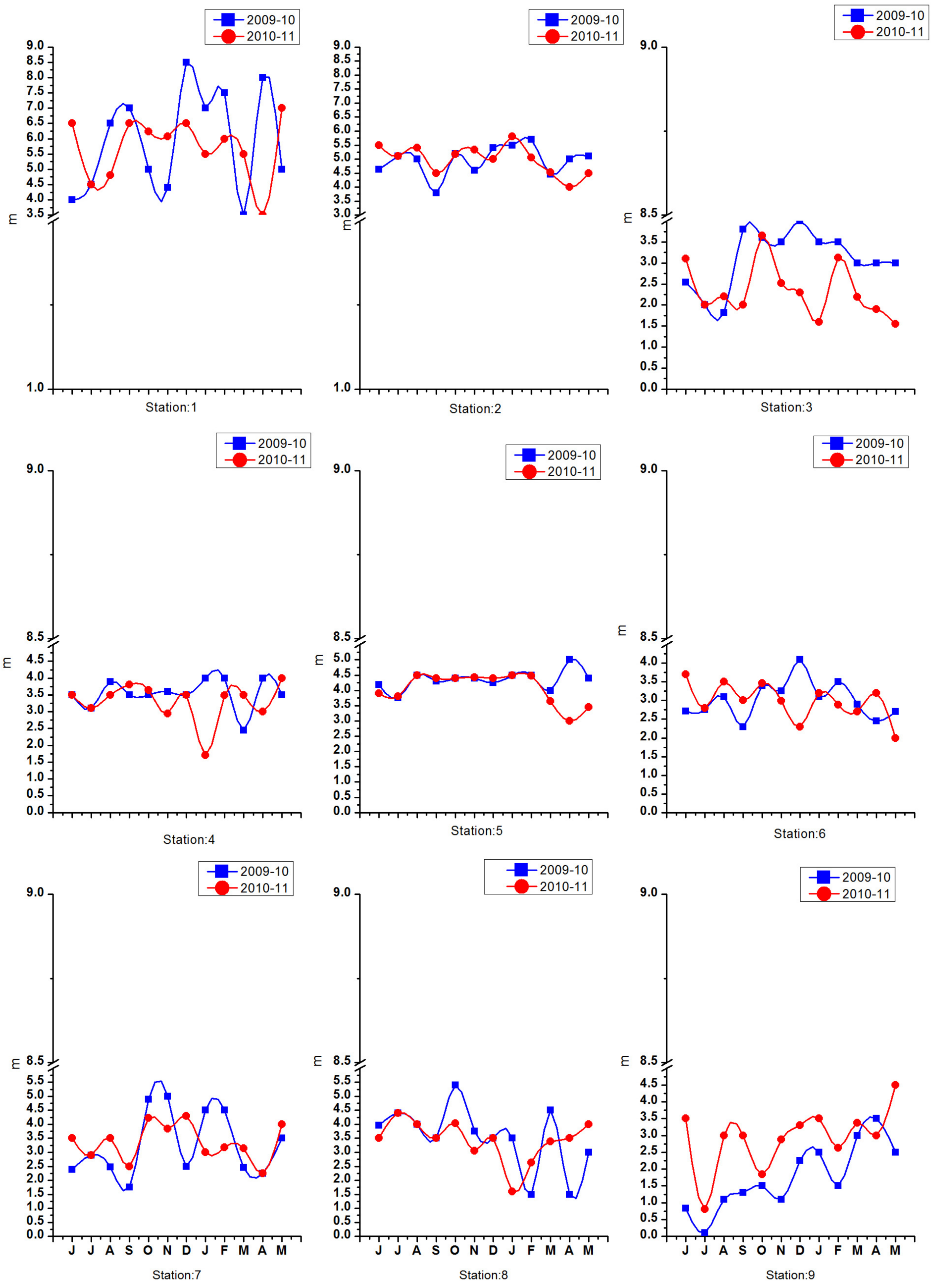


Fig. 3.3. **Mean monthly variation in depth in selected stations of Cochin estuary during 2009-11 period**

3.4.2.3 Atmospheric Temperature

The mean atmospheric temperature of the Cochin estuary was 28.52 ± 1.43 °C. The mean monthly variation of atmospheric temperature in Cochin estuary is presented in Table 3.4.1 and Fig.3.4. The maximum atmospheric temperature (35.00 ± 2.31 °C) was recorded from stations 8and 9 and the minimum (24.00 ± 2.31 °C) was observed at stations 1, 2, 3 and 5. The station wise variation of atmospheric temperature is presented in Table 3.4.3.The air temperature distribution was more or less uniform in the estuary, but it was comparatively higher in the northern zone (29.26 ± 0.52°C) of the estuary. In the northern zone, the temperature was higher at station 9 (29.85 °C) and lower at station 6 (28.66 °C). The zone wise variation of atmospheric temperature was lower in the southern zone (27.72 ± 0.46 °C) of the estuary. In the southern zone, the atmospheric temperature was higher at station 3 (28.05 °C) as compared to station 2 (27.40 °C). In the central zone of the estuary the atmospheric temperature was lower at station 1 (27.55 °C) and high at station 4 (28.41 °C).

The atmospheric temperature showed slight variations between the seasons. It was higher during pre-monsoon season (29.04 ± 0.56 °C) and lower during monsoon season (27.93 ± 0.56 °C). The annual comparison of monsoon period showed the maximum atmospheric temperature was observed at station 9 in September 2009 (35.00 °C) and minimum in July and September 2010 (24.00 °C). During the post-monsoon period, the highest atmospheric temperature was recorded in January 2010 (34.00 °C) and the lowest in January 2010 (24.00 °C). In the pre-monsoon period, the atmospheric temperature ranged from 24.00°C in February 2011 to 35.00°C in May 2010.

The annual variation of atmospheric temperature showed that the 2009-10 period was hotter (29.21 ± 1.34 °C) compared to the 2010-11 period (27.84 ± 1.21^{o}C). In 2009-10 period, the highest values was observed (30.91 ^{o}C) in September 2009 and lowest (26.85 ^{o}C) in August 2009. In the 2010-11 period, the atmospheric temperature ranged from 25.90 ^{o}C in July 2010 to 30.11 ^{o}C in April 2011.The mean monthly variation of atmospheric temperature showed the highest temperature in September 2009 (30.91 ^{o}C) and the lowest in July 2010 (25.90 ^{o}C).

ANOVA result of atmospheric temperature observed that it was significant at 5% level between stations ($p \leq 0.001$) (Table 3.4.4).

Table 3.4.1 Mean monthly variation of atmospheric temperature in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	27.00	28.00	30.00	29.20	29.00	26.50	26.00	27.00	28.00	27.86
J	26.00	27.00	27.00	28.00	26.00	27.00	29.80	32.00	29.00	27.98
A	25.00	26.80	28.00	28.00	28.00	28.50	25.00	25.50	28.00	26.98
S	27.20	30.00	32.00	31.00	27.00	29.00	33.00	34.00	35.00	30.91
O	32.00	30.50	32.00	28.00	31.00	29.00	30.00	32.00	31.50	30.67
N	27.00	31.00	29.00	32.00	28.20	30.00	29.00	28.00	31.00	29.47
D'09	26.00	26.00	33.00	28.00	29.00	30.00	30.00	29.00	30.00	29.00
J'10	28.00	26.00	28.00	27.00	24.00	26.00	31.00	34.00	29.00	28.11
F	29.00	28.00	26.00	26.00	32.10	28.00	29.00	32.00	32.20	29.14
M	27.00	29.00	29.00	27.00	28.00	30.10	30.00	32.00	30.00	29.12
A	32.00	29.20	29.00	31.00	29.00	29.80	30.00	34.00	32.00	30.67
M	28.00	27.00	29.00	28.00	32.00	32.00	32.00	35.00	33.50	30.72
J	27.00	28.00	28.00	29.00	29.00	31.00	34.00	28.00	29.20	29.24
J	24.00	24.00	25.10	27.00	30.00	27.00	26.00	25.00	25.00	25.90
A	26.00	26.00	26.00	29.00	29.00	30.00	30.00	29.00	29.00	28.22
S	26.00	24.00	24.00	27.00	29.00	27.00	27.00	27.00	27.00	26.44
O	29.00	28.00	29.00	30.00	28.00	29.00	27.00	28.00	26.00	28.22
N	28.00	27.00	29.00	30.00	29.00	27.00	29.00	29.00	28.00	28.44
D'10	27.00	26.00	27.00	29.00	26.00	28.00	26.00	26.00	28.90	27.10
J'11	26.00	25.00	27.00	28.00	28.00	29.00	28.00	29.30	30.00	27.81
F	29.00	26.00	24.00	25.00	28.00	25.00	28.50	25.00	33.00	27.06
M	28.00	27.00	26.00	25.00	28.00	27.00	27.00	26.00	28.00	26.89
A	31.00	31.00	27.00	29.00	27.00	31.00	30.00	32.00	33.00	30.11
M'11	26.00	27.00	29.00	28.00	27.50	31.00	30.00	29.00	30.00	28.61

Table 3.4.2 Mean seasonal variation of atmospheric temperature in selected stations Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	26.30 ± 1.01	25.75 ± 1.26	28.25 ± 2.63	27.50 ± 1.29	29.00 ± 2.16	28.50 ± 2.08
2	27.95 ± 1.46	25.50 ± 1.91	28.38 ± 2.75	26.50 ± 1.29	28.3 ± 1.01	27.75 ± 2.22
3	29.25 ± 2.22	25.78 ± 1.69	30.50 ± 2.38	28.00 ± 1.15	30.50 ± 2.38	26.50 ± 2.08
4	29.40 ± 1.51	28.00 ± 1.15	28.75 ± 1.89	29.25 ± 0.96	28.75 ± 2.22	26.75 ± 2.06
5	27.50 ± 1.29	29.25 ± 0.50	28.05 ± 2.95	27.75 ± 1.26	28.05 ± 2.95	27.63 ± 0.48
6	27.75 ± 1.19	28.75 ± 2.06	28.75 ± 1.89	28.25 ± 0.96	28.75 ± 1.89	28.50 ± 3.00
7	28.45 ± 3.67	29.25 ± 3.59	30.00 ± 0.82	27.50 ± 1.29	30.00 ± 0.82	28.88 ± 1.44
8	29.63 ± 4.03	27.25 ± 1.71	30.75 ± 2.75	28.08 ± 1.49	30.75 ± 2.75	28.00 ± 3.16
9	30.00 ± 3.37	27.55 ± 1.97	30.38 ± 1.11	28.23 ± 1.69	30.38 ± 1.11	31 ± 2.45

Table 3.4.3 Mean station wise variation of atmospheric temperature (minimum- maximum) in selected stations of Cochin estuary during 2009-11period

Stations	Surface	
	Min	Max
1	24.00	32.00
2	24.00	31.00
3	24.00	33.00
4	25.00	32.00
5	24.00	32.10
6	25.00	32.00
7	25.00	34.00
8	25.00	35.00
9	25.00	35.00

Table 3.4.4 ANOVA of atmospheric temperature in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	26	10.069	2.163
Season	2	22.025	4.732
Station	8	16.492	3.544*
Season * Station	16	5.363	1.152
Error	189	4.654	
Total	216		
$R^2 = 0.229$			

* Variation is significant at 5% level

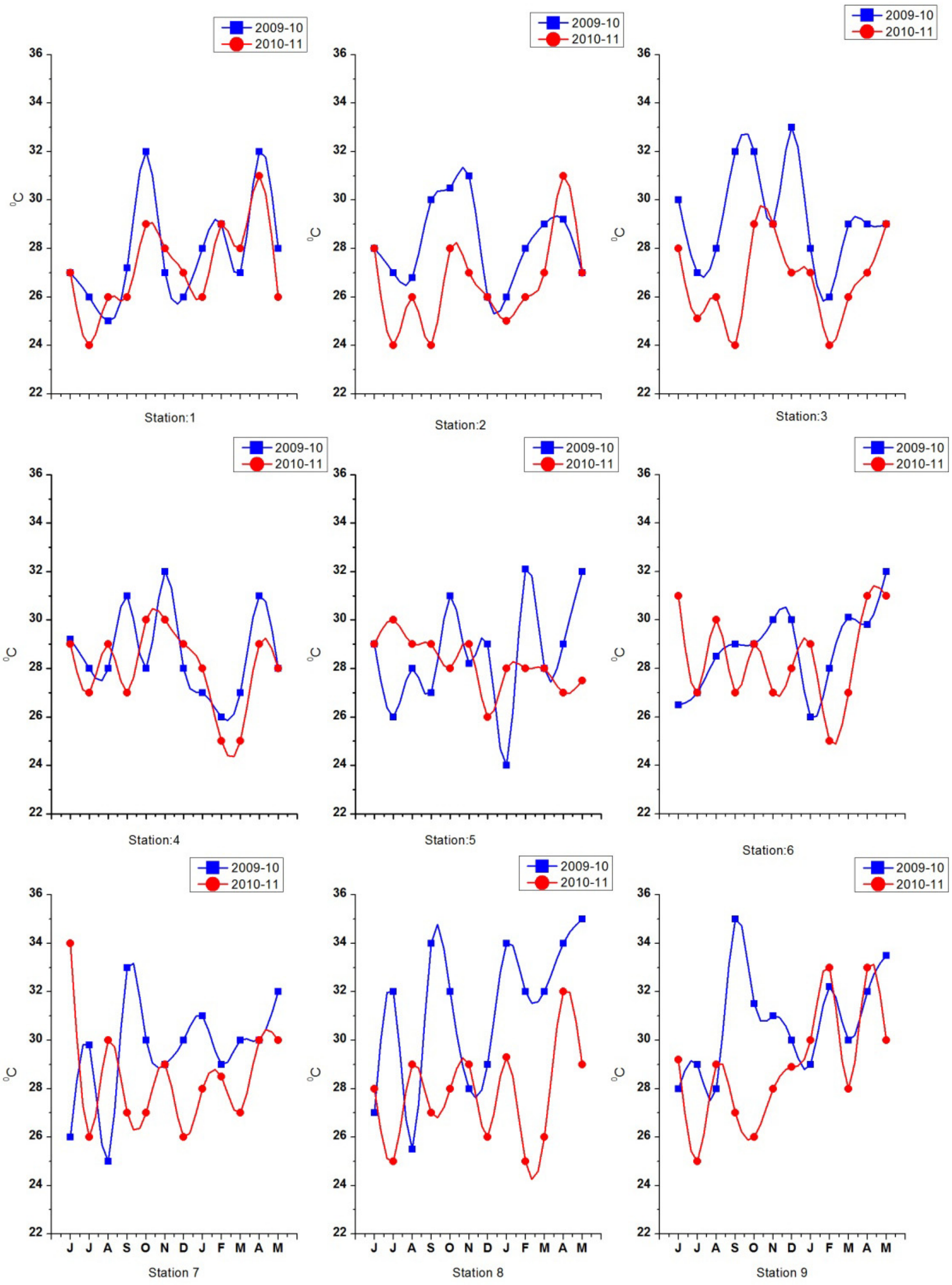


Fig.3.4. Mean monthly variation of atmospheric temperature in selected stations of Cochin estuary during 2009-11 period

3.4.2.4 Water temperature

The surface water temperature ranged from 34.00 °C (station 8 and 9) to 25.00 °C (stations 8 and 9), whereas the bottom water temperature varied from 33.00°C (station 9) to 25.00°C (station 5). The mean station wise water temperature was maximum (29.59 ± 0.21 °C) at station 4 and lowest at station 9 (28.93 ± 0.21 °C). The station wise variation of water temperature is presented in Table 3.5.3. The zone wise variation of water temperature was maximum in the southern zone (29.34 ± 0.22 °C) and minimum in the northern zone (29.17 ± 0.18°C). In the central zone, the water temperature was higher at station 4 (29.59 °C) compared to station 5 and station 1. The water temperature at station 3 (29.49 °C) was higher compared to station 2 (29.18 °C) in the southern zone. The water temperature in the northern zone ranged from 29.16 °C at station 6 to 29.31 °C at station 7.

The mean monthly variation of water temperature during the study period is given in Table 3.5.1 and Fig.3.5. Monthly mean values of temperature were found to be more or less similar throughout the study period. The maximum average temperature during 2009-10 was recorded in May 2010 (32.04 °C) and that in 2010-11 was 31.33 °C in May 2011. The water temperature in the estuary ranged from 27.39 °C in January 2010 to 32.04 °C in May 2010 during 2009-10 whereas in 2010-11 period it ranged from 26.28 °C in July 2010 to 31.33 °C in May 2011.

The average water temperature was lowest during the monsoon period season. The mean temperature during the pre-monsoon period was highest for the surface and bottom waters across all the stations. During the monsoon period the maximum temperature was recorded at station 3 (30.55 °C) in

September 2009 and minimum in July 2010 at station 9 (25.05 °C). The water temperature ranged from 26.50 °C in January 2010 and 26.50 °C in December 2010 to 31.00 °C in October 2009 during the post-monsoon season. The annual comparison of pre-monsoon period showed the minimum in February 2010 (28.00 °C) and maximum in May 2010 (33.50 °C).

ANOVA result of water temperature showed that it was significant at 1% level between seasons ($p \leq 0.001$), between seasons and stations ($p \leq 0.001$) (Table 3.5.4).

Table 3.5.1 Mean monthly variation of water temperature in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	28.58	28.62	29.77	29.42	27.97	27.80	27.25	26.93	26.85	28.13
J	28.25	28.35	29.00	29.75	27.15	27.40	26.75	27.30	26.50	27.83
A	28.00	27.70	29.75	28.00	27.75	27.50	27.00	26.00	26.05	27.53
S	29.50	29.80	30.55	30.50	29.00	28.50	28.00	27.50	28.00	29.04
O	31.50	31.50	30.00	31.50	31.50	31.00	30.25	30.00	29.50	30.75
N	29.00	30.00	30.55	30.50	30.00	30.00	29.90	29.50	29.50	29.88
D'09	29.00	30.00	30.50	30.25	30.75	30.50	30.10	29.75	29.50	30.04
J'10	26.50	26.50	26.50	27.00	26.50	27.50	30.50	28.00	27.50	27.39
F	29.90	29.50	30.00	28.00	30.00	29.75	31.10	31.00	31.05	30.03
M	29.55	31.00	31.50	30.40	30.05	30.05	31.50	31.50	30.50	30.67
A	30.05	30.10	30.50	32.00	29.50	30.80	31.50	31.50	30.50	30.72
M	30.05	30.10	30.50	32.00	32.80	33.00	33.05	33.40	33.50	32.04
J	30.50	28.80	29.05	27.80	30.00	29.80	29.50	29.50	29.30	29.36
J	26.50	26.90	27.00	27.50	26.00	26.00	25.60	26.00	25.05	26.28
A	27.50	27.00	27.40	27.55	26.50	26.50	26.00	26.50	25.10	26.67
S	28.00	27.00	28.00	27.50	28.00	27.50	27.35	28.50	28.00	27.76
O	29.00	29.50	29.39	29.81	29.69	29.75	30.19	29.31	29.00	29.52
N	28.27	28.78	28.70	29.35	28.58	28.33	28.36	28.35	28.17	28.54
D'10	28.30	28.60	28.45	29.00	28.00	27.00	26.75	26.75	26.50	27.71
J'11	27.50	28.25	28.25	29.25	28.05	28.25	28.15	29.00	29.00	28.41
F	29.89	30.18	30.63	30.60	30.59	30.90	31.79	31.85	31.39	30.87
M	30.30	30.56	30.63	30.78	30.81	30.72	31.18	31.70	31.30	30.89
A	30.00	30.50	30.50	30.50	30.85	29.75	30.00	31.00	31.00	30.46
M'11	31.00	31.00	30.75	31.25	31.00	31.50	31.75	32.25	31.50	31.33

Table 3.5.2 Mean seasonal variation of water temperature in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	28.58± 0.66	28.13±1.70	29.00 ±2.04	28.27±0.61	29.89±0.24	30.30±0.50
2	28.62 ±0.88	27.43±0.92	29.50±2.12	28.78±0.53	30.18±0.62	30.56±0.34
3	29.77± 0.63	27.86±0.89	29.39±1.94	28.70±0.50	30.63±0.63	30.63±0.10
4	29.42±1.05	27.59±0.14	29.81±1.95	29.35±0.34	30.60±1.89	30.78±0.33
5	27.97±0.77	27.63±1.80	29.69±2.21	28.58±0.79	30.59±1.50	30.81±0.17
6	27.80± 0.50	27.45±1.69	29.75±1.55	28.33±1.12	30.90±1.47	30.72±0.73
7	27.25±0.54	27.11±1.76	30.19±0.25	28.36±1.41	31.79±0.86	31.18±0.83
8	26.93± 0.66	27.63±1.65	29.31±0.90	28.35±1.14	31.85±1.06	31.70±0.52
9	26.85±0.83	26.86±2.13	29.00±1.00	28.17±1.18	31.39±1.43	31.30±0.21

Table 3.5.3 Mean station wise variation of water temperature (minimum-maximum) in selected stations of Cochin estuary during 2009-11period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	26.00	32.50	26.00	31.00
2	26.00	31.00	26.00	32.00
3	27.00	32.00	26.00	31.00
4	27.00	32.00	27.00	32.00
5	26.00	32.60	26.00	33.00
6	26.00	33.00	26.00	33.00
7	26.00	33.00	25.00	33.10
8	25.00	34.00	26.93	32.80
9	25.00	34.00	25.10	33.00

Table 3.5.4 ANOVA of water temperature in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	21.361	14.195
Season	2	340.031	225.972**
Station	8	2.111	1.403
Surface water, Bottom water	1	2.315E-5	0.000
Season * Station	16	5.577	3.706**
Station * Surface water, Bottom water	8	0.325	0.216
Season * Surface water, Bottom water	2	0.776	0.516
Error	394	1.505	
Total	432		
R^2= 0.571**			

** Variation is significant at 1% level

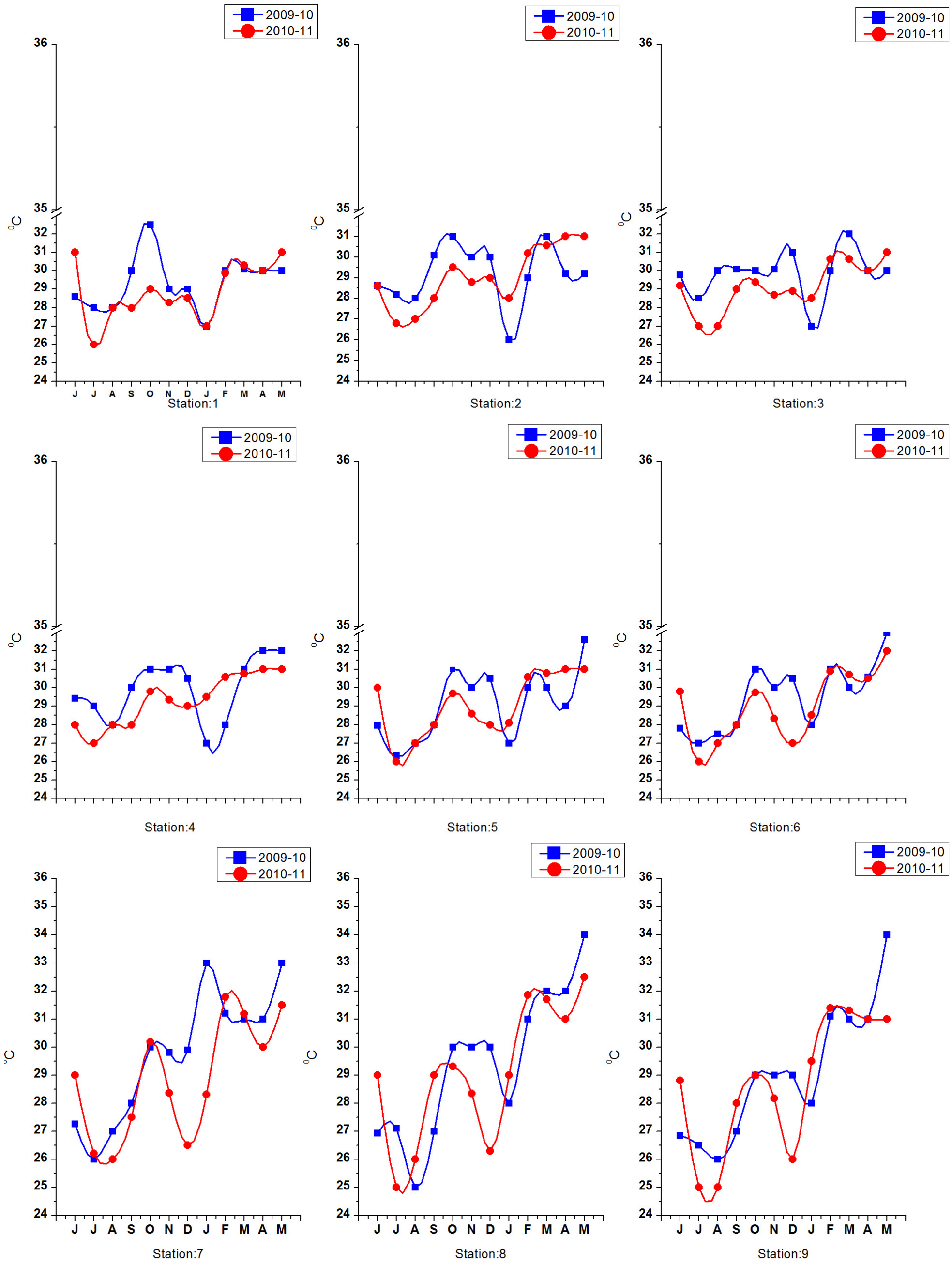


Fig.3.5. Mean monthly variation of water temperature in selected stations of Cochin estuary during 2009-11 period

3.4.2.5 Transparency

Transparency values were generally low (0.61 ± 0.15 m) in the estuary, especially during the monsoon period season. It was higher during the post-monsoon period (0.90 ± 0.15 m) and the pre-monsoon period (0.81 ± 0.15 m). The monsoon period for both years was compared and it was higher in September 2009 (1.90 m) and lower in July 2009 (0.10 m) and July 2010. In the post-monsoon period the values ranged from 0.45 m in December 2009 to 1.60 m in October 2009 and January 2011. The transparency values ranged from 0.25 m in March 2010 to 1.90 m in April 2011.

Mean station wise values showed that transparency was lowest at station 4 (0.55 m) and highest at station 8 (1.14 m). The station wise variation of transparency is presented in Table 3.6.3. The highest transparency of 0.99 m was recorded from northern zone of the estuary. The southern zone (0.58 ± 0.22 m) was found to be more turbid as compared to other zones. In the central zone, the transparency ranged from 0.55 m at station 4 to 0.70 m at station 1. The transparency was similar in station 2 (0.59 m) and station 3 (0.57 m) in the southern zone. The transparency in the northern zone of the estuary was lower at station 7 (0.89 m) and higher in station 8 (1.14 m).

The transparency values were higher during the 2009-10 period (0.82 m) in comparison to the 2010-11 period (0.73 m). The transparency ranged from 0.53 m in July 2010 to 1.00 m in February 2010 during 2009-10 period. In 2010-11, the maximum transparency was 1.04 m in

April 2011 and minimum of 0.32 m in July 2010. The average transparency of the estuary during the study period was 0.77 ± 0.18 m.

ANOVA result of transparency of the water body showed that it was significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.001$), between seasons and stations ($p \leq 0.01$) (Table 3.6.4).

Table 3.6.1 Mean monthly variation of transparency in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	0.62	0.47	0.50	0.45	0.53	1.30	0.87	1.00	0.57	0.70
J	0.25	0.40	0.40	0.25	0.50	1.00	1.00	0.90	0.10	0.53
A	0.62	0.50	0.60	0.50	0.50	1.00	1.00	1.10	1.10	0.77
S	1.00	0.50	0.50	0.60	0.60	1.90	0.60	1.00	0.50	0.80
O	1.00	0.60	0.80	0.60	0.75	1.00	1.00	1.60	1.50	0.98
N	0.90	0.90	0.60	1.00	0.90	1.00	1.10	1.25	1.00	0.96
D'09	1.10	0.90	0.45	0.50	0.50	0.70	1.10	1.25	1.00	0.83
J'10	1.00	1.00	0.50	1.00	1.00	0.90	0.90	1.40	1.00	0.97
F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
M	0.50	0.25	0.25	0.40	0.50	1.00	1.15	1.60	1.50	0.79
A	0.80	0.40	0.40	0.50	0.50	1.10	1.20	1.50	1.50	0.88
M	0.50	0.30	0.30	0.30	0.60	0.70	0.50	1.00	1.25	0.61
J	0.25	0.20	0.25	0.25	0.60	0.95	0.90	0.90	1.00	0.59
J	0.10	0.20	0.20	0.10	0.30	0.50	0.50	0.50	0.50	0.32
A	0.50	0.40	0.30	0.50	0.20	0.70	0.60	0.60	0.60	0.49
S	0.80	0.70	0.50	0.50	0.50	0.80	0.80	0.80	1.00	0.71
O	1.00	0.85	0.59	0.78	0.79	0.90	1.03	1.38	1.13	0.94
N	0.90	0.75	0.56	0.69	0.70	0.90	0.91	1.29	1.04	0.86
D'10	0.90	0.60	0.60	0.80	0.50	1.20	0.90	0.90	0.80	0.80
J'11	0.80	0.80	0.50	0.50	0.80	0.60	0.80	1.60	1.20	0.84
F	0.70	0.49	0.49	0.55	0.65	0.95	0.96	1.28	1.31	0.82
M	0.57	0.60	0.96	0.52	0.55	0.72	0.90	1.19	1.15	0.80
A	0.50	0.80	1.90	0.50	0.50	0.70	1.25	1.50	1.75	1.04
M'11	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.80	0.40	0.52

Table 3.6.2 Mean seasonal variation of transparency in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	0.62±0.31	0.41±0.31	1.00±0.08	0.90±0.08	0.70±0.24	0.57±0.09
2	0.47±0.05	0.38±0.24	0.85±0.17	0.75±0.11	0.49±0.35	0.60±0.14
3	0.50±0.08	0.31±0.13	0.59±0.15	0.56±0.05	0.49±0.35	0.96±0.66
4	0.45±0.15	0.34±0.20	0.78±0.26	0.69±0.14	0.55±0.31	0.52±0.02
5	0.53±0.05	0.40±0.18	0.79±0.22	0.70±0.14	0.65±0.24	0.55±0.07
6	1.30±0.42	0.74±0.19	0.90±0.14	0.90±0.24	0.95±0.17	0.72±0.18
7	0.87±0.19	0.70±0.18	1.03±0.10	0.91±0.09	0.96±0.32	0.90±0.31
8	1.00±0.08	0.70±0.18	1.38±0.17	1.29±0.29	1.28±0.32	1.19±0.29
9	0.57±0.41	0.78±0.26	1.13±0.25	1.04±0.17	1.31±0.24	1.15±0.56

Table 3.6.3 Mean station wise variation of transparency (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface	
	Min	Max
1	0.10	1.10
2	0.20	1.00
3	0.20	1.90
4	0.10	1.00
5	0.20	1.00
6	0.50	1.90
7	0.50	1.25
8	0.50	1.60
9	0.10	1.75

Table 3.6.4 ANOVA of transparency in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	26	0.551	8.915
Season	2	1.516	24.522**
Station	8	1.133	18.323**
Season * Station	16	0.140	2.260**
Error	189	0.062	
Total	215		
R^2= 0.551			

** Variation is significant at 1% level

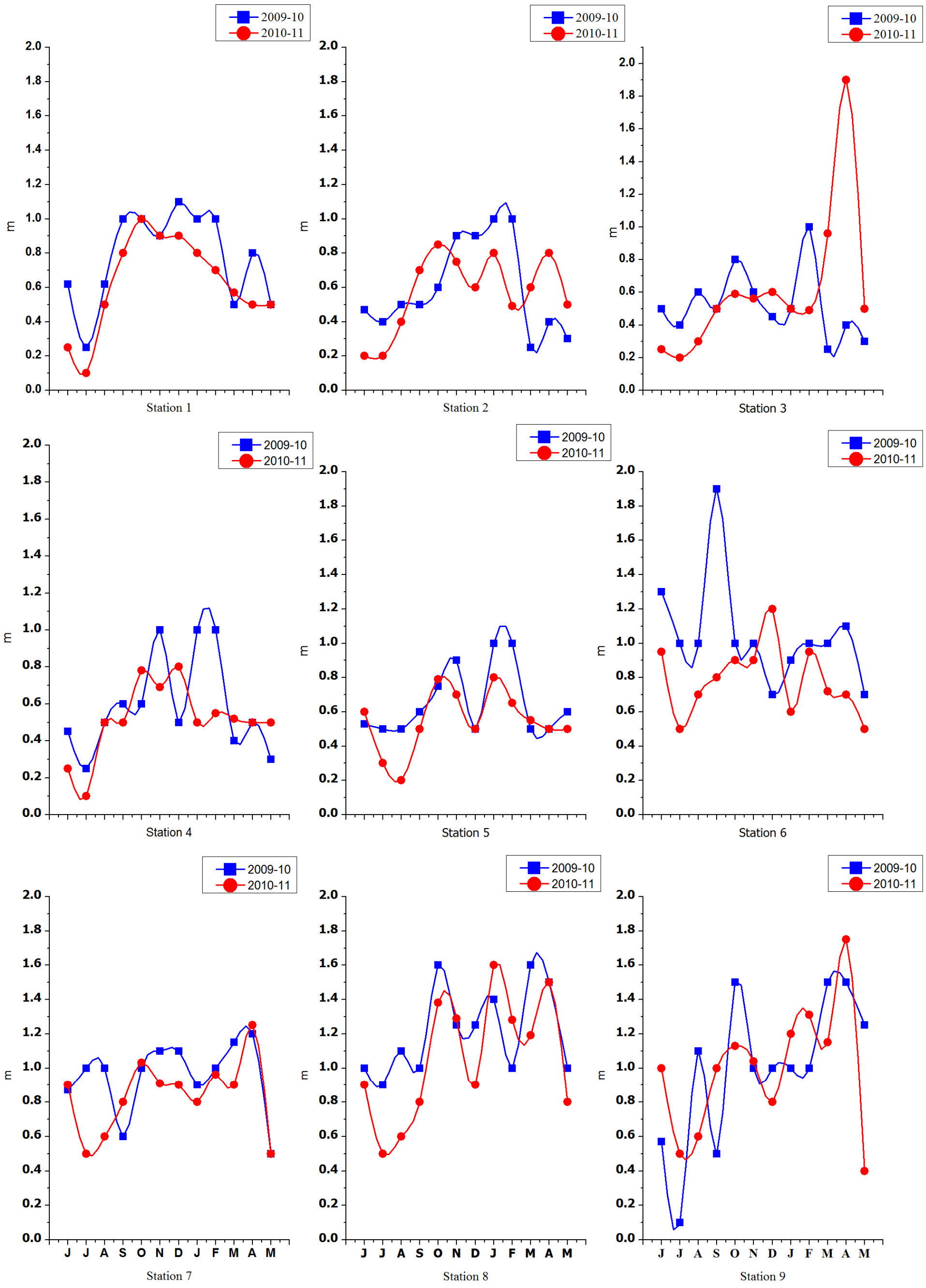


Fig.3.6. Mean monthly variation of transparency in selected stations of Cochin estuary during 2009-11 period

3.4.2.6 Light attenuation coefficient

The maximum value of the light attenuation coefficient (15.00) was recorded at stations 1, 4 and 9. The minimum value (0.79) was recorded at station 3. Mean station wise values ranged from 1.44 ± 0.76 at station 8 to 3.51 ± 0.76 at station 4. The station wise variation of light attenuation coefficient is shown in Table 3.7.3. The light extinction attenuation coefficient was higher in the southern zone of the estuary (3.25 ± 0.79) and lower in the northern zone (1.82 ± 0.79). The light attenuation coefficient ranged from 2.81 at station 5 to 3.51 at station 4 in the central zone of the estuary. The values were similar in the southern zone of the estuary as in the case of transparency and it was recorded as 3.17 at station 2 and 3.33 at station 3. In the northern zone the values ranged from 1.44 at station 8 to 2.24 at station 9.

The light attenuation coefficient values were higher during the monsoon period and lower during post-monsoon period. During the monsoon period the light attenuation coefficient showed minimum value (0.79) in September 2009 and maximum (15.00) in July 2009, (15.00) in July 2010. The values ranged from 0.94 in October 2009 to 3.33 in December 2009 during 2009-10 post-monsoon periods. In the post-monsoon period 2010-11 the values ranged from 0.94 in January 2011 to 3 in November and December 2010. During the pre-monsoon period, the highest temperature was recorded in March 2010 (6.00) and lowest in April 2011 (0.79).

The mean annual light attenuation coefficient was comparatively higher during the 2010-11 period (2.75 ±1.48) than the 2009-10 period

(2.48 ± 0.89). During 2009-10 period, the highest value (4.69) was recorded in July 2009 and lowest (1.50) in February 2010. In 2010-11 period the values ranged from 1.69 in October 2010 to 6.89 in July 2010. The mean light attenuation coefficient of the Cochin estuary was 2.56 ± 1.21.

ANOVA result of light attenuation coefficient showed that it was significant at 1% level between stations ($p \leq 0.001$). It was significant at 5% level between seasons ($p \leq 0.001$) (Table 3.7.4).

Table 3.7.1 Mean monthly variation of light attenuation coefficient in Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	2.42	3.19	3.00	3.33	2.83	1.15	1.72	1.50	2.63	2.42
J	6.00	3.75	3.75	6.00	3.00	1.50	1.50	1.67	15.00	4.69
A	2.42	3.00	2.50	3.00	3.00	1.50	1.50	1.36	1.36	2.18
S	1.50	3.00	3.00	2.50	2.50	0.79	2.50	1.50	3.00	2.25
O	1.50	2.50	1.88	2.50	2.00	1.50	1.50	0.94	1.00	1.70
N	1.67	1.67	2.50	1.50	1.67	1.50	1.36	1.20	1.50	1.62
D'09	1.36	1.67	3.33	3.00	3.00	2.14	1.36	1.20	1.50	2.06
J'10	1.50	1.50	3.00	1.50	1.50	1.67	1.67	1.07	1.50	1.66
F	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
M	3.00	6.00	6.00	3.75	3.00	1.50	1.30	0.94	1.00	2.94
A	1.88	3.75	3.75	3.00	3.00	1.36	1.25	1.00	1.00	2.22
M	3.00	5.00	5.00	5.00	2.50	2.14	3.00	1.50	1.20	3.15
J	6.00	7.50	6.00	6.00	2.50	1.58	1.67	1.67	1.50	3.82
J	15.00	7.50	7.50	15.00	5.00	3.00	3.00	3.00	3.00	6.89
A	3.00	3.75	5.00	3.00	7.50	2.14	2.50	2.50	2.50	3.54
S	1.88	2.14	3.00	3.00	3.00	1.88	1.88	1.88	1.50	2.24
O	1.50	1.76	2.54	1.92	1.90	1.67	1.46	1.09	1.33	1.69
N	1.67	2.00	2.68	2.17	2.14	1.67	1.65	1.16	1.44	1.84
D'10	1.67	2.50	2.50	1.88	3.00	1.25	1.67	1.67	1.88	2.00
J'11	1.88	1.88	3.00	3.00	1.88	2.50	1.88	0.94	1.25	2.02
F	2.14	3.06	3.06	2.73	2.31	1.58	1.56	1.17	1.15	2.08
M	2.63	2.50	1.56	2.88	2.73	2.08	1.67	1.26	1.30	2.07
A	3.00	1.88	0.79	3.00	3.00	2.14	1.20	1.00	0.86	1.87
M'11	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.88	3.75	2.96

Table 3.7.2 Mean seasonal variation of light attenuation coefficient in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	3.08±1.99	6.47± 5.95	1.51±0.12	1.68± 0.15	2.34±0.77	2.69 ±0.41
2	3.24±0.35	5.22± 2.71	1.83±0.45	2.03 ±0.32	4.06±1.94	2.61± 0.55
3	3.06±0.52	5.38± 1.89	2.68±0.63	2.68± 0.23	4.06±1.94	2.10 ±1.12
4	3.71±1.57	6.75 ±5.68	2.13±0.75	2.24± 0.52	3.31±1.46	2.90± 0.13
5	2.83±0.24	4.50± 2.27	2.04±0.67	2.23± 0.53	2.50±0.71	2.76± 0.33
6	1.24±0.34	2.15± 0.61	1.70±0.30	1.77± 0.52	1.63±0.35	2.20 ±0.59
7	1.81±0.47	2.26± 0.61	1.47±0.14	1.66 ±0.17	1.76±0.83	1.86± 0.79
8	1.51±0.12	2.26 ±0.61	1.10±0.13	1.21 ±0.32	1.23±0.31	1.33± 0.38
9	5.50±6.37	2.13 ±0.75	1.38±0.25	1.47± 0.28	1.18±0.24	1.76 ±1.34

Table 3.7.3 Mean station wise variation of light attenuation coefficient (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface	
	Min	Max
1	1.36	15.00
2	1.50	7.50
3	0.79	7.50
4	1.50	15.00
5	1.50	7.50
6	0.79	3.00
7	1.20	3.00
8	0.94	3.00
9	0.86	15.00

Table 3.7.4 ANOVA of light attenuation coefficient in selected stations of Cochin estuary during 2009- 2011 period

Source	df	Mean Square	F
Model	26	10.279	3.444
Season	2	53.212	17.830*
Station	8	13.836	4.636 **
Season * Station	16	3.134	1.050
Error	189	2.984	
Total	216		
R^2= 0.321			

** Variation is significant at 1% level

*Variation is significant at 5% level

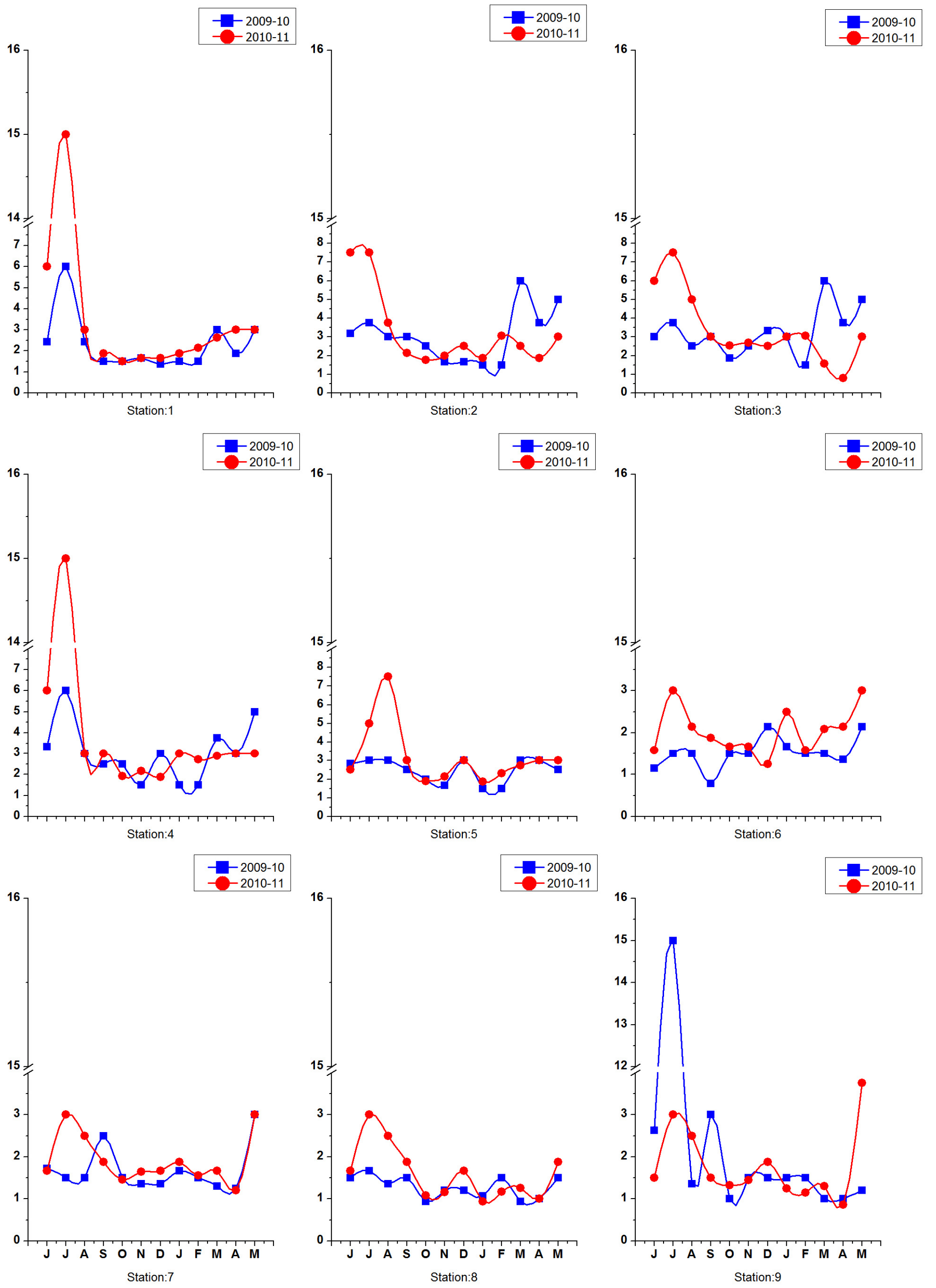


Fig. 3.7. Mean monthly variation of light attenuation coefficient in selected stations of Cochin estuary during 2009-11 period

3.4.2.7 Salinity

Salinity values showed wide variations from 0.01 ppt to 34 ppt in the surface and bottom waters. Bottom waters were more saline than the surface waters. Salinity was very low in the northern side of the estuary compared to the southern side. Salinity showed a definite trend from the southern zone to the northern zone, where it was found to be decreasing. Corresponding to the highest amount of rainfall received during the monsoon period season, salinity was found to be the lowest. Station wise mean value of salinity was maximum at station 1 (16.18 ppt) and minimum at station 8 (0.93 ppt). The mean station wise variation of salinity is presented in Table 3.8.3.The mean salinity was higher in the central zone of the estuary (11.62 ppt) and lower in the northern zone of the estuary (2.03 ppt). In the present study, salinity of the Cochin estuary as a whole was oligo-mesohaline in nature. Salinity of the central and southern zones of the estuary was mesohaline (5-18 ppt) in nature while the northern zone was oligohaline in nature (0.5-5 ppt). Fresh water condition (<0.5 ppt) prevailed during the monsoon period months in most of the stations except stations 1 and 2.

The inter-annual comparison of monsoon period showed the minimum (0.03 ppt) at station 7 and maximum (22.95 ppt) at station 1. During the post-monsoon period, the highest salinity was recorded in January 2010 (34.25 ppt) and the lowest in November 2009 (0.05 ppt). In the pre-monsoon period salinity ranged from 0.06 ppt in May 2011 to 26.30 in March 2010.

Annual mean values of salinity were comparatively lower (6.81 ±3.86 ppt) during the 2010-11 period compared to the 2009-10 period (7.88 ± 4.70 ppt). This may be attributed to the heavy rainfall in the 2010-11 period (4109.10mm) compared to the previous year (3314.20 mm). The salinity values ranged from 1.82 ppt to 19.23 in the year 2009-10. During 2010-11, the value was higher in January 2011 (13.09 ppt) and lower in June 2010 (0.30 ppt). The mean monthly variation recorded the highest salinity in January 2010 at station 4 (34.25 ppt) and the lowest in July 2010 at station 7 (0.03 ppt).

ANOVA of salinity was significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.001$), between seasons and stations ($p \leq 0.01$) whereas it was significant at 5% level between surface and bottom waters ($p \leq 0.05$) (Table 3.8.4).

Table 3.8.1 Mean monthly variation of salinity in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	19.96	7.24	6.27	9.32	6.12	2.65	2.28	2.88	2.81	6.61
J	22.95	7.94	3.53	11.86	6.18	3.53	2.65	1.76	1.15	6.84
A	20.83	10.88	4.69	6.65	6.53	2.12	1.81	1.24	1.24	6.22
S	16.11	2.91	10.59	9.44	5.65	2.30	2.39	5.65	6.04	6.79
O	3.77	3.96	4.25	1.52	2.26	1.81	0.45	0.18	0.18	2.04
N	24.15	20.20	10.91	16.90	4.86	2.82	0.75	0.14	0.05	8.98
D'09	17.40	16.35	15.40	16.55	11.16	4.49	2.63	0.35	0.13	9.38
J'10	31.00	3.87	31.95	34.25	30.40	18.70	12.15	3.50	7.28	19.23
F	21.00	13.40	9.67	13.40	15.80	6.03	2.52	1.08	1.62	9.39
M	25.25	24.00	15.70	26.30	11.20	5.15	4.02	0.55	0.30	12.50
A	12.35	8.30	5.90	12.05	1.80	0.90	1.15	0.14	0.08	4.74
M	5.65	3.52	2.36	2.75	1.08	0.24	0.20	0.09	0.46	1.82
J	1.15	0.59	0.21	0.30	0.13	0.07	0.06	0.07	0.08	0.30
J	1.25	0.80	3.45	0.17	0.09	0.13	0.03	0.05	0.07	0.67
A	2.68	0.98	0.37	1.52	0.51	0.11	0.05	0.04	0.04	0.70
S	14.85	17.70	13.56	10.28	4.83	0.39	0.09	0.05	0.04	6.87
O	19.08	11.09	15.63	17.30	12.17	6.95	3.99	1.04	1.91	9.91
N	21.53	16.60	12.43	15.87	11.64	7.75	4.39	0.91	1.61	10.30
D'10	21.90	17.10	8.25	13.15	7.80	2.46	0.38	0.10	0.12	7.92
J'11	23.60	21.60	13.40	17.15	14.95	13.85	8.81	1.60	2.81	13.09
F	16.06	12.31	8.41	13.62	7.47	3.08	1.97	0.46	0.61	7.11
M	15.49	8.64	6.59	9.89	4.14	1.40	1.22	0.23	0.25	5.32
A	17.90	8.37	8.85	12.92	3.81	0.95	1.56	0.16	0.08	6.07
M'11	12.50	5.23	2.51	3.13	1.14	0.18	0.15	0.06	0.07	2.77

Table 3.8.2 Mean seasonal variation of salinity in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	19.96±2.86	4.98±6.62	19.08±11.62	21.53±1.86	16.06±8.77	15.49±2.24
2	7.24±3.29	5.02±8.46	11.10±8.44	16.60±4.31	12.31±8.78	8.64±2.90
3	6.27±3.09	12.16±16.15	15.63±11.81	12.43±3.09	8.41±5.70	6.59±2.89
4	9.32±2.13	3.07±4.85	17.31±13.38	15.87±1.92	13.63±9.69	9.89±4.79
5	6.12±0.36	1.39±2.30	12.17±12.71	11.64±2.94	7.47±7.22	4.14±2.59
6	2.65±0.63	0.18±0.15	6.96±7.91	7.75±4.68	3.08±2.93	1.40±1.23
7	2.28±0.35	0.06±0.03	4.00±5.52	4.39±3.45	1.97±1.66	1.23±0.78
8	2.88±1.97	0.05±0.01	1.04±1.64	0.91±0.62	0.47±0.46	0.23±0.17
9	2.81±2.28	0.06±0.02	1.91±3.58	1.61±1.12	0.62±0.69	0.25±0.25

Table 3.8.3 Mean station wise variation of salinity (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.74	28.00	1.17	34.00
2	0.62	23.80	0.56	29.20
3	0.20	32.10	0.21	37.00
4	0.12	33.80	0.05	34.70
5	0.09	28.40	0.09	32.40
6	0.06	16.90	0.07	20.50
7	0.04	11.20	0.01	13.10
8	0.02	3.00	0.03	8.29
9	0.02	4.05	0.03	11.30

Table 3.8.4 ANOVA of salinity in selected stations of Cochin estuary during 2009--11 period

Source	df	Mean Square	F
Model	37	389.307	11.760
Season	2	1085.938	32.803**
Station	8	1371.448	41.428**
Surface water, Bottom water	1	132.037	3.988*
Season * Station	16	65.788	1.987**
Station * Surface water, Bottom water	8	6.831	0.206
Season * Surface water, Bottom water	2	10.804	0.326
Error	394	33.105	
Total	432		
R^2= 0.525**			

** Variation is significant at 1% level

*Variation is significant at 5% level

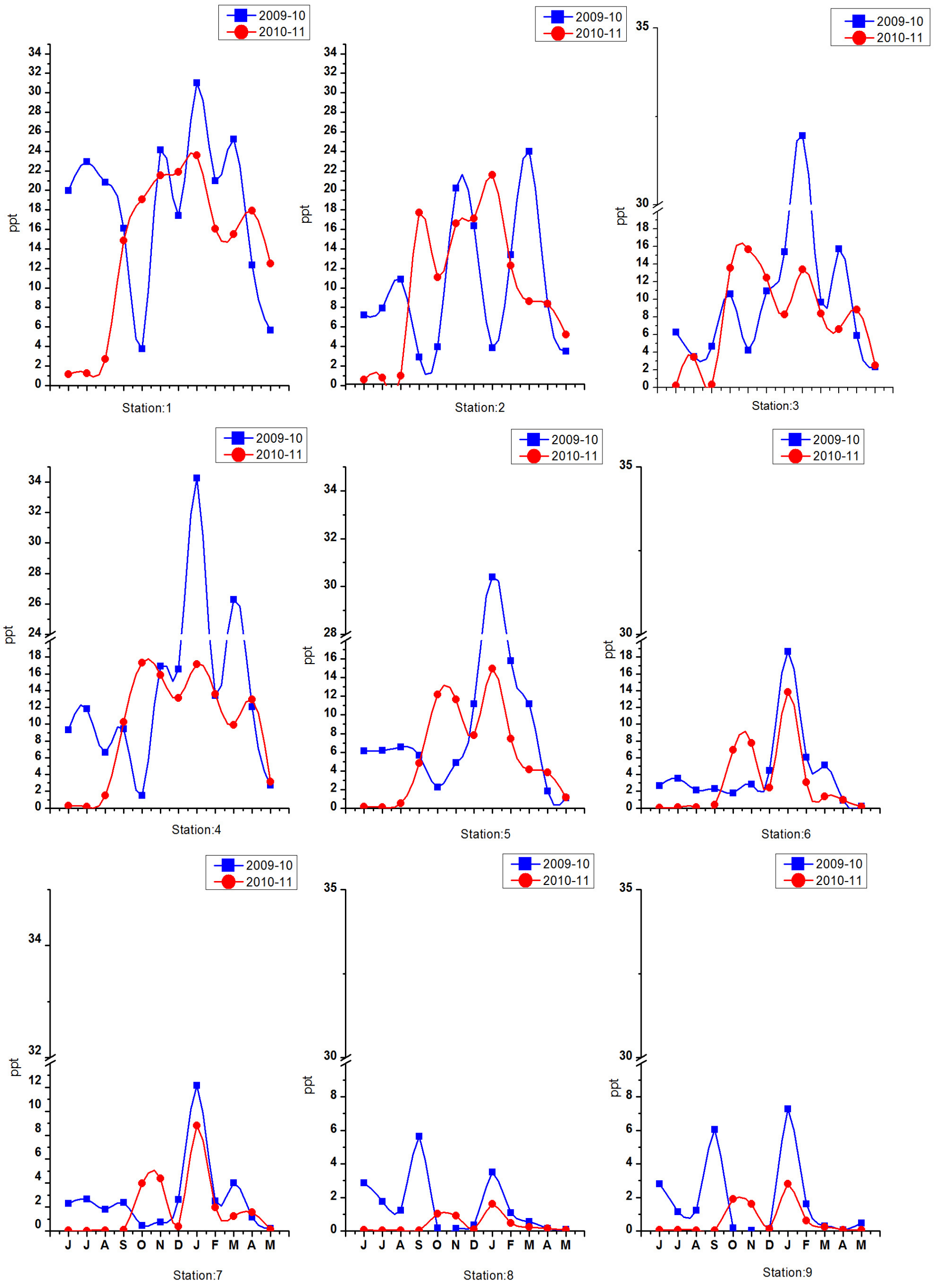


Fig.3.8. Mean monthly variation of salinity in selected stations of Cochin estuary during 2009-11 period

3.4.2.8 Total Dissolved Solids (TDS)

The TDS value of surface waters was observed to be maximum at station 5 (323.00 ppm) and minimum at station 9 (0.01 ppm). For bottom waters, TDS was maximum at station 5 (318.00 ppm) and minimum at station 8 and station 9 (0.02 ppm). The mean monthly variation of TDS in Cochin estuary during the study period is give in Table 3.9.1 and Fig.3.9. The lowest value of TDS recorded was 0.03 ppm at station 9 in August and September 2010. The highest value of TDS, 320.50 ppm was recorded at station 5 during August 2009. Station wise mean values recorded the highest at station 5 (25.24 ± 6.24 ppm) and lowest at station 1 (8.86 ± 6.24 ppm). The mean station wise variation of total dissolved solids is presented in Table 3.9.3. The highest TDS of 23.10 ± 3.77 ppm was recorded from southern zone and the lowest TDS of 15.88 ± 3.77 ppm was recorded from the central zone. In central zone, the TDS ranged from 8.86 ppm at station 1 to 24.99 ppm at station 5. The TDS values were higher at station 2 (23.28 ppm) in comparison with station 3 (22.93 ppm) in the southern zone. In the northern zone, the TDS was minimum at station 8 (14.55 ppm) and maximum at station 6 (25.24 ppm).

The mean annual TDS was found to be very high (30.18 ppm) during 2009-10 period compared to 2010-11 period (6.30). In 2009-10, the highest value was recorded in July 2009 (103.35 ppm) and lowest in May 2010 (1.43 ppm). In 2010-11 period, the minimum was recorded in June 2010 (0.18 ppm) and maximum in October 2010 (18.32 ppm). The mean monthly values of total dissolved solids (TDS) ranged from 0.30 ppm to 320.50 ppm.

The comparison of monsoon period in both the years of TDS showed the lowest in August 2010 (0.01 ppm) and highest in August 2009 (320.50 ppm). During post-monsoon period, the lowest TDS was observed in December 2010 (0.06 ppm) and the highest was in October 2009 (169.00 ppm). In the pre-monsoon period the TDS ranged from 0.04 ppm in April 2011 to16.40 ppm in March 2010.

ANOVA of TDS was significant at 1% level between seasons ($p \leq 0.001$) (Table 3.9.4).

Table 3.9.1 Mean monthly variation of total dissolved solids in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	8.19	99.70	71.92	45.42	131.05	83.12	51.73	39.48	74.08	67.19
J	1.95	283.83	211.50	128.05	70.87	94.25	73.60	51.45	14.65	103.35
A	8.08	4.50	1.96	2.55	320.50	63.55	42.70	30.30	29.35	55.94
S	14.55	10.78	2.32	5.65	1.78	91.55	38.90	36.70	178.25	42.27
O	1.74	1.80	1.91	1.12	1.05	169	64.20	11.69	6.94	28.83
N	21.55	17.71	9.45	15.15	4.38	2.58	28.71	125.95	42.10	29.73
D'09	9.94	9.05	8.49	9.30	6.25	2.53	1.48	0.63	0.07	5.30
J'10	17.10	13.23	11.65	16.10	11.95	7.01	4.53	1.39	1.76	9.41
F	10.75	15.30	9.91	9.41	6.84	5.77	6.33	1.03	1.60	7.44
M	13.75	14.40	11.10	16.40	4.74	2.36	1.92	0.35	0.24	7.25
A	10.90	7.23	4.14	10.55	1.59	0.79	1	0.12	0.07	4.04
M	4.49	2.76	1.85	2.15	0.84	0.18	0.16	0.07	0.35	1.43
J	0.67	0.36	0.12	0.20	0.09	0.05	0.04	0.05	0.08	0.18
J	0.92	1.22	153.95	0.24	0.06	0.09	0.06	0.04	0.06	17.40
A	1.73	0.55	0.25	1.04	0.35	0.08	0.03	0.01	0.03	0.45
S	7.64	9.49	5.79	2.80	1.88	0.41	0.07	0.04	0.03	3.13
O	12.58	10.44	7.87	10.42	5.90	45.28	24.73	34.91	12.72	18.32
N	11.56	9.34	6.31	8.31	6.15	18.44	10.27	12.02	4.90	9.70
D'10	6.30	2.84	1.97	2.91	2.42	0.72	0.08	0.06	0.07	1.93
J'11	15.80	14.75	9.09	11.60	10.12	9.33	6.01	1.10	1.92	8.86
F	9.97	9.92	6.75	9.63	3.50	2.27	2.35	0.39	0.56	5.04
M	8.11	7.35	4.67	7.88	2.73	2.18	1.25	0.47	0.44	3.90
A	9.90	7.68	4.89	11.05	2.68	1.08	0.90	0.17	0.04	4.26
M'11	4.47	4.46	2.39	2.97	2.01	3.21	0.50	0.87	0.73	2.40

Table 3.9.2 Mean seasonal variation of total dissolved solids in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	8.19±5.15	2.74±3.30	12.58±8.67	11.56±3.95	9.97±3.91	8.11±2.58
2	99.70±130.22	2.90±4.41	10.44±6.76	9.34±4.92	9.92±5.99	7.35±2.24
3	71.92±98.70	40.03±75.99	7.87±4.19	6.31±3.11	6.75±4.46	4.67±1.79
4	45.42±58.45	1.07±1.22	10.42±6.89	8.31±3.85	9.63±5.85	7.88±3.52
5	131.05±136.90	0.59±0.87	5.90±4.57	6.15±3.15	3.50±2.79	2.73±0.61
6	83.12±13.88	0.16±0.17	45.28±82.51	18.44±19.30	2.27±2.50	2.18±0.87
7	51.73±15.54	0.05±0.02	24.73±29	10.27±10.51	2.35±2.75	1.25±0.80
8	39.48±8.86	0.04±0.02	34.91±60.90	12.02±16.19	0.39±0.44	0.47±0.29
9	74.08±73.90	0.05±0.02	12.72±19.80	4.90±5.58	0.56±0.70	0.44±0.29

Table 3.9.3 Mean station wise variation of total dissolved solids (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.56	17.80	0.60	25.70
2	0.39	567.00	0.32	99.70
3	0.11	210.00	0.13	307.00
4	0.15	242.00	0.24	45.42
5	0.06	323.00	0.06	318.00
6	0.05	171.00	0.04	167.00
7	0.03	73.60	0.03	90.20
8	0.00	57.90	0.02	194.00
9	0.01	261.00	0.02	95.50

Table 3.9.4 ANOVA of total dissolved solids in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	4048.871	1.791
Season	2	38269.349	16.932**
Station	8	1686.795	0.746
Surface water, Bottom water	1	305.105	0.135
Season * Station	16	2877.939	1.273
Station * Surface water, Bottom water	8	1333.526	0.590
Season * Surface water, Bottom water	2	1377.413	0.609
Error	394	2260.147	
Total	432		
R^2= 0.144			

** Variation is significant at 1% level

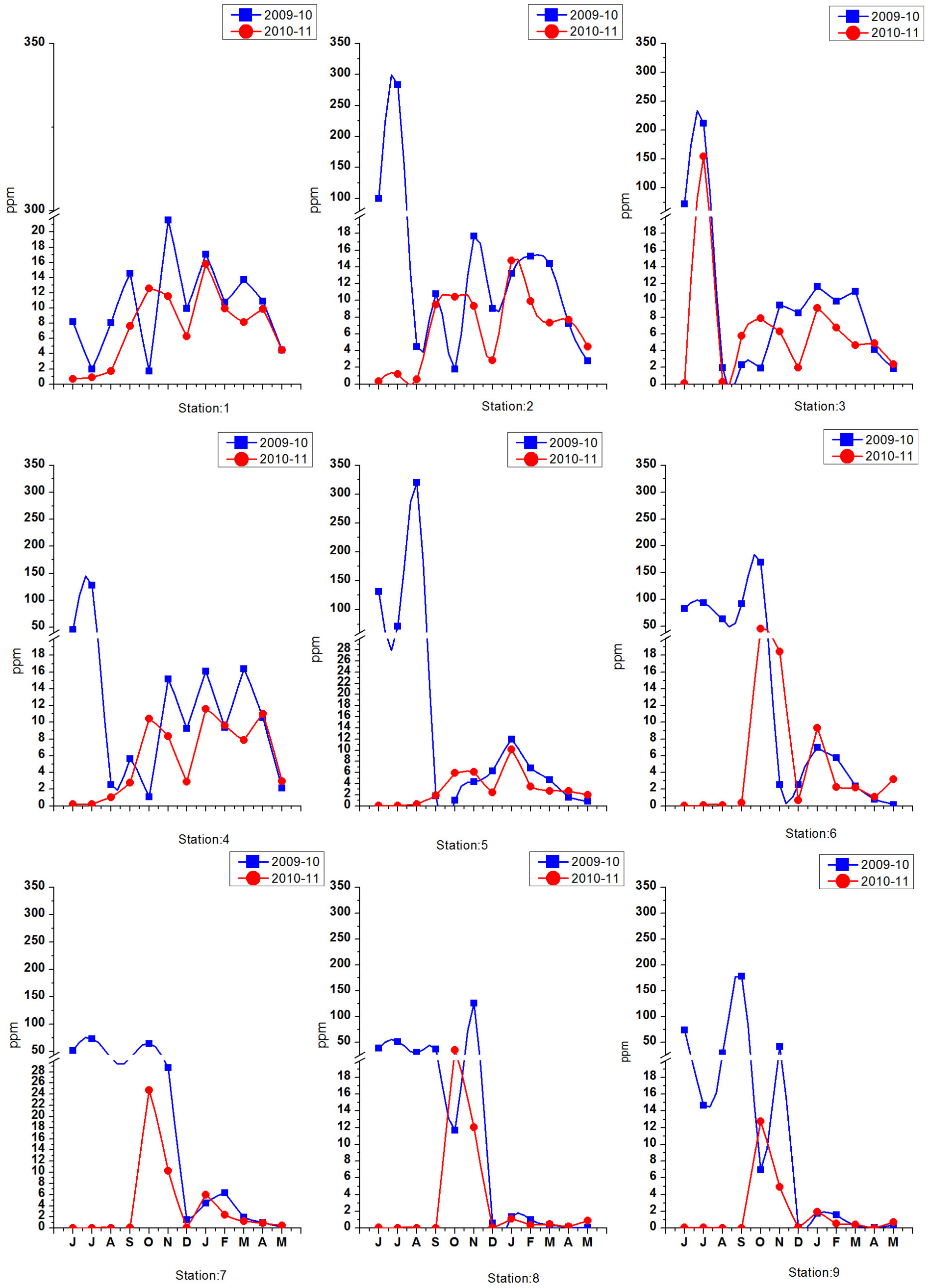


Fig. 3.9. **Mean monthly variation of total dissolved solids in selected stations of Cochin estuary during 2009-11 period**

3.4.2.9 Conductivity

The conductivity values ranged from 0.03 to 475.00 mS in surface waters and from 0.04 to 390.00 mS in the bottom waters during the study period. Station wise mean value of conductivity was the highest at station 5 (50.62 ± 12.46 mS) and lowest at station 2 (14.25 ± 12.46 mS). The mean station wise variation of conductivity is shown in Table 3.10.3.The highest conductivity (34.10 ± 6.11 mS) was recorded from the northern zone and lowest conductivity (22.37 ± 6.11 mS) was recorded from the southern zone. In the central zone, the conductivity ranged from 17.06 mS at station 1 to 50.62 mS at station 5. The conductivity values were higher at station 3 (30.49 mS) compared to station 2 (14.25 mS) in the southern zone. In the northern zone the salinity ranged from 27.19 mS at station 8 to 49.45 mS at station 6.

The lowest mean monthly value of conductivity recorded was 0.05 mS at station 8 in July and August 2010 and at station 9 in August and September 2010. The highest mean monthly value recorded was 391 mS at station 3 during July 2009. In 2009-10 period, the mean annual conductivity was (52.08 mS) and it was 8.97 mS observed during the 2010-11 period.

The season wise variation of conductivity in the estuary was analysed and is given in Table 3.10.2. During the monsoon period, the highest conductivity of 677 mS was observed in August 2009 and the lowest was recorded from 0.05 mS in July, August and September 2010. In the post-monsoon period the conductivity ranged from 0.11 mS in December 2010 to 352.50 mS in October 2009. The maximum conductivity was observed in March 2010 (31.35 mS) and the minimum in April 2010 (0.12 mS) during the pre-monsoon period season.

ANOVA of conductivity was significant at 1% level between seasons ($p \leq 0.001$) (Table 3.10.4).

Table 3.10.1 Mean monthly variation of conductivity in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	18.48	12.14	133.61	86.20	269.67	158.50	105.73	74.48	137.99	110.76
J	3.63	1.13	391.00	239.55	128.68	173.00	157.00	93.90	27.58	135.05
A	17.65	9.90	4.30	5.56	677.00	128.00	87.20	60.45	58.90	116.55
S	34.15	25.40	5.54	13.50	3.34	174.50	73.00	69.10	327.50	80.67
O	3.64	3.87	3.99	2.38	2.24	352.50	134.95	23.73	15.01	60.26
N	40.40	33.85	18.30	29.10	8.28	4.88	55.76	233.00	81.10	56.07
D'09	19.05	17.25	16.30	17.90	12.00	4.82	2.85	0.37	0.13	10.07
J'10	30.45	23.70	20.60	28.70	21.20	14.15	8.53	2.47	3.14	16.99
F	20.45	29.25	18.65	17.60	13.03	10.98	12.38	2.00	3.10	14.16
M	25.95	28.00	22.00	31.35	9.11	4.50	3.77	0.69	0.46	13.98
A	20.75	13.45	7.58	20.35	2.94	1.10	1.94	0.23	0.12	7.61
M	8.56	5.34	3.59	4.32	1.71	0.38	0.33	0.15	1.17	2.84
J	1.21	0.69	0.31	0.36	0.15	0.09	0.08	0.09	0.14	0.35
J	1.69	1.49	0.50	0.22	0.12	0.19	0.10	0.05	0.09	0.49
A	2.82	0.95	0.44	1.86	0.59	0.13	0.06	0.05	0.05	0.77
S	14.05	16.90	10.51	5.09	3.44	0.74	0.12	0.07	0.05	5.66
O	23.39	19.67	14.80	19.52	10.93	94.09	50.52	64.89	24.85	35.85
N	21.21	17.30	11.70	15.55	11.33	37.54	20.53	22.34	9.51	18.56
D'10	11.44	5.24	3.60	5.32	4.46	1.29	0.14	0.11	0.12	3.52
J'11	28.80	27.00	16.70	21.80	18.60	17.25	10.94	2.02	3.58	16.30
F	18.93	19.01	12.96	18.40	6.70	4.24	4.60	0.76	1.21	9.65
M	15.40	12.37	6.93	14.06	4.01	2.06	2.43	0.59	0.87	6.52
A	17.45	11.77	3.20	19.46	3.95	1.48	2.27	0.31	0.13	6.67
M'11	9.83	6.34	4.65	4.33	1.39	0.46	0.43	0.70	1.26	3.27

Table 3.10.2 Mean seasonal variation of conductivity in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	18.48±12.47	4.94±6.11	23.39±15.79	21.21±7.25	18.93±7.36	15.40±3.99
2	12.14±10.03	5.01±7.94	19.67±12.55	17.30±9.04	19.01±11.60	12.37±5.19
3	133.61±182.00	2.94±5.05	14.80±7.42	11.70±5.78	12.96±8.77	6.94±4.30
4	86.20±108.48	1.88±2.26	19.52±12.55	15.55±7.29	18.41±11.11	14.06±6.90
5	269.67±292.53	1.08±1.59	10.93±7.94	11.33±5.78	6.70±5.32	4.01±2.17
6	158.50±21.58	0.29±0.30	94.09±172.33	37.54±40.51	4.24±4.84	2.06±1.60
7	105.73±36.71	0.09±0.03	50.52±61.08	20.53±21.66	4.61±5.37	2.43±1.71
8	74.48±14.18	0.07±0.02	64.89±112.57	22.34±30.10	0.77±0.86	0.59±0.20
9	137.99±134.61	0.08±0.04	24.85±38.05	9.52±10.93	1.21±1.33	0.87±0.52

Table 3.10.3 Mean station wise variation of conductivity (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.99	32.70	1.07	48.10
2	0.74	30.80	0.63	48.70
3	0.21	392.00	0.41	390.00
4	0.29	453.00	0.07	86.20
5	0.12	683.00	0.12	671.00
6	0.09	353.00	0.08	352.00
7	0.05	135.00	0.06	188.00
8	0.05	104.00	0.04	362.00
9	0.03	475.00	0.04	180.00

Table 3.10.4 ANOVA of conductivity in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	11366.496	2.147
Season	2	84834.787	16.024**
Station	8	7455.372	1.408
Surface water, Bottom water	1	17.200	0.003
Season * Station	16	11097.739	2.096
Station * Surface water, Bottom water	8	1216.777	0.230
Season * Surface water, Bottom water	2	1966.271	0.371
Error	394	5294.153	
Total	432		
R^2= 0.168			

** Variation is significant at 1% level

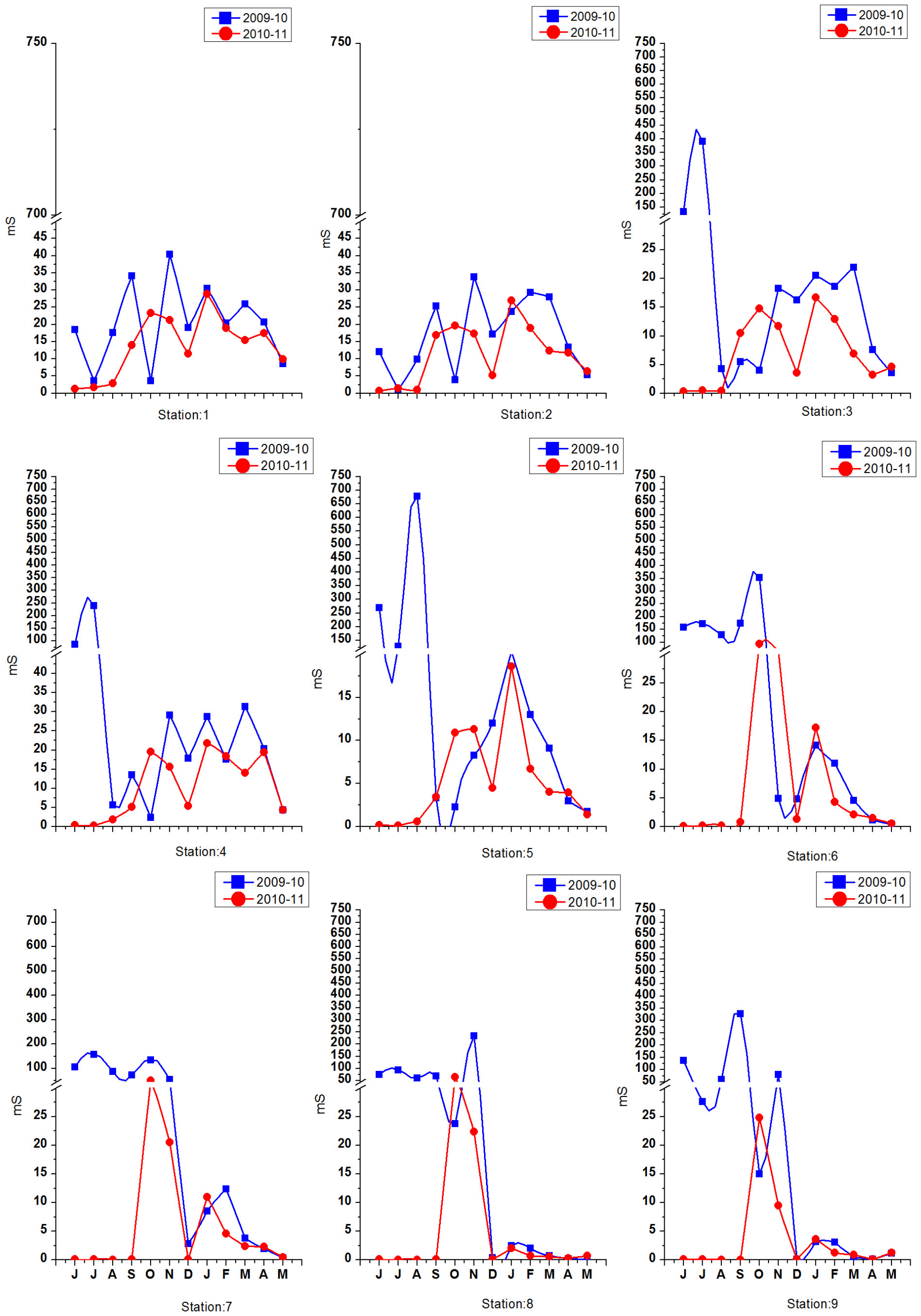


Fig. 3.10. Mean monthly variation of conductivity in selected stations of Cochin estuary during 2009-11 period

3.4.2.10 Turbidity

High turbidity values were observed in the estuary with an average of 8.65 ± 5.42 NTU, with the peak concentration occurring during southwest monsoon period (14.66 ± 5.23 NTU). In the monsoon period, turbidity ranged between 2.95 NTU in September 2010 to 56.50 NTU in June 2010. The maximum turbidity was observed in December 2009 (17.50 NTU) and the minimum was in November 2009 (0.55 NTU) during the post-monsoon period whereas in the pre-monsoon period the range was between 0.37 in March 2010 to 23 in May 2011.

Highest mean turbidity value was observed at station 3 (13.51 NTU) and the lowest was observed at station 8 (4.25 NTU). The mean station wise variation of turbidity is presented in Table 3.11.3. Bottom waters were found to be more turbid than the surface waters. The southern zone (12.89 NTU) was more turbid compared to the other zones. The highest turbidity was observed at station 4 (11.14 NTU) and lowest was at station 5 (8.50 NTU) in the central zone. The turbidity values were higher at station 3 (13.51 NTU) compared with station 2 (12.26 NTU) in the southern zone. In the northern zone, turbidity ranged from 4.25 NTU at station 8 to 6.91 NTU at station 6.

Mean annual variation of turbidity showed the peak (9.39 NTU) during 2010-11 period. The mean monthly values of turbidity showed the maximum in June 2010 (56.50 NTU) at station 2 and the minimum in March 2010 (0.37 NTU) at station 8.

ANOVA of turbidity was significant at 1% level significance between seasons ($p \leq 0.001$), between stations ($p \leq 0.001$), between surface and bottom waters ($p \leq 0.01$) (Table 3.11.4).

Table 3.11.1 Mean monthly variation of turbidity in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	16.85	15.47	19.93	17.15	14.98	12.12	10.13	8.52	13.88	14.34
J	31.05	19.50	26.60	21.00	18.35	12.10	10.55	9.70	6.45	17.26
A	13.45	19.10	20.20	20.60	14.65	10.25	9.30	7.65	10.20	13.93
S	6.05	7.80	13.00	9.85	11.95	14.00	10.55	8.20	25.00	11.82
O	2.40	3.65	12.10	4.30	4.50	2.05	2.50	1.65	4.00	4.13
N	0.86	0.89	11.37	4.68	1.23	0.81	0.55	0.83	1.05	2.47
D'09	7.05	8.60	17.50	11.45	8.05	2.50	1.95	2.20	3.80	7.01
J'10	6.90	7.00	5.96	5.60	5.60	2.80	5.25	2.02	4.00	5.01
F	2.30	2.30	3.00	6.65	2.80	2.35	2.15	1.15	1.60	2.70
M	2.70	18.00	19.50	5.60	3.10	1.08	0.63	0.37	0.41	5.71
A	2.20	7.05	8.55	5.70	6.35	4.15	1.69	1.55	1.65	4.32
M	15.50	14.80	7.75	5.85	3.00	2.25	1.90	1.26	2.65	6.11
J	37.50	56.50	21.00	39.00	10.55	7.20	6.10	6.50	6.70	21.23
J	24.00	14.50	32.00	23.50	12.50	41.50	11.50	10.00	23.00	21.39
A	9.40	9.90	9.95	7.85	12.50	7.90	12.50	14.00	10.35	10.48
S	2.95	8.80	7.05	7.45	12.45	7.30	4.10	5.00	6.20	6.81
O	4.30	5.03	11.73	6.51	4.84	2.04	2.56	1.67	3.21	4.65
N	3.90	6.64	10.54	6.12	8.43	3.43	3.89	3.49	4.20	5.63
D'10	2.90	6.65	4.90	4.10	15.50	3.70	5.60	4.45	5.20	5.89
J'11	4.50	8.25	15.00	7.75	4.95	4.55	3.50	4.35	4.20	6.34
F	5.68	10.54	9.70	5.95	3.81	2.46	1.59	1.08	1.58	4.71
M	10.04	13.48	11.65	11.63	6.95	5.44	3.76	1.88	3.36	7.58
A	15.50	6.90	4.25	21.00	7.35	3.70	2.25	1.95	3.20	7.34
M'11	8.95	23.00	21.00	7.95	9.70	10.15	7.45	2.60	5.31	10.68

Table 3.11.2 Mean seasonal variation of turbidity in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	16.85±10.49	18.46±15.45	4.30±3.15	3.90±0.71	5.68±6.55	10.04±4.08
2	15.47±5.42	22.43±22.85	5.04±3.45	6.64±1.31	10.54±7.16	13.48±6.89
3	19.93±5.56	17.50±11.38	11.73±4.72	10.54±4.21	9.70±6.98	11.65±6.98
4	17.15±5.16	19.45±15.02	6.51±3.34	6.12±1.52	5.95±0.48	11.63±6.67
5	14.98±2.62	12.00 ±0.97	4.85±2.83	8.43±5.00	3.81±1.70	6.95±2.42
6	12.12±1.53	15.98±17.02	2.04±0.88	3.43±1.04	2.46±1.27	5.44±3.37
7	10.13±0.59	8.55±4.09	2.56±1.97	3.89±1.27	1.59±0.67	3.76±2.62
8	8.52±0.87	8.88±4.01	1.68±0.61	3.49±1.29	1.08±0.50	1.88±0.62
9	13.88±8.01	11.56±7.85	3.21±1.44	4.20±0.81	1.58±0.92	3.36±1.53

Table 3.11.3 Mean station wise variation of turbidity (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.32	33.00	1.40	42.00
2	0.57	52.00	1.20	61.00
3	0.73	30.00	3.40	34.00
4	0.36	34.00	3.60	44.00
5	0.75	18.50	1.70	18.20
6	0.74	35.00	0.87	48.00
7	0.49	12.00	0.50	14.00
8	0.33	17.00	0.40	11.00
9	0.34	36.00	0.47	31.00

Table 3.11.4 ANOVA of turbidity in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	359.083	8.723
Season	2	3937.056	95.639**
Station	8	509.979	12.388**
Surface water, Bottom water	1	355.250	8.630**
Season * Station	16	48.172	1.170
Station *Surface water, Bottom water	8	25.530	0.620
Season * Surface water, Bottom water	2	0.934	0.023
Error	394	41.166	
Total	432		
R^2= 0.450			

** Variation is significant at 1% level

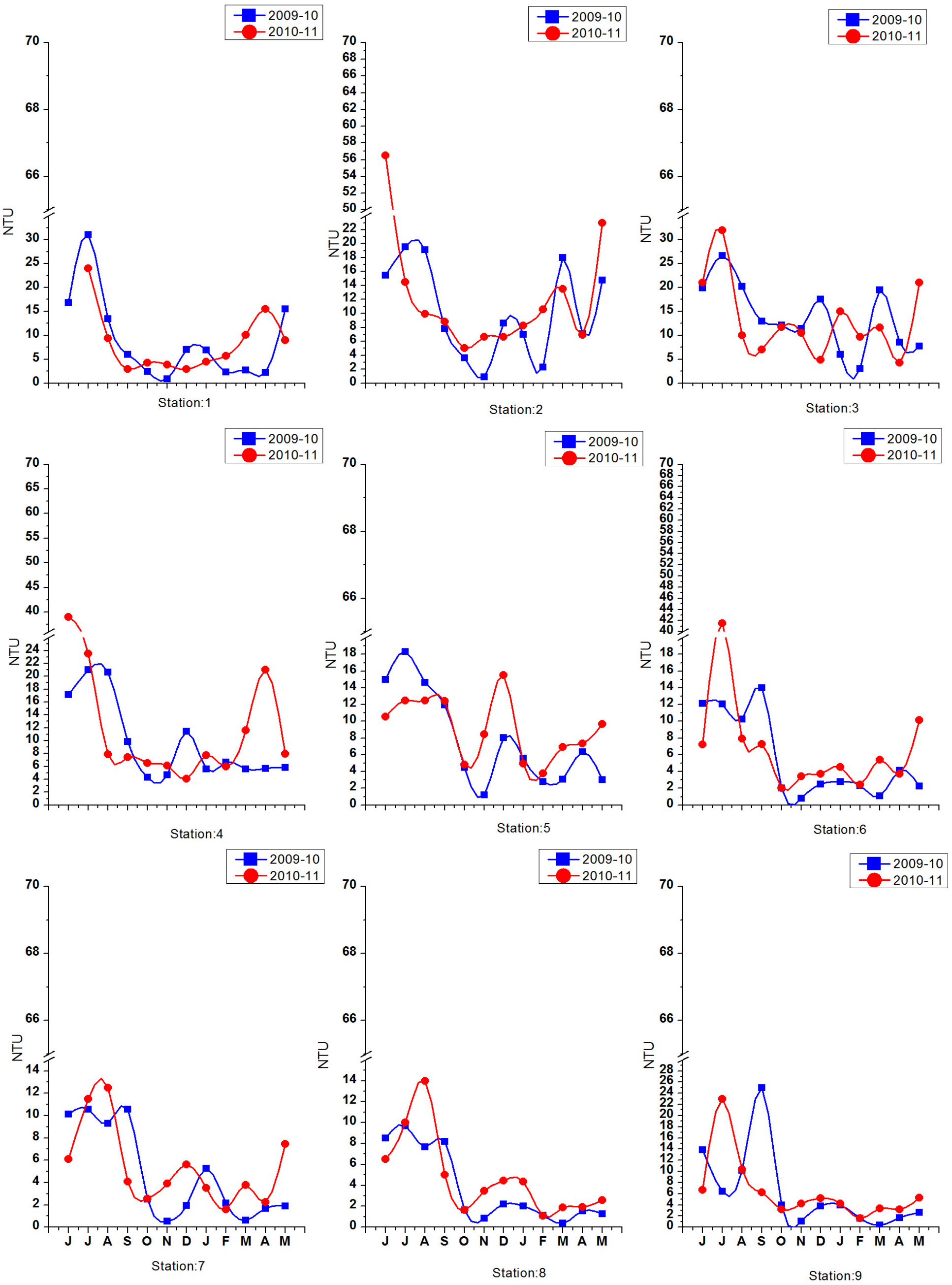


Fig. 3.11. Mean monthly variation of turbidity in selected stations of Cochin estuary during 2009-11 period

3.4.3 Chemical parameters

3.4.3.1 Dissolved Oxygen

The average dissolved oxygen in the Cochin estuary was 6.20 ± 0.89 mg L^{-1} during the period of the study. The dissolved oxygen values were higher in the surface waters of the estuary. Mean station wise value was maximum at station 9 (6.88±0.36 mg L^{-1}) and minimum at station 3 (5.81±0.36 mg L^{-1}). The station wise variation of dissolved oxygen is shown in Table 3.12.3. The dissolved oxygen concentration was higher in the northern zone (6.42 ± 0.29 mg L^{-1}) of the estuary and lower in the southern zone (5.87 ± 0.29 mg L^{-1}) of the estuary. In the central zone, the maximum dissolved oxygen was reported at station 4 (6.24 mg L^{-1}) and minimum at station 1 (6.09 mg L^{-1}). The dissolved oxygen values ranged from 5.81 mg L^{-1} at station 3 and 5.84 mg L^{-1} at station 2 in the southern zone. In the northern zone, the highest dissolved oxygen was observed at station 9 (6.88 mg L^{-1}) and the lowest was recorded at station 6 (5.88 mg L^{-1}).

The inter annual comparison of dissolved oxygen showed the highest mean monthly dissolved oxygen value of 9.02 mg L^{-1} that was recorded at station 2 in October 2009. The lowest value of 2.25 mg L^{-1} was recorded at station 6 in March 2010. In 2009-10 periods, the values ranged between 3.86 mg L^{-1} in March 2010 to 7.69 mg L^{-1} in October 2009 whereas in 2010-11 periods, the values ranged between 5.03 mg L^{-1} in July 2010 to 7.19 mg L^{-1} in October 2010. The dissolved oxygen values were found to be lower during the pre-monsoon period (5.55 ± 0.59 mg L^{-1}) and higher during the post-monsoon period (6.70 ± 0.59 mg L^{-1}).

The ANOVA result of dissolved oxygen showed that variations between seasons ($p \leq 0.001$) and between stations ($p \leq 0.001$) were significant at 1% level (Table 3.12.4).

Table 3.12.1 Mean monthly variation of dissolved oxygen in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	6.83	6.61	5.99	6.97	5.91	5.54	6.26	6.46	8.24	6.53
J	6.21	5.55	6.53	6.21	2.61	2.61	2.61	2.61	7.32	4.69
A	7.76	7.35	5.71	7.75	7.35	4.25	6.00	5.80	8.01	6.66
S	6.53	6.94	5.72	6.94	7.76	7.76	8.16	8.97	7.39	7.35
O	8.20	9.02	6.94	8.62	8.20	6.53	7.76	8.16	5.80	7.69
N	6.94	6.94	6.12	6.12	6.37	6.13	6.74	7.55	7.56	6.72
D'09	6.90	6.09	5.28	6.09	6.09	6.49	6.89	7.31	6.86	6.44
J'10	6.09	5.69	6.09	6.50	6.49	6.89	7.29	6.90	5.31	6.36
F	6.12	5.31	5.51	5.72	6.74	5.96	5.35	7.35	6.33	6.04
M	5.31	4.08	4.69	5.11	2.66	2.25	3.27	3.68	3.67	3.86
A	4.59	5.10	5.10	4.59	6.12	6.12	5.61	6.63	6.12	5.55
M	5.71	4.90	5.71	5.92	5.10	4.29	4.49	6.12	5.92	5.35
J	5.51	6.12	6.33	5.92	5.71	6.53	7.35	7.35	8.37	6.58
J	4.08	3.68	4.08	5.30	4.47	4.90	5.72	6.53	6.53	5.03
A	6.53	6.53	6.94	6.94	5.30	8.57	7.76	6.98	8.17	7.08
S	6.53	4.90	6.12	6.94	7.35	7.35	7.35	7.35	7.35	6.80
O	7.53	7.43	6.11	7.33	7.79	6.51	7.17	7.48	7.38	7.19
N	6.03	5.84	6.02	6.37	7.43	6.07	7.36	6.93	7.30	6.59
D'10	4.52	4.84	4.68	5.32	6.05	4.84	6.86	7.26	8.47	5.87
J'11	6.05	5.25	7.26	6.45	8.47	6.86	8.06	6.05	6.05	6.72
F	5.43	4.85	5.25	5.33	5.15	5.15	5.18	5.94	5.51	5.31
M	5.58	5.51	5.65	5.68	6.16	6.15	5.90	6.28	7.75	6.07
A	5.65	6.45	6.05	5.65	5.65	6.46	5.65	5.24	6.86	5.96
M'11	5.65	5.25	5.65	6.05	5.67	6.86	6.86	7.66	6.89	6.28

Table 3.12.2 Mean seasonal variation of dissolved oxygen in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	6.83±0.67	5.66±1.16	7.03±0.87	6.03±1.23	5.43±0.65	5.58±0.1
2	6.61±0.77	5.31±1.29	6.93±1.48	5.84±1.14	4.85±0.54	5.51±0.68
3	5.99±0.39	5.87±1.24	6.11±0.68	6.02±1.06	5.25±0.45	5.65±0.33
4	6.97±0.63	6.28±0.81	6.83±1.2	6.37±0.82	5.33±0.6	5.68±0.29
5	5.91±2.34	5.71±1.21	6.79±0.96	7.43±1.02	5.15±1.8	5.66±0.41
6	5.04±2.17	6.84±1.54	6.51±0.31	6.07±0.88	4.65±1.81	6.15±0.73
7	5.76±2.31	7.04±0.91	7.17±0.46	7.36±0.51	4.68±1.05	5.9±0.71
8	5.96±2.62	7.05±0.39	7.48±0.53	6.93±0.63	5.94±1.59	6.28±1.02
9	7.74±0.46	7.6±0.84	6.38±1.02	7.3±0.99	5.51±1.24	6.75±0.93

Table 3.12.3 Mean station wise variation of dissolved oxygen (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	8.24	4.08	8.16	4.08
2	9.06	3.27	8.97	4.08
3	8.16	3.67	7.35	4.08
4	7.43	4.90	9.8	4.08
5	8.87	2.61	8.16	2.4
6	8.98	2.04	8.16	2.45
7	8.87	2.61	8.16	2.61
8	8.97	2.61	8.97	2.61
9	8.97	3.67	8.98	3.67

Table 3.12.4 ANOVA of dissolved oxygen in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	5.024	3.199
Season	2	49.416	31.466**
Station	8	6.277	3.997**
Surface water, Bottom water	1	0.542	0.0345
Season * Station	16	1.903	1.212
Station * Surface water, Bottom water	8	0.634	0.404
Season * Surface water, Bottom water	2	0.386	0.246
Error	394	1.570	
Total	432		
R^2= 0.208			

** Variation is significant at 1% level

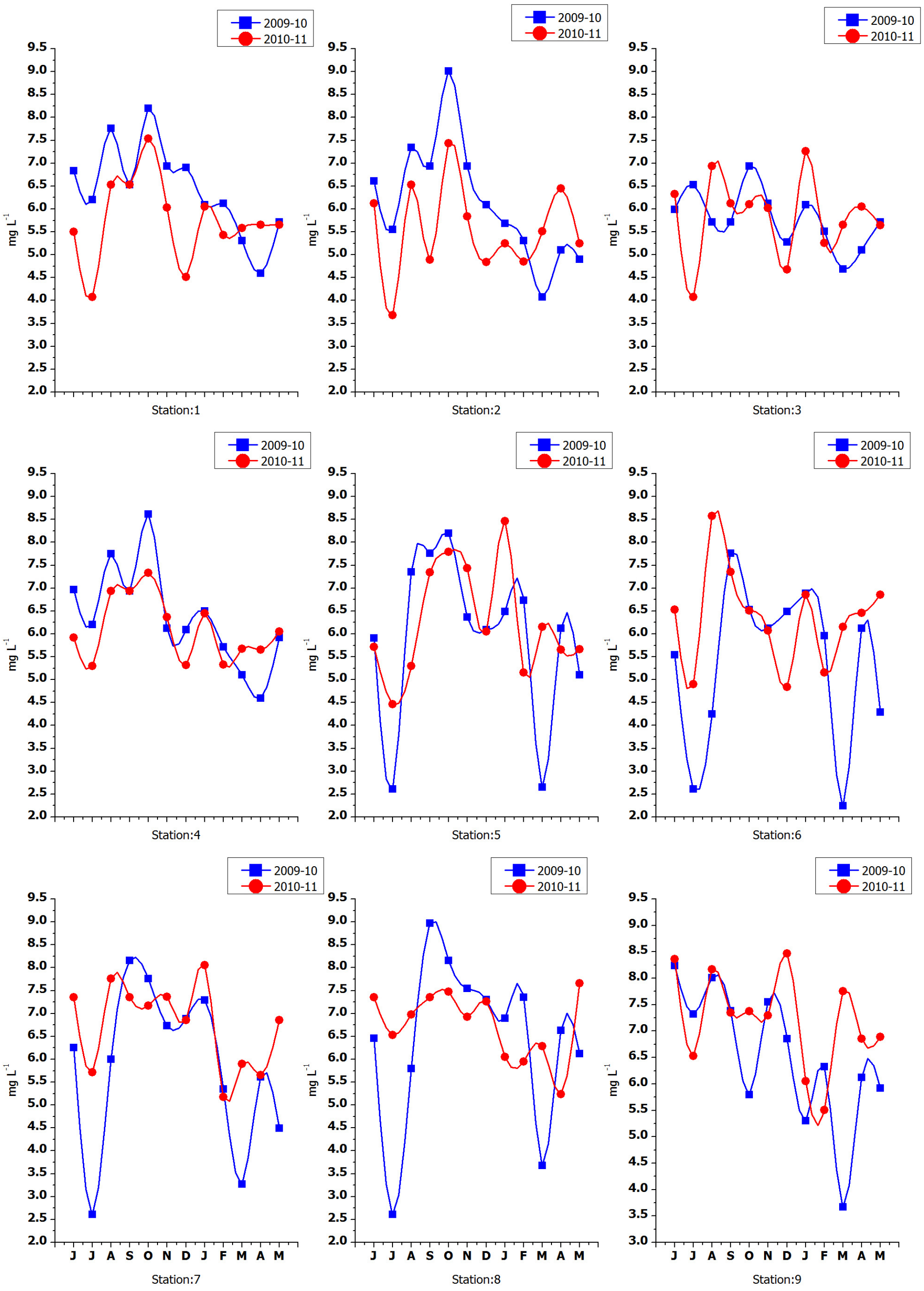


Fig.3.12. Mean monthly variation of dissolved oxygen in selected stations of Cochin estuary during 2009-11 period

3.4.3.2 pH

pH was found to be more or less uniform throughout the study period. The vertical gradient of the pH was less significant in the estuary. The surface water pH ranged from 8.90 at station 6 to 4.21 at station 9. The bottom water pH ranged from 8.45 at station 2 to 3.35 at station 9. The average pH of the Cochin estuary was generally on an alkaline side (7.25 ± 0.40).

During post-monsoon period the pH values were highest (7.47 ± 0.21) followed by pre-monsoon period (7.21 ± 0.21) and monsoon period (7.07 ± 0.21). During the monsoon period, the minimum pH (4.51) was recorded in July 2010 at station 7 and the maximum (8.5) in July 2009 at station 1. The range of pH during post-monsoon period was from 6.24 in October 2009 at station 9 to 8.44 in January 2011 at station 1. In the pre-monsoon period, the values were higher (8.02) in April 2011 at station 1 and lower (5.59) in May 2010 at station 5.

A gradual decrease in pH from the marine waters of station 1 (7.66 ± 0.36) to the fresh water at station 9 (6.60 ± 0.36) was evident during all the seasons of the year. However, the peak monsoon period was marked by heavy rains and land runoff, the pH values tended to fall in all the stations of the estuary. As a result pH value shifted for a brief acidic phase during the monsoon period of 2010-11. Northern zones (6.92 ± 0.34)of the estuary were slightly acidic in nature while the southern zone (7.49 ± 0.34) and the central zone (7.52 ± 0.34) were on the alkaline side. In the central zone, the maximum pH was recorded at station 1 (7.66) and the minimum at station 5 (7.31). In the southern zone, the values were higher at station 2 (7.63) compared to station 3 (7.36). In the northern zone, the pH values ranged from 6.60 at station 9 to 7.20 at station 6.

The mean monthly variation of pH in Cochin estuary during the study period is given in Table 3.13.1 and Fig.3.13. Mean month wise variations in pH ranged from 4.51 in July 2010 to 8.50 in July 2009. The annual variations in pH showed a slightly higher pH in 2009-10 period (7.29 ± 0.33) compared to 2010-11 period (7.20 ± 0.48). During 2009-10 period, the highest value of 7.80 was observed in July 2009 and the lowest (6.52) in May 2010. During 2010-11 period the values ranged from 6.24 in July 2010 to 7.95 in January 2011.

ANOVA of pH was significant at 1% level between seasons ($p \leq 0.001$) and between stations ($p \leq 0.001$) (Table 3.13.4).

Table 3.13.1 Mean monthly variation of pH in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	7.95	7.68	7.32	7.30	7.59	7.55	7.11	7.49	6.81	7.42
J	8.50	7.90	7.80	7.80	8.10	7.70	7.70	8.20	6.54	7.80
A	7.41	7.39	7.11	6.91	6.97	6.86	6.77	6.77	6.58	6.97
S	7.95	7.75	7.05	7.20	7.70	8.10	6.85	7.50	7.30	7.49
O	8.10	7.82	7.69	7.99	7.63	6.69	6.63	6.63	6.24	7.27
N	8.12	7.84	7.55	7.70	6.94	6.90	6.64	6.68	6.56	7.21
D'09	7.89	7.76	7.62	7.84	7.66	7.17	7.06	7.00	6.76	7.42
J'10	8.11	8.03	7.80	8.07	7.90	7.56	7.78	7.12	6.63	7.67
F	7.72	7.66	7.15	7.71	7.55	7.49	7.28	6.51	6.54	7.29
M	7.53	7.55	7.30	7.73	7.23	7.10	7.07	6.94	6.73	7.24
A	7.51	7.50	7.19	7.62	7.03	6.98	7.04	7.15	6.92	7.22
M	5.88	6.85	6.84	6.95	5.59	7.00	6.55	6.44	6.58	6.52
J	5.85	6.85	6.42	6.67	6.82	6.57	6.59	6.51	6.21	6.50
J	7.13	7.07	7.28	7.54	6.58	6.17	4.51	4.98	4.93	6.24
A	7.41	7.51	7.03	7.05	7.16	7.22	6.70	6.65	4.93	6.85
S	7.82	7.91	7.67	7.76	7.37	6.72	6.82	6.67	6.45	7.24
O	8.05	7.86	7.66	7.90	7.53	7.08	7.03	6.86	6.55	7.39
N	8.06	7.83	7.62	7.84	7.62	7.33	7.48	7.23	6.96	7.55
D'10	7.68	7.34	7.25	7.41	7.34	7.05	7.31	7.43	7.03	7.32
J'11	8.44	8.30	7.95	8.21	7.99	7.85	8.10	7.41	7.30	7.95
F	7.16	7.39	7.12	7.50	6.85	7.14	6.98	6.76	6.69	7.07
M	7.69	7.65	7.34	7.69	7.29	7.40	7.12	7.03	6.93	7.35
A	8.02	7.93	7.64	7.78	7.58	7.36	7.49	7.58	7.56	7.66
M'11	7.90	7.65	7.25	7.80	7.45	7.70	6.90	6.75	6.55	7.33

Table 3.13.2 Mean seasonal variation of pH in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	7.95±0.44	7.05±0.85	8.06±0.11	8.06±0.31	7.16±0.86	7.69±0.38
2	7.68±0.21	7.34±0.47	7.86±0.12	7.83±0.39	7.39±0.37	7.66±0.22
3	7.32±0.34	7.10±0.52	7.67±0.11	7.62±0.29	7.12±0.20	7.34±0.22
4	7.30±0.37	7.26±0.49	7.90±0.16	7.84±0.33	7.50±0.37	7.69±0.14
5	7.59±0.47	6.98±0.35	7.53±0.41	7.62±0.27	6.85±0.87	7.29±0.32
6	7.55±0.52	6.67±0.43	7.08±0.38	7.33±0.37	7.14±0.24	7.40±0.23
7	7.11±0.42	6.16±1.10	7.03±0.54	7.48±0.45	6.99±0.31	7.12±0.26
8	7.49±0.58	6.20±0.82	6.86±0.24	7.23±0.26	6.76±0.34	7.03±0.39
9	6.81±0.35	5.63±0.81	6.55±0.22	6.96±0.31	6.69±0.17	6.93±0.45

Table 3.13.3 Mean station wise variation of pH (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	5.09	8.60	4.83	8.41
2	6.88	8.14	6.72	8.45
3	6.47	8.00	6.36	8.09
4	6.59	8.54	6.58	8.06
5	4.57	8.27	6.58	8.20
6	6.45	8.90	5.49	7.81
7	4.96	8.30	4.05	8.16
8	6.22	8.20	3.73	8.20
9	4.21	8.00	3.35	7.42

Table 3.13.4 ANOVA of pH in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	1.926	6.436
Season	2	6.102	20.389**
Station	8	6.264	20.932**
Surface water, Bottom water	1	0.101	0.338
Season * Station	16	0.418	1.397
Station * Surface water, Bottom water	8	0.119	0.397
Season * Surface water, Bottom water	2	0.600	2.005
Error	394	0.299	
Total	432		
R^2= 0.377			

**Variation is significant at 1% level

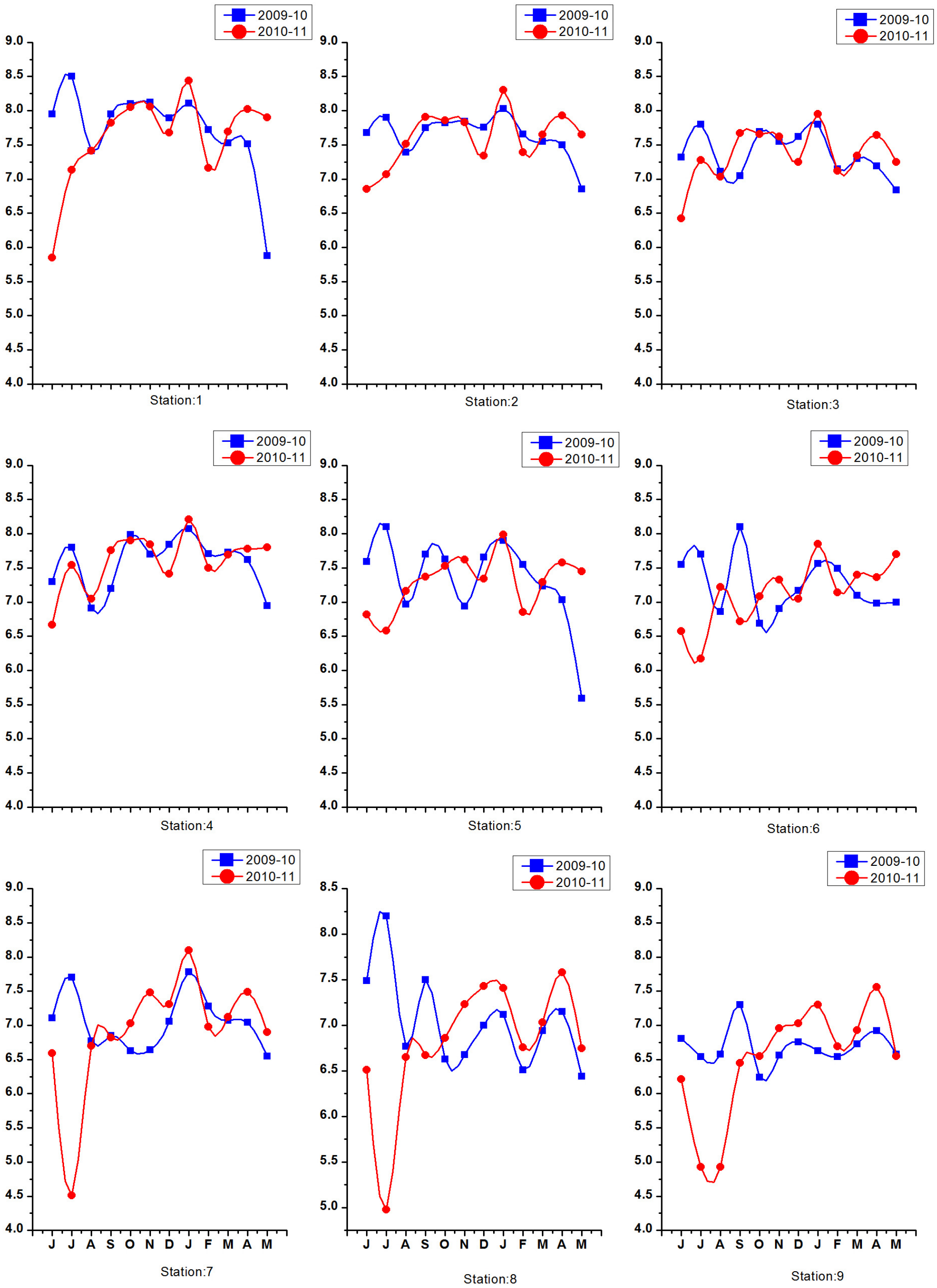


Fig. 3.13. Mean monthly variation of pH in selected stations of Cochin estuary during 2009-11 period

3.4.3.3 Free carbon dioxide

The surface waters of station 4 (30.00 mg L^{-1}) showed a high amount of free carbon dioxide, while the lowest amount was observed at station 8 (1.50 mg L^{-1}). In the bottom waters, it ranged from 20 mg L^{-1} at station 3 to 1 mg L^{-1} at station 9.

The mean station wise variation of free carbon dioxide is presented in Table 3.14.3. Station wise mean values of dissolved carbon dioxide showed the maximum at station 3 (9.35 ± 0.87 mg L^{-1}) and minimum at station7 (7.28 ±0.87 mg L^{-1}). The dissolved carbon dioxide values were found to be higher in the central zone (8.60 ± 0.40 mg L^{-1}) and lower in the northern zone (7.81 ± 0.40 mg L^{-1}). The free carbon dioxide value in the central zone was maximum (9.80 mg L^{-1}) at station 1 and minimum (7.88 mg L^{-1}) at station 4. In the southern the values were higher at station 3 (9.35 mg L^{-1}) compared to station 2 (7.32 mg L^{-1}). In the northern zone, the free carbon dioxide values ranged from 7.28 mg L^{-1} at station 7 to 8.97 mg L^{-1} at station 6.

The mean season wise variation of free carbon dioxide in Cochin estuary during the study period is presented in Table 3.14.2. The free carbon dioxide was higher during the monsoon period (8.47 ± 0.39 mg L^{-1}) and lower during the pre-monsoon period (7.75 ± 0.39 mg L^{-1}). During the monsoon period, the highest free carbon dioxide (18.1 mg L^{-1}) was observed in September 2009 at station 1 and lowest (3.75 mg L^{-1}) was recorded in July 2010 at station 9. In the post-monsoon period, the maximum value of 17 mg L^{-1} was observed at station 4 in December 2009 and minimum value of 2 mg L^{-1} was observed at station 2 in January 2010. In the pre-monsoon period, the values ranged from 1.50 mg L^{-1} in April 2011 at station 9 to 21.50 mg L^{-1} in April 2010 at station 1.

The mean monthly values of free carbon dioxide in Cochin estuary during 2009-11 period is given in Table 3.14.1 and Fig.3.14. Free carbon dioxide values displayed the highest mean monthly value at station 1 in April 2010 (21.50 mg L^{-1}) and minimum in April 2011 at Station 9 (1.50 mg L^{-1}). Mean annual values of carbon dioxide were 9.07 ± 1.24 mg L^{-1} during the 2009-10 period and 7.31 ± 2.19 mg L^{-1} during the 2010-11 period. The range of values during 2009-10 period was 6.34 mg L^{-1} in January 2010 to 11.21 mg L^{-1} in December 2009 whereas in the 2010-11 period the values ranged from 2.67 mg L^{-1} in April 2011 to 11.28 mg L^{-1} in May 2011.

ANOVA of free carbon dioxide showed that it was significant at 1% level between stations ($p \leq 0.01$) (Table 3.14.4).

Table 3.14.1 Mean monthly variation of free carbon dioxide in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	14.70	10.00	9.83	7.53	6.67	9.67	8.08	8.50	10.33	9.48
J	11.00	9.00	10.00	8.00	9.00	9.00	9.00	9.50	7.75	9.14
A	15.00	13.00	11.50	8.10	4.50	11.50	7.50	9.50	15.50	10.68
S	18.10	8.00	8.00	6.50	6.50	8.50	7.75	6.50	7.75	8.62
O	4.00	6.50	14.50	8.50	9.00	10.10	5.50	4.50	7.75	7.82
N	9.00	9.00	7.75	3.50	6.00	15.50	11.00	12.50	10.50	9.42
D'09	10.50	8.00	13.50	17.00	9.00	10.00	13.00	7.00	12.90	11.21
J'10	5.30	2.00	5.90	5.15	9.00	8.50	7.00	6.00	8.25	6.34
F	7.00	6.50	11.50	10.00	14.60	9.00	5.50	8.00	8.00	8.90
M	7.00	6.50	11.50	10.00	14.60	9.00	5.50	8.00	8.00	8.90
A	21.50	8.00	6.00	8.10	9.00	7.50	7.50	7.45	6.00	9.01
M	7.00	9.00	7.00	6.00	11.50	12.50	9.50	8.50	13.00	9.33
J	6.50	5.50	13.50	11.50	7.00	9.00	7.50	9.15	9.50	8.79
J	8.55	6.80	10.40	5.33	5.85	6.00	4.15	4.30	3.75	6.13
A	4.65	7.20	7.90	7.15	8.15	8.25	7.20	6.65	4.50	6.85
S	13.30	8.35	10.50	5.75	9.40	5.85	9.20	4.90	5.75	8.11
O	7.20	6.38	10.41	8.54	8.25	11.03	9.13	7.50	9.85	8.70
N	7.20	6.26	7.80	7.58	7.67	7.83	5.64	6.23	5.03	6.80
D'10	9.55	6.75	7.25	9.05	7.50	7.05	4.55	5.95	2.25	6.66
J'11	4.85	5.65	5.75	5.15	7.25	5.40	3.25	5.25	3.00	5.06
F	10.63	7.50	9.00	8.53	12.43	9.50	7.00	7.99	8.75	9.03
M	7.88	6.83	8.50	7.68	8.98	8.50	6.83	7.33	6.42	7.66
A	3.00	3.00	3.50	3.50	3.00	2.50	2.00	2.00	1.50	2.67
M'11	10.00	10.00	13.00	11.00	11.50	13.50	11.50	12.00	9.00	11.28

Table 3.14.2 Mean seasonal variation of free carbon dioxide in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	14.70±2.91	8.25±3.72	7.20±3.05	7.20±1.92	10.63±7.25	7.88±3.46
2	10.00 ±2.16	6.96±1.18	6.38±3.09	6.26±0.46	7.50±1.22	6.83±2.90
3	9.83±1.43	10.58±2.29	10.41±4.23	7.80±1.94	9.00 ±2.92	8.50±3.89
4	7.53±0.73	7.43±2.82	8.54±6.01	7.58±1.73	8.53±1.91	7.68±3.12
5	6.67±1.84	7.60±1.52	8.25±1.50	7.67±0.42	12.43±2.71	8.98±4.24
6	9.67±1.31	7.28±1.59	11.03±3.07	7.83±2.36	9.50±2.12	8.50±4.55
7	8.08±0.66	7.01±2.10	9.13±3.47	5.64±2.52	7.00 ±1.91	6.83±3.88
8	8.50±1.41	6.25±2.18	7.50±3.49	6.23±0.94	7.99±0.43	7.33±4.11
9	10.33±3.65	5.88±2.55	9.85±2.36	5.03±3.42	8.75±2.99	6.42±3.48

Table 3.14.3 Mean station wise variation of free carbon dioxide (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	3.00	28.00	3.00	18.00
2	2.00	10.00	2.00	16.00
3	3.00	17.00	3.00	20.00
4	3.00	30.00	4.00	13.00
5	3.00	15.20	3.00	14.00
6	2.00	18.00	3.00	17.00
7	2.00	16.00	2.00	16.00
8	1.50	13.00	2.00	14.00
9	2.00	16.00	1.00	16.00

Table 3.14.4 ANOVA of free carbon dioxide in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	20.481	1.554
Season	2	21.497	1.632
Station	8	36.422	2.764**
Surface water, Bottom water	1	0.238	0.018
Season * Station	16	18.434	1.399
Station * Surface water, Bottom water	8	15.522	1.178
Season * Surface water, Bottom water	2	2.032	0.154
Error	394	13.176	
Total	432		
R^2= 0.127			

**Variation is significant at 1% level

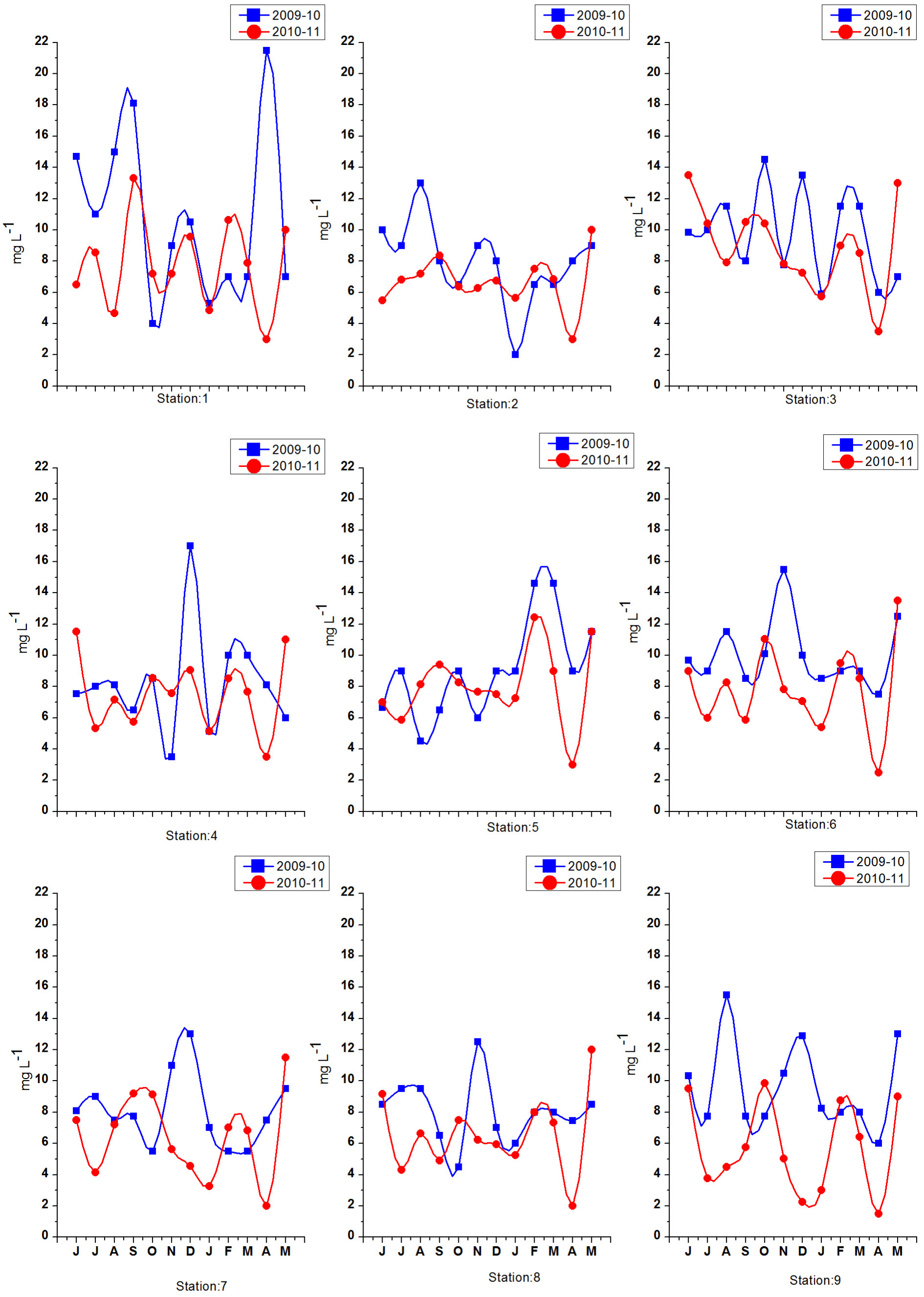


Fig.3.14. **Mean monthly variation of free carbon dioxide in selected stations of Cochin estuary during 2009-11 period**

3.4.3.4 Total alkalinity

The average alkalinity value of the Cochin estuary was 36.26 ± 14.32 mg L^{-1} during the study period. Bottom waters showed higher alkalinity values during the study period. The highest mean alkalinity value was recorded at station 4 (101.50 mg L^{-1}) in April 2010. The mean station wise value of alkalinity was maximum at station 1 (47.77 ± 8.31mg L^{-1}) and minimum at station 9 (24.86 ± 8.31 mg L^{-1}). The alkalinity values were found to be higher in the central zone (42.46 ± 7.62 mg L^{-1}) and lower in the northern zone (28.90 ± 7.62mg L^{-1}). In the central zone, the highest alkalinity of 37.77 mg L^{-1} was observed at station 1 and lowest value of 36.72 mg L^{-1} at station 5. The alkalinity was higher at station2 (45.84 mg L^{-1}) compared to station 3(37.52 mg L^{-1}). In the northern zone, the alkalinity values ranged from 24.86 mg L^{-1} at station 9 to 35.41 mg L^{-1} at station 6.

Mean seasonal variation of total alkalinity in selected stations of Cochin estuary during 2009-11 period is given in Table 3.15.2. Relatively high alkalinity was observed during the post-monsoon period (40.22 ± 5.09 mg L^{-1}), when compared to the pre-monsoon period(38.05 ± 5.09 mg L^{-1}) and monsoon period (20.05 ± 5.09 mg L^{-1}). During monsoon period, the maximum alkalinity was observed in September 2010 (87 mg L^{-1}) at station 2 and the minimum in September 2009 (8 mg L^{-1}) at stations 2, 3 and 4. The range of alkalinity during the post-monsoon period was 12.50 mg L^{-1} in December 2009 at station 9 to 82.50 mg L^{-1} in December 2010 at station 1 and station 2.

The alkalinity was observed to be higher (41.45 ± 14.25 mg L^{-1}) during 2010-11 period. During 2009-10 period, the highest alkalinity

(54.06 mg L^{-1}) was recorded in February 2010 and the lowest (13.22 mg L^{-1}) in September 2009. During 2010-11 period, the highest value was 70.31 mg L^{-1} in September 2010 to 27.22 mg L^{-1} in June 2010.

The ANOVA of alkalinity showed that variations between seasons ($p \leq 0.001$), between stations ($p \leq 0.001$) were significant at 1 % level whereas it was significant at 5% level between seasons and stations ($p \leq 0.05$) (Table 3.15.4).

Table 3.15.1 Mean monthly variation of total alkalinity in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	26.33	16.33	15.83	21.75	24.50	22.17	19.33	19.00	23.17	20.93
J	25.50	22.50	19.00	35.75	23.00	15.00	14.50	17.50	26.00	22.08
A	40.50	18.50	20.50	21.50	39.50	32.50	27.50	25.50	21.50	27.50
S	13.00	8.00	8.00	8.00	11.00	19.00	16.00	14.00	22.00	13.22
O	32.00	30.50	33.50	26.50	24.00	17.50	18.00	17.00	14.00	23.67
N	58.50	57.00	39.00	45.50	22.50	22.50	18.50	17.00	16.00	32.94
D'09	46.00	28.00	32.50	42.00	26.50	34.00	18.00	13.50	12.50	28.11
J'10	62.50	70.00	57.50	53.00	60.00	47.50	28.50	22.00	25.50	47.39
F	93.00	68.00	67.50	62.00	55.00	42.00	40.00	26.50	32.50	54.06
M	30.00	29.00	27.50	33.00	41.00	39.50	31.00	19.00	18.50	29.83
A	49.50	87.50	65.00	101.50	48.00	40.50	23.50	21.00	19.00	50.61
M	31.50	26.00	23.50	29.00	15.50	23.00	17.50	23.50	12.50	22.44
J	25.00	29.00	34.50	30.50	31.50	27.00	23.50	20.50	23.50	27.22
J	26.50	37.50	25.00	36.50	31.00	34.00	18.50	27.00	15.00	27.89
A	51.50	38.00	25.00	37.50	39.50	35.00	31.00	32.50	24.50	34.94
S	84.75	87.00	62.00	65.00	62.00	70.25	73.75	56.00	72.00	70.31
O	49.75	46.38	40.63	41.75	33.25	30.38	20.75	17.38	17.00	33.03
N	63.92	59.63	45.54	51.00	45.08	47.38	44.08	37.96	32.08	47.41
D'10	82.50	82.50	54.50	64.25	67.00	68.75	76.00	70.00	55.75	69.03
J'11	59.50	50.00	41.50	47.00	35.00	43.00	35.50	26.50	23.50	40.17
F	51.00	52.63	45.88	56.38	39.88	36.25	28.00	22.50	20.63	39.24
M	48.67	52.21	40.63	44.13	36.63	34.75	25.67	26.50	22.54	36.86
A	56.00	39.00	34.00	35.00	35.00	28.00	23.00	29.00	21.00	33.33
M'11	39.00	65.00	42.00	41.00	35.00	40.00	26.00	28.00	26.00	38.00

Table 3.15.2 Mean seasonal variation of total alkalinity in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	26.33±11.24	46.94±27.99	49.75±13.76	63.92±13.73	51±29.37	48.67±7.13
2	16.33±6.11	47.88±26.41	46.38±20.50	59.63±16.24	52.63±30.11	52.21±10.62
3	15.83±5.57	36.63±17.50	40.63±11.61	45.54±6.34	45.88±23.61	40.63±4.95
4	21.75±11.33	42.38±15.40	41.75±11.15	51.00±9.61	56.38±33.48	44.13±9.00
5	24.50±11.68	41.00±14.53	33.25±17.91	45.08±15.51	39.88±17.23	36.63±2.30
6	22.17±7.49	41.56±19.45	30.38±13.34	47.38±15.97	36.25±8.89	34.75±5.01
7	19.33±5.81	36.69±25.24	20.75±5.17	44.08±23.36	28.00±9.72	25.67±2.05
8	19.00±4.81	34.00±15.47	17.38±3.50	37.96±22.96	22.50±3.24	26.50±2.86
9	23.17±2.01	33.75±25.85	17.00±5.85	32.08±16.94	20.63±8.45	22.54±2.45

Table 3.15.3 Mean station wise variation of total alkalinity (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	13.00	89.00	13.00	98.00
2	8.00	94.50	8.00	98.00
3	8.00	77.00	8.00	72.00
4	8.00	83.00	8.00	120.00
5	11.00	77.50	11.00	68.00
6	15.00	78.00	15.00	62.50
7	12.00	61.00	15.00	91.00
8	12.00	70.00	14.00	70.00
9	11.00	64.00	10.00	80.00

Table 3.15.4 ANOVA of total alkalinity in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	1159.518	4.022
Season	2	3736.111	12.958**
Station	8	3317.491	11.506**
Surface water, Bottom water	1	589.167	2.043
Season * Station	16	496.398	1.722*
Station * Surface water, Bottom water	8	44.705	0.155
Season * Surface water, Bottom water	2	0.417	0.001
Error	394	288.321	
Total	432		
R^2= 0.274			

*Variation is significant at 5% level

**Variation is significant at 1% level

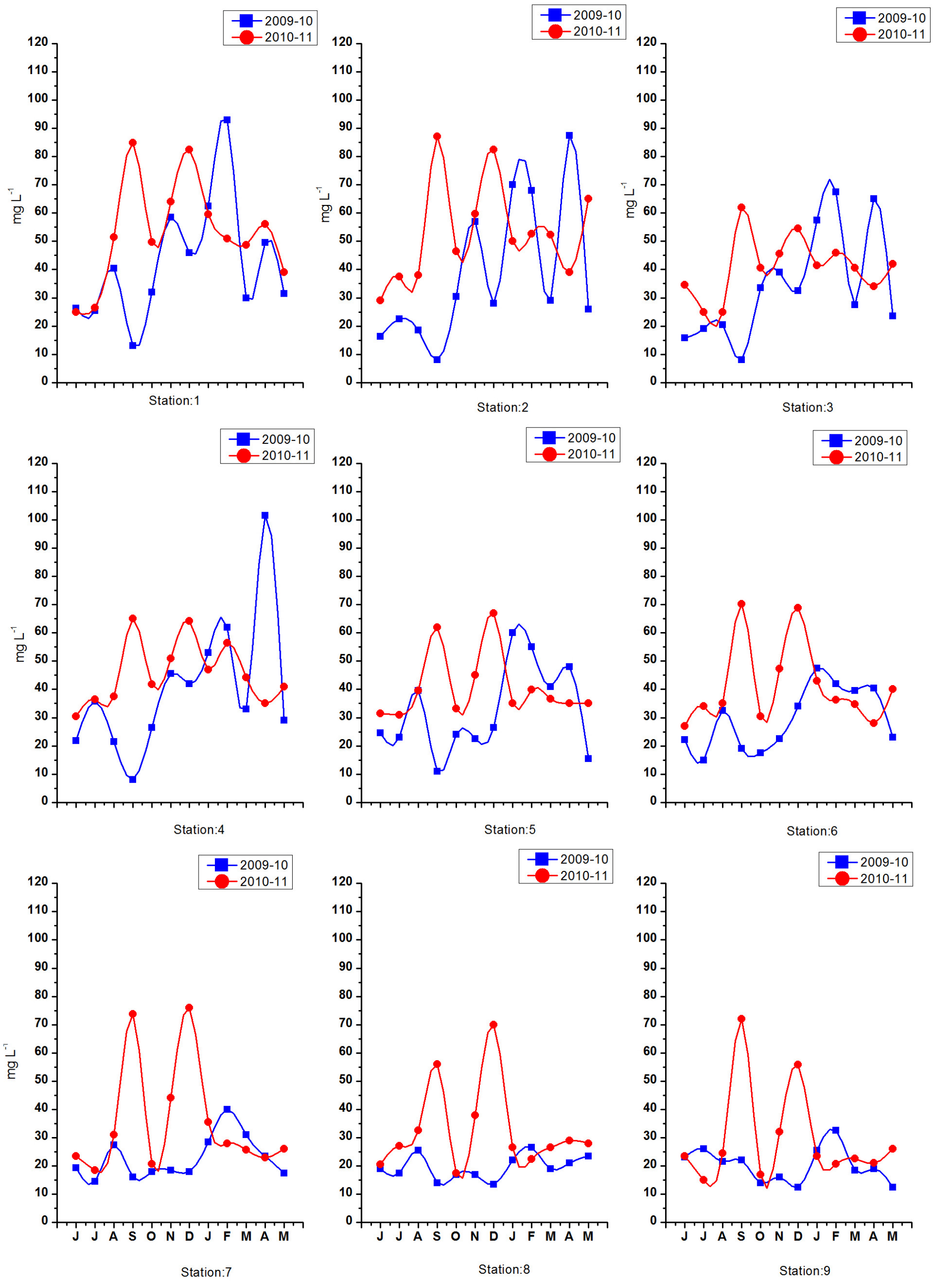


Fig.3.15. Mean monthly variation of total alkalinity in selected stations of Cochin estuary during 2009-11 period

3.4.3.5 Total Hardness

The average total hardness of the estuary was1823.29±1596.76mg L^{-1}. The total hardness of the bottom waters was higher in comparison with the surface waters. Station wise mean value was highest at station 1 (3233.85 mg L^{-1}) and lowest at station 9 (61 mg L^{-1}). The mean monthly variation of total hardness in Cochin estuary during 2009-11 period is given in Table 3.16.1 and Fig.3.16. The minimum total hardness value of 30 mg L^{-1} was observed at station 7 in July 2010 and the maximum value of 13150 mg L^{-1} were recorded at station 5 in May 2010. The maximum was recorded in the central zone of the estuary (2752.88 mg L^{-1}) and the minimum in the northern zone (824.08 mg L^{-1}). In the central zone, the total hardness varied between 2256.33 mg L^{-1} at station 5 and 3233.85 mg L^{-1} at station 1. In the southern zone, the highest value of 2803.81 mg L^{-1} was observed at station 2 and the lowest was recorded from 2050.83 mg L^{-1} at station 3. The range of total hardness in the northern zone was from 611.74 mg L^{-1} at station 9 to 1079 mg L^{-1} at station 6.

The total hardness of the estuary drastically decreased during monsoon period of the 2010-11 period. During the monsoon period, the highest total hardness was in July 2009 at station 4 and the lowest (30 mg L^{-1}) in July 2010 at station 7. The maximum value of total hardness 7900 mg L^{-1} was observed in January 2010 at station 1 and minimum value of 40 mg L^{-1} was recorded in January 2010 at station 1 during the post-monsoon period. In the pre-monsoon period, the maximum and minimum values ranged from 13150 mg L^{-1} in May 2010 at station 5 to 350 mg L^{-1} in March 2010 at station 8.

The total hardness was higher during the 2009-10 period (1906.96 ± 1287.82mg L^{-1}). In 2009-10 period, the highest and the lowest values ranged from 525 mg L^{-1} in August 2009 to 4666.67 mg L^{-1} in January 2010. In 2010-11 period the maximum value recorded was 5320 mg L^{-1} in April 2011 to 88.78 mg L^{-1} in August 2010.

ANOVA of total hardness was significant at 1% level between seasons ($p \leq 0.001$) and between stations ($p \leq 0.001$) where as it was significant at 5% level between surface and bottom waters ($p \leq 0.05$) (Table 3.16.4).

Table 3.16.1 Mean monthly variation of total hardness in selected stations of Cochin estuary during 2009-11 period

Month	Stations									
	1	2	3	4	5	6	7	8	9	Mean
J'09	2073.00	1203.00	456.00	3616.00	436.00	228.00	176.00	163.00	284.00	959.44
J	2320.00	760.00	320.00	9200.00	560.00	280.00	240.00	240.00	572.00	1610.22
A	1800.00	1150.00	550.00	650.00	200.00	105.00	90.00	100.00	80.00	525
S	2100.00	1700.00	500.00	1000.00	550.00	300.00	200.00	150.00	200.00	744.44
O	5100.00	4150.00	4500.00	2550.00	2450.00	1000.00	750.00	400.00	300.00	2355.56
N	2100.00	1300.00	1450.00	1000.00	550.00	450.00	250.00	400.00	350.00	872.22
D'09	6250.00	5700.00	4900.00	6150.00	3850.00	1800.00	1350.00	650.00	500.00	3461.11
J'10	7900.00	7650.00	6150.00	6750.00	5950.00	3150.00	2200.00	850.00	1400.00	4666.67
F	3850.00	2950.00	1950.00	2650.00	2650.00	1300.00	700.00	500.00	600.00	1905.56
M	1700.00	2550.00	1450.00	2500.00	950.00	600.00	500.00	350.00	400.00	1222.22
A	1800.00	1700.00	2050.00	2800.00	900.00	700.00	750.00	500.00	450.00	1294.44
M	2300.00	1450.00	700.00	1050.00	13150.00	3700.00	3450.00	1950.00	1650.00	3266.67
J	396.00	200.00	124.00	140.00	96.00	56.00	64.00	84.00	44.00	133.78
J	280.00	165.00	120.00	90.00	90.00	75.00	30.00	45.00	110.00	111.67
A	240.00	110.00	70.00	130.00	70.00	50.00	39.00	55.00	35.00	88.78
S	550.00	590.00	440.00	190.00	150.00	100.00	60.00	60.00	50.00	243.33
O	5338.00	4700.00	4250.00	4113.00	3200.00	1600.00	1138.00	575.00	638.00	2838.89
N	2169.00	1957.00	1640.00	1691.00	1303.00	810.00	536.00	275.00	309.00	1187.78
D'10	370.00	230.00	160.00	120.00	190.00	90.00	50.00	50.00	40.00	144.44
J'11	800.00	940.00	510.00	840.00	520.00	740.00	420.00	200.00	250.00	580
F	2413.00	2163.00	1538.00	2250.00	4413.00	1575.00	1350.00	825.00	775.00	1922.22
M	7044.00	6534.00	4233.00	4803.00	4084.00	2192.00	1970.00	2515.00	1605.00	3886.67
A	10880.00	10120.00	6880.00	6240.00	3600.00	1800.00	2000.00	4520.00	1840.00	5320
M'11	7840.00	7320.00	4280.00	5920.00	4240.00	3200.00	2560.00	2200.00	2200.00	4417.78

Table 3.16.2 Mean seasonal variation of total hardness in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	2073.25±213.12	366.50±139.08	5337.50±2445.19	2169.17±2247.22	2412.50±993.63	7044.17±3502.35
2	1203.25±385.60	266.25±218.99	4700 ±2681.11	1956.67±1961.37	2162.50±705.19	6534.17±3295.82
3	456.50±98.77	188.50±169.46	4250±1994.58	1640±1851.07	1537.50±616.95	4232.50±2181.33
4	3616.50±3950.60	137.50±41.13	4112.50±2783.10	1690.83±1737.42	2250±809.32	4803.33±1810.20
5	436.50±167.40	101.50±34.19	3200±2278.16	1303.33±1347.90	4412.50±5881.52	4084.17±349.53
6	228.25±87.59	70.25±22.51	1600±1172.60	810±618.44	1575±1450	2191.67±718.89
7	176.50±63.42	48.25±16.38	1137.50±839.02	535.83±451.46	1350±1404.16	1970±494.44
8	163.25±57.93	61±16.55	575±217.94	275±220.79	825±753.33	2515±1524.83
9	284±209.46	59.75±34.06	637.50±515.39	309.17±247.49	775±589.49	1605±605.02

Table 3.16.3 Mean station wise variation of total hardness (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	140.00	10400.00	220.00	11360.00
2	80.00	7500.00	140.00	15920.00
3	80.00	6480.00	60.00	7280.00
4	60.00	8080.00	80.00	17920.00
5	40.00	7800.00	60.00	18500.00
6	48.00	3400.00	40.00	4000.00
7	20.00	3600.00	20.00	3300.00
8	40.00	2515.00	40.00	8080.00
9	30.00	1840.00	40.00	2560.00

Table 3.16.4 ANOVA of total hardness in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	25447073.947	6.055
Season	2	203110422.549	48.332**
Station	8	49184689.520	11.704**
Surface water, Bottom water	1	24692526.676	5.876*
Season * Station	16	6531521.629	1.554
Station * Surface water, Bottom water	8	1167978.030	0.278
Season * Surface water, Bottom water	2	1651338.898	0.393
Error	394	4202367.506	
Total	432		
R^2= 0.363			

*Variation is significant at 5% level
**Variation is significant at 1% level

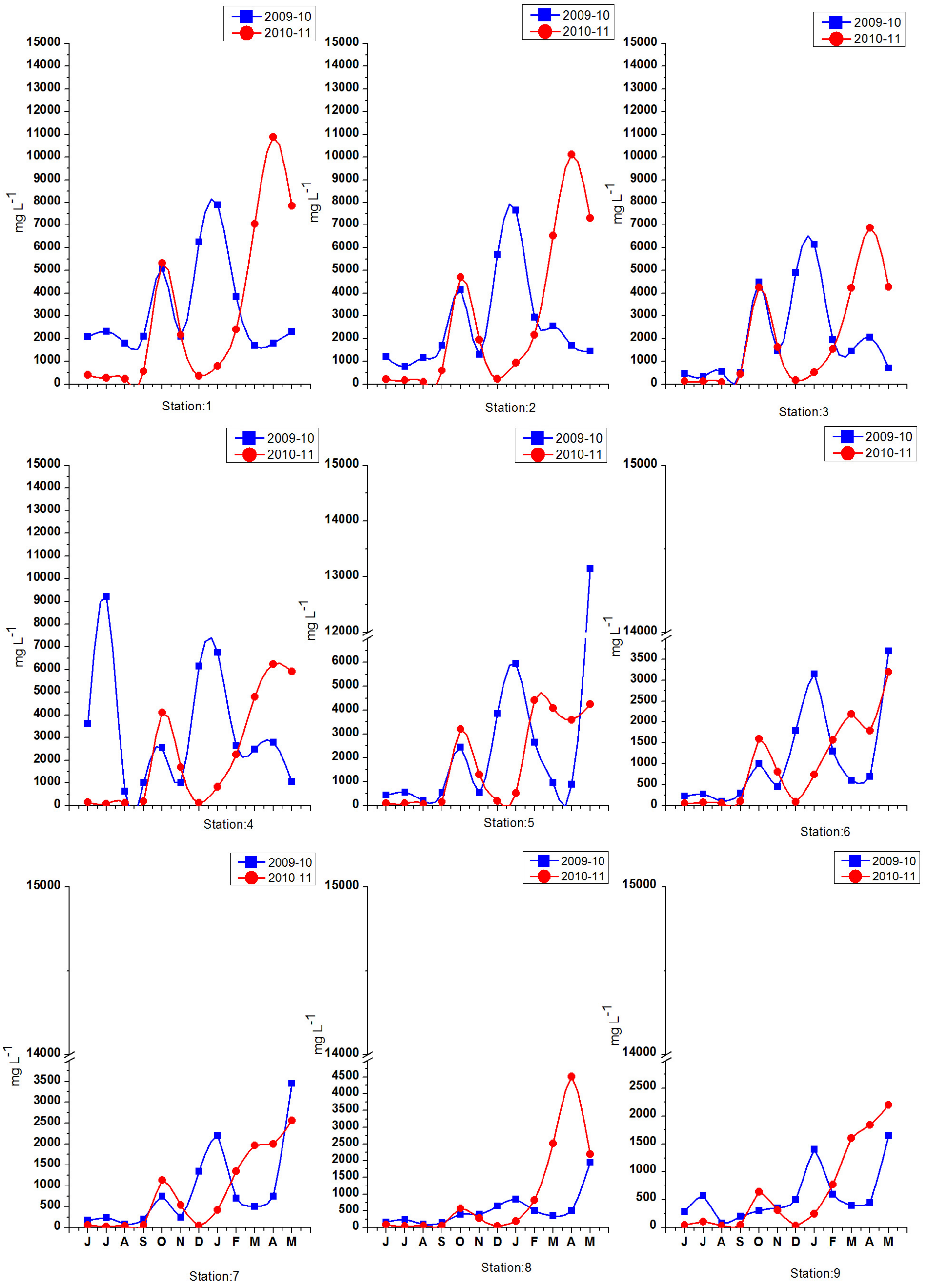


Fig.3.16. **Mean monthly variation of total hardness in selected stations of Cochin estuary during 2009-11 period**

3.4.3.6 Biological Oxygen Demand

The average biological oxygen demand (BOD) during the present study was 2.42 ± 1.53 mg L^{-1}. The surface waters showed the highest biological oxygen demand values. Mean station wise value of BOD was the highest at station 5 (3.15 ± 0.37 mg L^{-1}) and lowest at station 7 (1.89 ± 0.37 mg L^{-1}). The maximum BOD was recorded in the central zone (2.67 ± 0.23 mg L^{-1}) and minimum in the northern zone (2.22 ± 0.23 mg L^{-1}). In the central zone, the BOD values ranged from 2.33 mg L^{-1} at station 4 to 3.15 mg L^{-1} at station 5. The maximum value of BOD in the southern zone was recorded at station 3 (2.57 mg L^{-1}) and the minimum (2.31 mg L^{-1}) at station 2. In the northern zone, the values ranged from 1.89 mg L^{-1} at station 7 to 2.68 mg L^{-1} at station 6.

Among the seasons, BOD was higher during the monsoon period (2.91 ± 0.43 mg L^{-1}) as compared to the post-monsoon period (2.12 ± 0.43 mg L^{-1}) and pre-monsoon period (2.22 ± 0.43 mg L^{-1}). In the monsoon period the BOD values ranged from nil in July 2009 at station 5, 6, 7 and 8 and in August 2009 at station 7, to 7.15 mg L^{-1} in August 2010 at station 6. During the post-monsoon period, the highest concentration was 10.68 mg L^{-1} in October 2009 at station 2 and the lowest value of zero was recorded in November 2009 at station 7, 8 and 9 and in January 2010 at station 8. In the pre-monsoon period the maximum and minimum value ranged between zero in March 2010 at station 5, 6, 7, 8 and 9, to 5.27 in May 2011 at station 5.

The mean annual values of BOD was higher during 2009-10 (2.44 ± 1.70 mg L^{-1}) compared to 2010-11 (2.40 ± 1.42 mg L^{-1}) period. In the first year the highest value of BOD 7.12 mg L^{-1} was recorded in October 2009 and the lowest was 0.99 mg L^{-1} in March 2010. In the second year the values ranged from 0.37 mg L^{-1} in December 2010 to 5.45 mg L^{-1} in August 2010 (Table 3.17.1).

ANOVA of BOD was significant at 1% level between seasons ($p \leq 0.001$) (Table 3.17.4).

Table 3.17.1 Mean monthly variation of biological oxygen demand in selected stations of Cochin estuary during 2009-11period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	3.35	2.29	1.82	1.71	1.50	1.02	0.00	1.59	3.64	1.87
J	4.25	1.96	1.31	2.29	0.00	0.00	0.00	0.00	2.84	0.68
A	2.86	1.23	0.40	0.81	1.64	0.53	0.00	3.31	2.30	1.30
S	2.94	3.68	3.76	2.05	4.49	3.84	2.77	3.42	5.79	3.63
O	8.08	10.68	6.12	8.66	8.24	4.57	4.98	6.04	6.70	7.12
N	2.86	1.23	0.41	1.63	3.88	1.64	0.00	0.00	0.00	1.19
D'09	0.00	0.82	2.86	1.64	2.86	2.85	1.22	2.05	2.04	1.81
J'10	2.13	1.33	0.67	1.40	2.95	4.24	3.41	0.00	2.94	2.05
F	2.45	1.84	3.27	3.88	3.68	4.90	3.27	3.27	3.27	3.31
M	1.55	2.12	3.47	1.76	0.00	0.00	0.00	0.00	0.00	0.63
A	2.99	2.70	4.30	2.19	5.12	2.72	1.81	2.03	2.32	2.91
M	1.84	1.01	1.63	2.04	1.63	1.22	0.61	0.81	1.43	1.36
J	3.87	0.61	3.47	1.84	1.22	0.41	1.64	1.43	2.25	1.86
J	3.76	3.19	3.51	4.48	2.25	3.07	3.47	4.49	3.88	3.56
A	5.55	5.63	5.88	5.88	4.28	7.15	4.08	5.71	4.90	5.45
S	3.73	3.70	1.92	3.14	5.15	5.15	5.95	3.95	3.35	4.00
O	3.27	3.51	2.51	3.33	4.48	3.32	2.38	1.85	2.72	3.04
N	0.00	0.00	0.70	0.00	3.24	2.31	2.00	0.59	0.00	0.88
D'10	0.00	0.00	0.28	0.12	1.25	1.64	0.06	0.00	0.00	0.00
J'11	0.00	0.00	0.00	0.00	3.98	1.96	3.58	0.03	0.00	0.39
F	2.21	1.92	3.16	2.47	2.56	2.00	1.37	1.22	1.55	2.05
M	1.17	2.00	3.35	1.79	3.42	2.97	1.03	2.02	1.10	2.09
A	1.65	2.45	4.45	1.25	2.45	2.86	1.65	2.44	1.66	2.32
M'11	0.00	1.65	2.45	1.65	5.27	4.06	0.05	2.39	0.09	1.92

Table 3.17.2 Mean seasonal variation of biological oxygen demand in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	3.35±0.64	4.23±0.88	3.27±3.43	0.82±1.63	2.21±0.64	1.26±0.94
2	2.29±1.03	3.28±2.07	3.51±4.78	0.88±1.76	1.92±0.70	2±0.33
3	1.82±1.42	3.70±1.63	2.51±2.64	0.87±1.13	3.16±1.12	3.35±0.83
4	1.71±0.65	3.83±1.74	3.33±3.55	0.86±1.65	2.47±0.96	1.79±0.51
5	1.91±1.87	3.22±1.81	4.48±2.55	3.24±1.42	2.61±2.25	3.42±1.30
6	1.35±1.71	3.94±2.88	3.32±1.35	2.31±0.73	2.21±2.11	2.97±0.84
7	0.69±1.38	3.78±1.78	2.40±2.22	2.00±1.46	1.42±1.44	1.03±0.70
8	2.08±1.62	3.90±1.80	2.02±2.84	0.62±0.86	1.53±1.43	2.02±0.56
9	3.64±1.54	3.59±1.11	2.92±2.80	0.68±1.36	1.75±1.39	1.10±0.71

Table 3.17.3 Mean station wise variation of biological oxygen demand (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0	9.30	0	6.85
2	0	12.41	0	8.94
3	0	7.18	0	6.21
4	0	10.12	0	7.19
5	0	9.63	0	6.85
6	0	8.16	0	6.53
7	0	7.35	0	5.06
8	0	6.53	0	8.98
9	0	6.53	0	6.86

Table 3.17.4 ANOVA of biological oxygen demand in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	6.068	1.586
Season	2	27.975	7.311**
Station	8	5.010	1.309
Surface water, Bottom water	1	0.383	0.100
Season * Station	16	6.181	1.615
Station * Surface water, Bottom water	8	2.605	0.681
Season * Surface water, Bottom water	2	4.182	1.093
Error	394	3.826	
Total	432		
R^2= 0.130			

** Variation is significant at 1% level

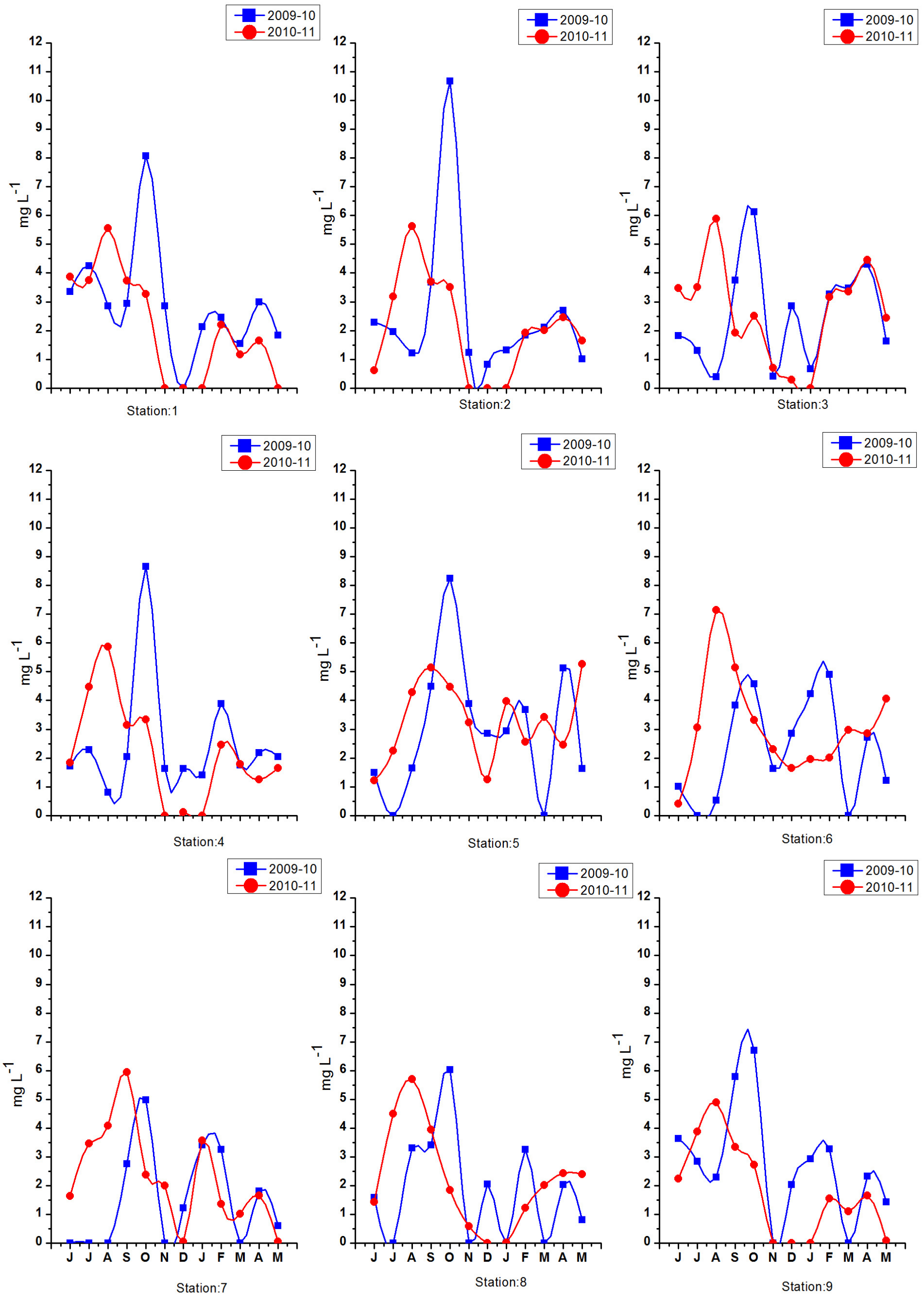


Fig.3.17. Mean monthly variation of BOD in selected stations of Cochin estuary during 2009-11 period

3.4.3.7 Ammonia-nitrogen

The average value of ammonia-nitrogen in the Cochin estuary was 11.48 ± 8.02 µmol L^{-1}. Ammonia values ranged from 0.35 µmol L^{-1} to 59.03 µmol L^{-1}. Mean monthly variation of ammonia-nitrogen in selected stations of Cochin estuary during 2009-11period is presented in Table 3.18.1 and Fig.3.18. The minimum value of 0.35 µmol L^{-1} was recorded at station 8 in August 2009 and the maximum value of 59.03 µmol L^{-1} was at station 2 in April 2011. The ammonia-nitrogen values were found to be comparatively higher at station 9 during the entire study period. In the northern zone, surface waters contain more ammonia than the bottom waters, while the central and southern zones have higher concentrations in the bottom waters. The ammonia-nitrogen values were higher in the northern zone (13.85 ± 2.46 µmol L^{-1}) of the estuary. In the central zone, the concentration of ammonia was high (10.20 µmol L^{-1}) at station 5 and low at station 1. In the southern zone, the station 3 showed higher value (10.99 µmol L^{-1}) compared to station 2 (9.23 µmol L^{-1}).

It was higher during the 2010-11 period (12.21 ± 10.16 µmol L^{-1}) and the maximum was recorded during the pre-monsoon period (13.45 ± 2.36 µmol L^{-1}). During the monsoon period, the highest ammonia-nitrogen (51.90 µmol L^{-1}) was observed in September 2009 at station 9 to 0.35 µmol L^{-1} in August 2009 at station 8. In the post-monsoon period, the range of ammonia- nitrogen was 0.53 µmol L^{-1} in October 2009 at station 3 to 60.03 µmol L^{-1} in December 2009 at station 6. In the pre-monsoon period, the maximum and minimum values of ammonia-nitrogen ranged from 1.90 µmol L^{-1} in March 2010 at station 1 to 59.03 µmol L^{-1} in April 2011 at station 2. In the first year, the highest concentration of ammonia- nitrogen value of 24.36 µmol L^{-1}) was observed in December 2009 and the lowest of 4.43 µmol L^{-1} in October 2009. In the second year, the maximum concentration of ammonia 42.01 µmol L^{-1} was recorded in April 2011 and the minimum value of 5.02 µmol L^{-1} in August 2010.

ANOVA result observed that the variations were significant between seasons ($p \leq 0.01$) and stations ($p \leq 0.001$) whereas it was significant at 5% level between seasons and stations ($p \leq 0.05$) (Table 3.18.4).

Table 3.18.1 Mean monthly variation of ammonia-nitrogen in selected stations of Cochin estuary during 2009-11period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	7.56	6.20	6.78	6.34	14.43	9.35	7.20	4.95	29.43	10.25
J	5.18	6.63	5.93	8.05	24.48	11.23	10.43	7.33	23.97	11.47
A	12.88	7.33	8.30	7.15	9.08	5.75	4.23	0.35	12.43	7.50
S	4.63	4.65	6.13	3.83	9.75	11.08	6.95	7.18	51.90	11.79
O	0.90	0.85	0.53	0.68	0.78	1.05	1.63	0.70	32.73	4.43
N	25.28	17.03	20.33	11.55	13.80	18.33	16.25	12.13	19.45	17.13
D'09	26.03	18.23	26.88	15.88	13.35	60.03	30.38	7.88	20.58	24.36
J'10	5.25	3.75	4.63	3.03	4.38	5.90	2.75	7.05	44.58	9.04
F	8.43	6.30	7.28	5.50	3.50	2.38	2.15	3.73	5.78	5.01
M	1.90	6.23	16.28	9.10	5.10	4.73	2.43	5.58	6.73	6.45
A	6.58	2.98	13.58	6.25	12.40	7.95	34.63	7.15	8.43	11.11
M	6.73	6.40	8.85	11.05	12.88	17.85	12.63	8.45	8.73	10.40
J	3.20	6.30	15.90	15.60	13.50	6.73	6.43	4.25	37.24	12.13
J	3.38	4.63	3.05	5.90	14.63	15.80	6.35	2.93	4.53	6.80
A	3.80	2.95	2.15	2.93	13.90	8.88	2.94	3.75	3.85	5.02
S	4.33	3.78	5.08	9.83	3.23	7.48	6.90	3.83	9.40	5.98
O	14.36	9.96	13.09	7.78	8.07	21.33	12.75	6.94	29.33	13.73
N	5.85	6.33	8.54	6.99	5.82	11.55	8.87	7.30	33.03	10.48
D'10	2.20	2.55	5.23	2.93	3.33	9.05	9.70	5.08	39.15	8.80
J'11	0.98	6.48	7.30	10.28	6.08	4.28	4.15	9.88	30.60	8.89
F	5.91	5.48	11.49	7.98	8.47	8.23	12.96	6.23	7.41	8.24
M	13.86	22.99	19.47	15.75	13.09	22.88	14.75	19.63	25.53	18.66
A	30.43	59.03	39.65	34.40	26.53	55.03	26.53	48.60	57.88	42.01
M'11	5.25	4.48	7.28	4.88	4.28	5.40	4.78	4.05	11.30	5.74

Table 3.18.2 Mean seasonal variation of ammonia-nitrogen in selected stations of Cochin estuary during 2009-11 period

Stations	**Monsoon period**		**Post-monsoon period**		**Pre-monsoon period**	
	Mean ± SD		**Mean ± SD**		**Mean ± SD**	
	2009-10	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**
1	7.56±3.77	3.68±0.50	14.37±13.16	5.85±6.04	5.91±2.80	13.86±11.72
2	6.20±1.13	4.42±1.43	9.97±8.94	6.33±3.03	5.48±1.67	23.00±25.48
3	6.79±1.07	6.55±6.36	13.09±12.54	8.54±3.33	11.50±4.16	19.47±14.37
4	6.34±1.81	8.57±5.48	7.79±7.14	7.00±3.05	7.98±2.57	15.75±13.25
5	14.44±7.11	11.32±5.41	8.08±6.52	5.83±1.94	8.47±4.86	13.09±9.65
6	9.35±2.55	9.72±4.15	21.33±26.81	11.55±7.18	8.23±6.81	22.89±22.76
7	7.20±2.54	5.66±1.83	12.75±13.50	8.87±3.56	12.96±15.25	14.76±8.97
8	4.95±3.26	3.69±0.55	6.94±4.72	7.30±1.98	6.23±2.04	19.63±20.51
9	29.43±16.57	13.76±15.85	29.34±11.81	33.03±4.36	7.42±1.40	25.53±22.93

Table 3.18.3 Mean station wise variation of ammonia-nitrogen (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.45	26.80	0.85	34.05
2	1.10	48.55	0.60	69.50
3	0.70	29.15	0.35	50.15
4	1.05	29.10	0.30	41.40
5	0.80	33.00	0.75	32.30
6	0.90	81.15	1.20	38.90
7	1.05	60.10	0.95	42.85
8	0.20	62.35	0.50	34.85
9	1.70	90.00	1.25	52.43

Table 3.18.4 ANOVA of ammonia-nitrogen in selected stations of Cochin estuary during 2009-11 period

Source	**df**	**Mean Square**	**F**
Model	37	391.591	3.023
Season	2	799.880	6.176**
Station	8	1049.806	8.105**
Surface water, Bottom water	1	78.192	0.604
Season * Station	16	230.737	1.782**
Station * Surface water, Bottom water	8	87.347	0.674
Season * Surface water, Bottom water	2	10.955	0.085
Error	394	129.518	
Total	432		
R^2= 0.221			

**Variation is significant at 1% level

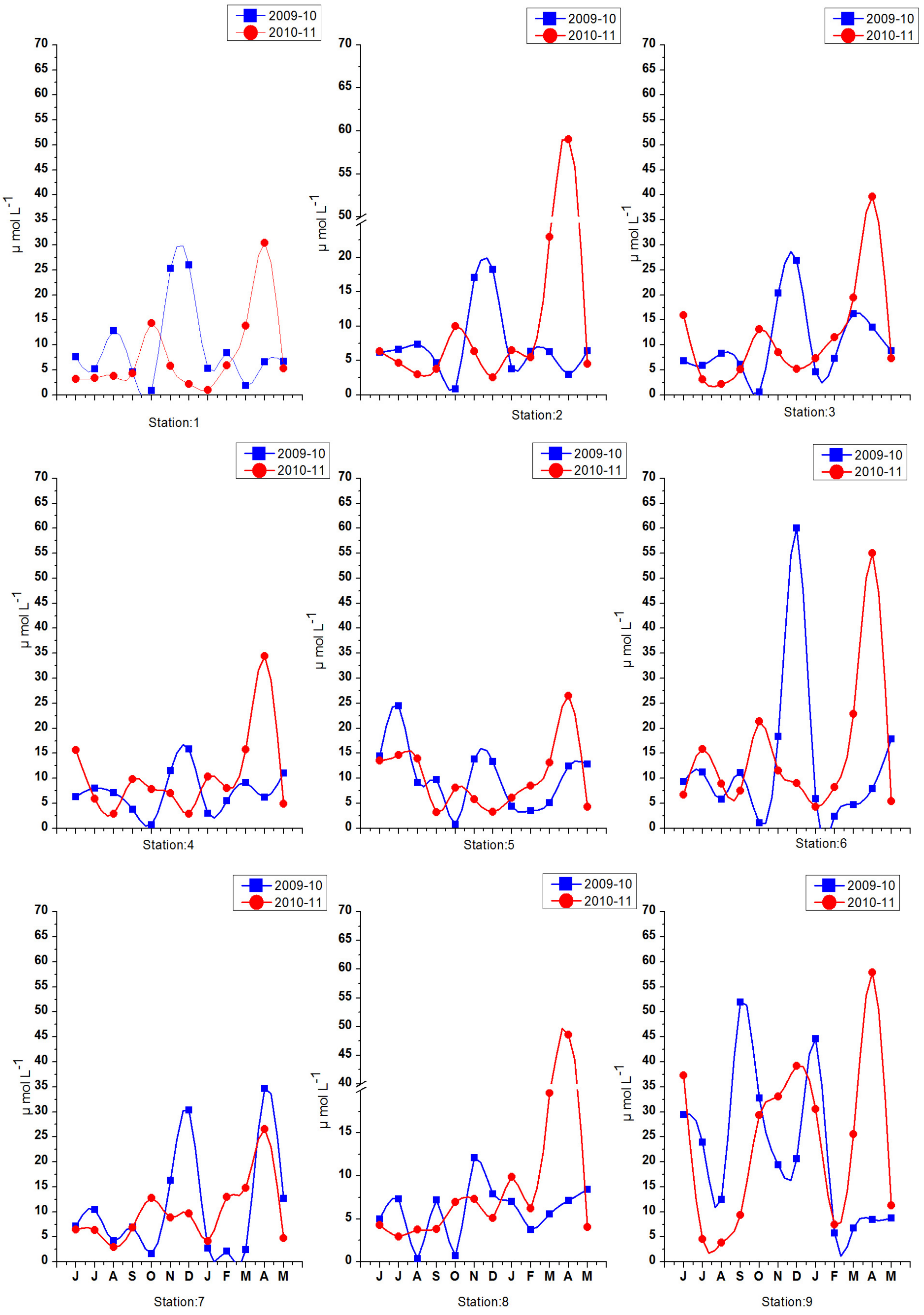


Fig. 3.18. Mean monthly variation of ammonia- nitrogen in selected stations of Cochin estuary during 2009-11 period

3.4.3.8 Nitrite-nitrogen

The average nitrite-nitrogen of the estuary was 0.72 ± 0.43 µmol L^{-1}. The nitrite-nitrogen content of the bottom waters was higher in most of the stations. Mean station-wise values ranged from 0.43 ± 0.26 µmol L^{-1} at station 8 to 1.10 ± 0.26 µmol L^{-1} at station 3. The nitrite-nitrogen was higher in the southern zone of the estuary (1.07 ± 0.29 µmol L^{-1}). The station wise comparison of nitrite-nitrogen in the central zone showed the highest (0.89 µmol L^{-1}) at station 4 and the lowest (0.64 µmol L^{-1}) at station 5. In the southern zone, the maximum and minimum were 1.10 µmol L^{-1} at station 3 and 1.04 µmol L^{-1} at station 2. In the northern zone, the nitrite-nitrogen concentration ranged from 0.43 µmol L^{-1} at station 8 to 0.61 µmol L^{-1} at station 9.

It was higher during the pre-monsoon period (1.01 ± 0.28 µmol L^{-1}) and lower during the post-monsoon period (0.45 ± 0.28 µmol L^{-1}). The range of nitrite-nitrogen concentration during the monsoon period was from 0.06 µmol L^{-1} in July 2009 at station 6, to 2.16 µmol L^{-1} in July 2009 at station 4. During the post-monsoon period, the highest value of 1.37 µmol L^{-1} was found in November 2009 at station 3 and the lowest of 0.05 µmol L^{-1} was observed in November 2009 at station 3. In the pre-monsoon period, the nitrite-nitrogen concentration values ranged from 0.02 µmol L^{-1} in May 2010 at station 7 to 6.06 µmol L^{-1} in March 2010 at station 3.

The annual distribution of nitrite-nitrogen showed that it was higher during the 2009-10 periods (0.79 ± 0.50 µmol L^{-1}) than the 2010-11 periods (0.65 ± 0.37 µmol L^{-1}). During 2009-10 periods the highest value of 1.91 µmol L^{-1} was observed in March 2010 and the lowest of 0.19 µmol L^{-1} was observed in May 2010. In 2010-11 periods, the highest value of 1.51 µmol L^{-1} was recorded in April 2011and the lowest of 0.36 µmol L^{-1} was in July 2010 (Table 3.19.1).

The variations between seasons ($p \leq 0.001$), between stations ($p \leq 0.001$) and between seasons and stations ($p \leq 0.001$) were significant at 1% level (Table 3.19.4).

Table 3.19.1 Mean monthly variation of nitrite-nitrogen in selected stations of Cochin estuary during 2009-11period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	1.22	1.13	1.08	1.15	0.79	0.47	0.63	0.54	0.95	0.89
J	1.98	1.90	1.83	2.16	0.57	0.06	0.22	0.29	0.60	1.07
A	1.36	1.18	1.05	1.06	1.30	1.09	1.00	0.97	1.00	1.11
S	0.33	0.30	0.37	0.25	0.51	0.27	0.68	0.37	1.27	0.48
O	0.77	0.05	0.20	0.10	0.15	0.33	0.57	0.64	0.31	0.35
N	0.72	0.40	1.37	0.69	0.43	0.61	0.38	0.26	0.32	0.58
D'09	0.36	0.59	0.56	0.60	0.76	0.79	0.66	0.38	0.49	0.58
J'10	0.65	0.62	0.46	0.55	0.34	0.39	0.33	0.33	0.84	0.50
F	0.36	0.50	0.86	0.57	0.29	0.37	0.38	0.33	0.17	0.42
M	2.00	4.32	6.06	1.68	1.24	0.61	0.54	0.34	0.43	1.91
A	2.29	3.18	1.78	2.91	0.64	0.47	0.57	0.22	0.32	1.37
M	0.20	0.14	0.22	0.07	0.25	0.25	0.02	0.26	0.35	0.19
J	0.94	1.37	1.43	0.96	0.91	0.31	0.26	0.12	1.53	0.87
J	0.36	0.33	0.37	0.41	0.63	0.54	0.18	0.23	0.21	0.36
A	0.37	0.42	0.29	0.46	0.61	0.39	0.51	0.23	0.14	0.38
S	0.26	0.32	0.36	0.33	0.39	0.60	0.46	0.32	0.45	0.39
O	0.63	0.41	0.65	0.48	0.42	0.53	0.48	0.40	0.49	0.50
N	0.31	0.31	0.42	0.33	0.34	0.43	0.41	0.41	0.83	0.42
D'10	0.15	0.20	0.28	0.31	0.29	0.40	0.32	0.55	1.11	0.40
J'11	0.16	0.33	0.32	0.20	0.31	0.37	0.42	0.29	0.89	0.36
F	1.21	2.03	2.23	1.31	0.60	0.42	0.38	0.29	0.32	0.98
M	1.14	1.77	1.64	1.55	1.05	0.58	0.46	0.69	0.50	1.04
A	1.81	2.49	2.16	2.79	1.69	0.65	0.49	1.20	0.37	1.51
M'11	0.39	0.78	0.55	0.55	0.86	0.67	0.52	0.59	0.82	0.63

Table 3.19.2 Mean seasonal variation of nitrite-nitrogen in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	1.22±0.68	0.48±0.31	0.63±0.18	0.31±0.22	1.21±1.09	1.14±0.58
2	1.13±0.65	0.61±0.51	0.41±0.26	0.31±0.09	2.03±2.04	1.77±0.72
3	1.08±0.60	0.61±0.55	0.65±0.51	0.42±0.16	2.23±2.63	1.64±0.78
4	1.15±0.78	0.54±0.29	0.48±0.26	0.33±0.12	1.31±1.26	1.55±0.93
5	0.79±0.36	0.64±0.21	0.42±0.25	0.34±0.06	0.60±0.46	1.05±0.46
6	0.47±0.44	0.46±0.13	0.53±0.21	0.43±0.07	0.42±0.15	0.58±0.11
7	0.63±0.32	0.35±0.16	0.48±0.15	0.41±0.07	0.38±0.25	0.46±0.06
8	0.54±0.30	0.23±0.08	0.40±0.17	0.41±0.10	0.29±0.06	0.69±0.38
9	0.95±0.28	0.58±0.64	0.49±0.25	0.83±0.26	0.32±0.11	0.50±0.23

Table 3.19.3Mean station wise variation of nitrite-nitrogen (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.10	2.06	0.08	2.70
2	0.02	4.45	0.08	4.18
3	0.12	4.94	0.23	7.17
4	0.10	3.56	0.04	2.60
5	0.06	1.46	0.16	1.92
6	0.04	1.07	0.06	1.11
7	0.02	0.97	0.02	1.03
8	0.12	0.93	0.12	1.94
9	0.12	1.48	0.04	2.37

Table 3.19.4 ANOVA of nitrite-nitrogen in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	2.129	5.400
Season	2	10.912	27.669**
Station	8	3.165	8.026**
Surface water, Bottom water	1	0.368	0.932
Season * Station	16	1.902	4.824**
Station * Surface water, Bottom water	8	0.103	0.260
Season * Surface water, Bottom water	2	0.006	0.016
Error	394	0.394	
Total	432		
R^2= 0.336			

** 1% level of Significance

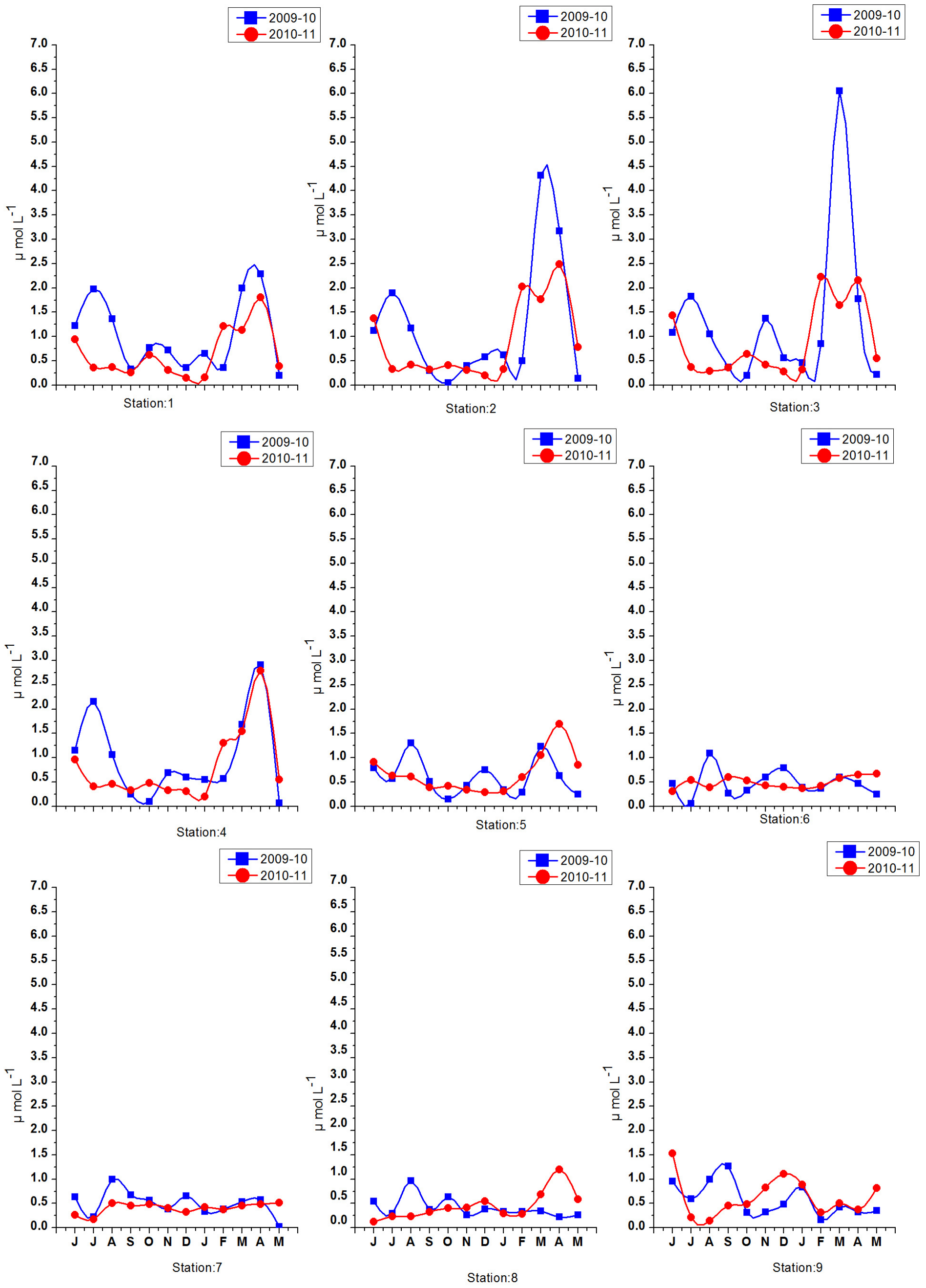


Fig. 3.19. Mean monthly variation of nitrite- nitrogen in selected stations of Cochin estuary during 2009-11 period

3.4.3.9 Nitrate-nitrogen

The average nitrate-nitrogen of the estuary was 13.12 ± 10.54 µmol L^{-1}. The nitrate -nitrogen content of the bottom waters was higher in most of the stations. Mean station-wise values of nitrate-nitrogen ranged from 9.84 ± 2.24 µmol L^{-1} at station 1 to 16.16 ± 2.24 µmol L^{-1} at station 9. The nitrate-nitrogen values were higher in the southern zone (13.40 ± 0.24µmol L^{-1}) of the estuary and lower in the northern zone (12.92 ± 0.24 µmol L^{-1}). In the central zone, the nitrate – nitrogen concentration was highest (16.15 µmol L^{-1}) at station 4 and lowest (9.85 µmol L^{-1}) at station 1. The maximum concentration of 14.25 µmol L^{-1} was observed at station 3 and minimum value of 12.56 µmol L^{-1} was observed at station 2 in the southern zone. In the northern zone, the values ranged from 10.13 µmol L^{-1} at station 6 to 16.16 µmol L^{-1} at station 9.

It was higher during the monsoon period (22.42 ± 8.49 µmol L^{-1}) compared to the other seasons. During the monsoon period, the highest nitrite-nitrogen concentration of 71.61 µmol L^{-1} was recorded in August 2009 at station 4 and the lowest value of 0.77 µmol L^{-1} was recorded in September 2010 at station 8 and 9. In the post-monsoon period, the values ranged from 0.05 µmol L^{-1} in October 2009 at station 2 to 1.37 µmol L^{-1} in November 2009 at station 3. During the pre-monsoon period, the maximum concentration of phosphate-phosphorus 18.82 µmol L^{-1} was found in March 2010 at station 3 and the minimum concentration of 0.46 µmol L^{-1} was recorded in April 2010 at station 6.

The average monthly nitrate-nitrogen values ranged from 0.46 µmol L^{-1} at station 6 in April 2010 to 71.61µmol L^{-1} at station 4 in August 2009.

The mean annual values of nitrate-nitrogen was higher during the 2009-10 period (15.99 ± 12.39 µmol L^{-1}) compared to the 2010-11 period (10.25 ± 7.78 µmol L^{-1}). In 2009-10 period, the nitrate-nitrogen concentration ranged from 4.73 µmol L^{-1} in January 2010 to 39µmol L^{-1} in July 2009. In the 2010-11 period, the values ranged from 2.35 µmol L^{-1} in December 2010 to 27.57 µmol L^{-1} in July 2010 (Table 3.20.1).

ANOVA result of nitrate-nitrogen was significant at 1% level between seasons ($p \leq 0.001$) and was significant at 5% level of significance between stations ($p \leq 0.05$) and between seasons and stations ($p \leq 0.05$) (Table 3.20.4).

Table 3.20.1 Mean monthly variation of nitrate-nitrogen in selected stations of Cochin estuary during 2009-11period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	12.24	25.35	23.31	42.54	30.70	25.04	33.46	27.08	31.72	27.94
J	25.86	27.08	41.00	50.34	39.78	44.98	53.40	50.34	18.21	39.00
A	2.60	41.62	20.50	71.61	42.69	18.06	31.52	18.82	57.23	33.85
S	8.27	7.34	8.42	5.67	9.64	12.09	15.46	12.09	19.74	10.97
O	19.89	23.26	21.42	18.97	19.89	11.02	4.59	5.21	29.53	17.09
N	18.67	15.91	33.82	21.42	20.81	21.73	21.12	33.35	43.76	25.62
D'09	9.39	5.51	9.79	11.17	11.17	7.50	6.43	5.66	6.27	8.10
J'10	5.82	3.83	9.34	4.90	7.04	2.91	0.92	2.91	4.90	4.73
F	7.96	4.90	8.57	11.79	5.21	5.82	7.96	4.44	5.82	6.94
M	5.05	13.13	18.82	9.03	2.45	2.60	2.76	0.77	3.37	6.44
A	7.96	7.19	14.08	10.41	8.87	0.46	3.06	2.76	1.07	6.20
M	10.41	9.18	1.21	8.26	4.13	1.38	3.83	5.36	1.23	5.00
J	14.23	11.48	11.48	15.45	9.79	7.80	8.11	12.40	28.77	13.28
J	14.08	21.66	22.36	25.40	36.88	19.38	31.37	39.65	37.34	27.57
A	9.18	19.89	27.54	12.09	20.50	19.59	27.02	29.07	34.73	22.18
S	7.50	5.36	3.52	5.05	6.27	6.58	5.36	0.77	0.77	4.57
O	13.44	12.13	18.59	14.11	14.73	10.79	8.26	11.78	21.11	13.88
N	7.23	6.80	9.82	8.63	7.15	5.99	7.85	10.06	12.54	8.45
D'10	2.45	1.99	2.15	2.60	1.38	1.53	2.30	5.86	0.92	2.35
J'11	5.81	6.28	8.72	9.18	5.36	5.66	13.01	12.55	15.61	9.13
F	7.84	8.60	10.67	9.87	5.16	2.56	4.40	3.33	2.87	6.14
M	7.05	7.92	6.87	7.27	5.34	3.05	3.86	3.97	3.30	5.40
A	9.03	10.87	7.04	9.18	5.82	4.13	3.98	7.35	5.97	7.04
M'11	4.28	4.29	2.91	2.76	5.05	2.45	3.21	1.23	1.07	3.03

Table 3.20.2 Mean seasonal variation of nitrate-nitrogen in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	12.24±9.90	11.25±3.43	13.44±6.91	7.23±4.60	7.84±2.19	7.05±2.02
2	25.35±14.05	14.59±7.59	12.13±9.15	6.80±4.15	8.60±3.49	7.92±2.73
3	23.31±13.45	16.22±10.79	18.59±11.59	9.82±6.76	10.67±7.57	6.87±3.17
4	42.54±27.48	14.50±8.46	14.11±7.54	8.63±4.72	9.87±1.56	7.27±3.20
5	30.70±14.94	18.36±13.75	14.73±6.72	7.15±5.60	5.16±2.72	5.34±0.34
6	25.04±14.31	13.34±7.12	10.79±8.01	5.99±3.79	2.56±2.34	3.05±0.77
7	33.46±15.55	17.96±13.14	8.26±8.87	7.85±4.38	4.40±2.41	3.86±0.49
8	27.08±16.67	20.47±17.28	11.78±14.43	10.06±2.99	3.33±2.02	3.97±2.54
9	31.72±18.04	25.40±16.81	21.11±18.86	12.54±8.52	2.87±2.23	3.30±2.02

Table 3.20.3 Mean station wise variation of nitrate-nitrogen (minimum- maximum)in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.92	24.79	1.22	26.93
2	1.22	67.63	0.31	27.23
3	0.28	36.41	2.14	45.59
4	1.53	61.20	0.61	82.01
5	1.22	41.00	1.22	58.14
6	0.31	36.41	0.61	53.55
7	0.61	53.24	0.31	53.55
8	0.61	50.80	0.61	49.88
9	0.61	47.12	0.61	82.01

Table 3.20.4 ANOVA of nitrate-nitrogen in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	721.845	6.307
Season	2	10384.365	90.728**
Station	8	241.591	2.111*
Surface water, Bottom water	1	106.634	0.932
Season * Station	16	220.377	1.925*
Station * Surface water, Bottom water	8	28.954	0.253
Season * Surface water, Bottom water	2	71.252	0.623
Error	394	114.456	
Total	432		
R^2= 0.372			

*Variation is significant at 5% level

** Variation is significant at 1% level

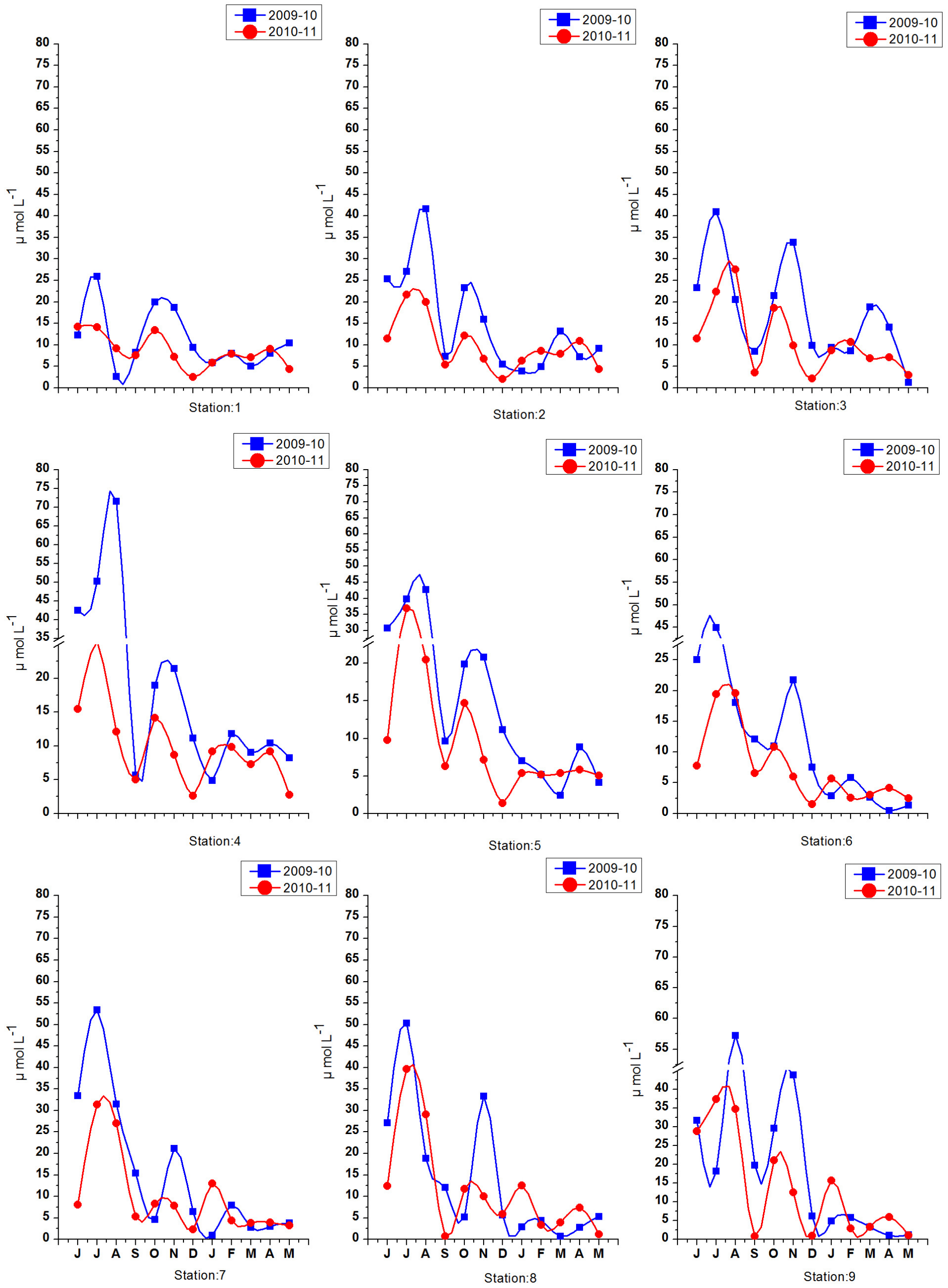


Fig.3.20. Mean monthly variation of nitrate-nitrogen in selected stations of Cochin estuary during 2009-11 period

3.4.3.10 Phosphate-phosphorus

Comparatively higher content of phosphate-phosphorus was observed in the bottom waters as compared to the surface waters. The average phosphate-phosphorus of the estuary was 7.38 ± 8.18 µmol L^{-1}. Mean station wise values were observed to be highest at station 9 (11.85 ± 1.79 µmol L^{-1}) and lowest at station 1 (5.96 ± 1.79 µmol L^{-1}). The phosphate-phosphorus was higher in the northern zone of the estuary (8.23 ± 0.88 µmol L^{-1}). In the central zone, the range of phosphate-phosphorus was high (7.65 µmol L^{-1}) at station 5 and low (5.96 µmol L^{-1}) at station 1. In the central zone, the maximum value of 7.59 µmol L^{-1} was recorded at station 3 and the minimum value of 6.32 µmol L^{-1} was observed at station 2. The phosphate-phosphorus concentration values ranged from 6.81 µmol L^{-1} at station 7 to 11.85 µmol L^{-1} at station 9 in the northern zone of the estuary.

Phosphate-phosphorus showed a threefold increase during the pre-monsoon period (12.22 ± 4.19 µmol L^{-1}) in comparison with the post-monsoon period (5.10 ± 4.19 µmol L^{-1}) and monsoon period (4.83 ± 4.19 µmol L^{-1}). During the monsoon period, the highest concentration of phosphate-phosphorus 18.60 µmol L^{-1} was recorded in August 2009 at station 8 and the lowest of 0.37 µmol L^{-1} was found in June 2010 at station 8. In the post-monsoon period, the values ranged from 0.35 µmol L^{-1} in January 2011 at station 1 to 35.84 µmol L^{-1} in October 2009 at station 9. In the pre-monsoon period, the values ranged from 0.13 µmol L^{-1} in April 2010 at station 1 to 44.27 µmol L^{-1} in February 2010 at station 2.

Mean monthly variation ranged from 44.27µmol L^{-1} in February 2010 to 0.13 µmol L^{-1} in April 2010 (Table 3.21.1 and Fig.3.21). The inter-annual variation showed that it was higher (9.26 µmol L^{-1}) during the 2009-10 period compared to the 2010-11 period (5.51 µmol L^{-1}). The range of maximum and minimum values during 2009-10 period was 0.99 µmol L^{-1} in April 2010 to 38.41 µmol L^{-1} in February 2010. During 2010-11 period, the concentration values ranged from 1.21 µmol L^{-1} in January 2011 to 17.08 µmol L^{-1} in February 2011.

Phosphate variations were significant at 1% level between seasons ($p \leq 0.001$) (Table 3.21.4).

Table 3.21.1 Mean monthly variation of phosphate-phosphorus in selected stations of Cochin estuary during 2009-11period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	3.55	3.97	4.91	4.11	3.36	3.83	3.06	2.00	15.64	4.94
J	1.70	2.99	3.14	4.26	2.07	2.50	2.63	0.71	11.48	3.50
A	4.39	4.00	4.69	4.43	2.33	3.55	3.06	2.74	18.60	5.31
S	4.56	4.93	6.90	3.66	5.70	5.44	3.49	2.56	16.84	6.01
O	4.99	5.34	4.28	7.55	7.22	4.28	4.93	4.93	35.84	8.82
N	5.19	3.96	7.08	4.73	3.77	5.76	2.91	3.38	10.28	5.23
D'09	4.15	5.38	4.67	4.19	4.28	4.22	4.80	3.87	10.73	5.14
J'10	3.42	3.16	4.19	3.96	3.31	3.87	2.97	3.08	6.35	3.81
F	39.88	44.27	40.57	38.53	37.44	43.50	36.64	37.31	27.52	38.41
M	7.01	10.19	17.20	1.49	40.42	23.46	38.38	35.60	36.47	23.36
A	0.93	1.14	2.97	1.01	0.69	0.76	0.90	0.39	0.13	0.99
M	7.05	2.13	5.16	2.86	6.95	12.43	6.37	3.38	3.96	5.59
J	2.56	3.81	8.71	5.07	1.74	0.91	0.63	0.37	3.42	3.02
J	4.17	3.94	5.72	7.74	5.27	4.52	1.38	6.34	2.90	4.66
A	11.51	7.53	6.80	8.80	9.23	4.39	2.14	1.81	5.59	6.42
S	4.65	4.95	4.82	4.65	4.26	4.61	4.39	3.72	7.19	4.80
O	4.44	4.46	5.05	5.11	4.64	4.53	3.90	3.81	15.80	5.75
N	2.88	3.99	4.97	4.61	3.23	3.83	3.42	5.64	7.44	4.45
D'10	3.87	6.15	7.33	7.85	4.05	5.59	5.48	11.89	5.23	6.38
J'11	0.35	1.36	2.52	0.86	1.01	1.38	0.89	1.21	1.29	1.21
F	13.72	14.43	16.48	10.97	21.37	20.03	20.57	19.17	17.02	17.08
M	5.45	6.00	7.61	4.68	8.16	8.12	7.77	7.86	10.44	7.34
A	1.47	1.06	2.97	1.60	1.47	2.54	1.51	2.63	1.94	1.91
M'11	1.16	2.52	3.40	1.49	1.64	1.79	1.23	1.79	12.36	3.04

Table 3.21.2 Mean seasonal variation of phosphate-phosphorus in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	3.55±1.31	5.72±3.96	4.44±0.81	2.89±1.81	13.72±17.68	5.45±5.85
2	3.97±0.79	5.06±1.73	4.46±1.09	3.99±1.98	14.43±20.30	6.00±5.99
3	4.91±1.54	6.51±1.67	5.06±1.37	4.97±1.96	16.48±17.24	7.62±6.27
4	4.12±0.33	6.57±2.02	5.11±1.66	4.61±2.88	10.97±18.39	4.69±4.44
5	3.37±1.65	5.13±3.11	4.65±1.76	3.23±1.59	21.38±20.47	8.16±9.34
6	3.83±1.22	3.61±1.80	4.53±0.84	3.83±1.79	20.04±18.18	8.12±8.43
7	3.06±0.35	2.14±1.62	3.90±1.11	3.42±1.90	20.57±19.70	7.77±9.05
8	2.00±0.92	3.06±2.58	3.82±0.81	5.64±4.55	19.17±20.01	7.86±8.00
9	15.64±3.03	4.78±1.99	15.80±13.50	7.44±6.13	17.02±17.74	10.44±6.30

Table 3.21.3 Mean station wise variation of phosphate-phosphorus (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.09	42.31	0.60	37.45
2	0.47	41.97	1.29	46.57
3	2.84	38.83	1.51	42.31
4	1.03	42.31	0.69	34.74
5	0.69	40.25	0.34	48.38
6	0.52	20.03	0.22	70.39
7	0.52	39.43	0.73	42.66
8	0.30	33.88	0.43	42.66
9	0.04	38.44	0.22	36.94

Table 3.21.4 ANOVA of phosphate-phosphorus in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	206.228	2.547
Season	2	2525.147	31.184**
Station	8	154.087	1.903
Surface water, Bottom water	1	10.802	0.133
Season * Station	16	62.694	0.774
Station * Surface water, Bottom water	8	31.947	0.395
Season * Surface water, Bottom water	2	38.985	0.481
Error	394	80.976	
Total	432		
R^2= 0.193			

** Variation is significant at 1% level

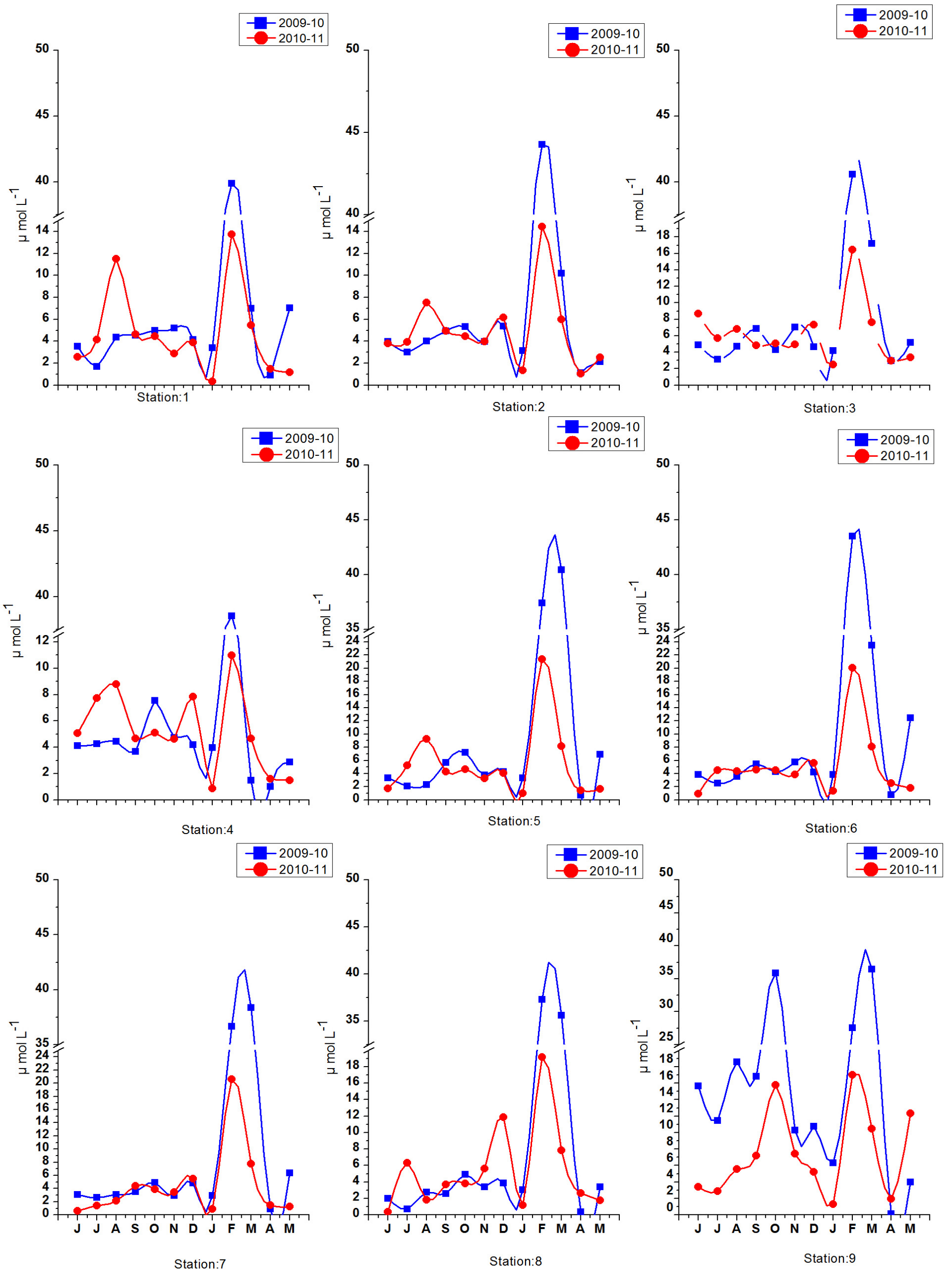


Fig.3.21. **Mean monthly variation of phosphate-phosphorus in selected stations of Cochin estuary during 2009-11 period**

3.4.3.11 Silicate-silicon

The average value of silicate-silicon in the Cochin estuary was 32.53 ± 11.82 µmol L^{-1}. Mean station wise values ranged from 41.83 µmol L^{-1} (station 8) to 22.71 µmol L^{-1} (station 1). At most stations, the surface water contains more silicate than the bottom water. In the central zone, the silicate-silicon concentration was higher at station 5 (34.66 µmol L^{-1}) and lower at station 1 (22.71 µmol L^{-1}). In the central zone, the maximum concentration of 31.94 µmol L^{-1} was recorded at station 3 and minimum concentration of 28.85 µmol L^{-1} was observed at station 2. In the northern zone, the values ranged from 26.61 µmol L^{-1} at station 9 to 41.83 µmol L^{-1} at station 8.

Silicate-silicon values were found to be higher during the monsoon period (37.50 ± 4.32 µmol L^{-1}), which may be due to the heavy land runoff. During the monsoon period, the highest silicate-silicon concentration of 83.37 µmol L^{-1} was observed in July 2009 at station 4 and the lowest value of 1.44 µmol L^{-1} was recorded in July 2010 at station 7. In the post-monsoon period the silicate-silicon values ranged from 9.5 µmol L^{-1} in January 2011 at station 1 to 78.4 µmol L^{-1} in November 2009 at station 8. In the pre-monsoon period, the values ranged from 12.81 µmol L^{-1} in April 2011 at station 1 to 62.78 µmol L^{-1} in May 2010 at station 6.

Mean monthly values showed maximum (83.07 µmol L^{-1}) in July 2009 at station 4 and minimum (1.44 µmol L^{-1}) in July 2010 at station 7. Silicate-silicon values were higher (37.36 ± 10.99 µmol L^{-1}) during the 2009-10 period. During 2009-10 period, the silicate-silicon values ranged from 21.34 µmol L^{-1} in December 2009 to 55.37 µmol L^{-1} in July 2009. In

2010-11 period, the values ranged from 4.88 µmol L^{-1} in July 2010 to 51.67 µmol L^{-1} in August 2010 (Table 3.22.1).

ANOVA result of silicate showed that it was significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.001$) and between seasons and stations ($p \leq 0.001$) (Table 3.22.4).

Table 3.22.1 Mean monthly variation of silicate-silicon in Cochin estuary during 2009-11period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	40.65	53.96	59.11	62.51	58.50	45.64	38.27	47.15	20.50	47.37
J	49.48	58.01	59.25	83.37	59.38	57.94	49.19	58.10	23.63	55.37
A	33.64	52.95	71.76	62.33	58.75	38.16	31.59	47.55	25.43	46.91
S	38.84	50.92	46.33	41.83	57.38	40.82	34.05	35.80	12.45	39.82
O	20.41	19.18	24.08	30.74	28.02	34.88	69.46	63.05	41.79	36.85
N	24.46	38.84	59.92	39.54	59.72	66.06	42.71	78.40	45.46	50.57
D'09	11.89	15.10	16.41	13.89	15.66	31.12	29.05	38.86	20.05	21.34
J'10	15.80	21.74	23.86	26.87	21.02	25.05	30.72	31.55	17.56	23.80
F	16.16	20.80	31.14	19.51	22.19	31.50	37.22	48.87	38.32	29.52
M	16.48	27.68	35.08	19.09	21.76	38.30	46.08	38.64	30.65	30.42
A	22.05	19.60	16.30	19.11	45.41	26.76	21.94	44.58	39.63	28.38
M	22.33	26.33	34.11	29.12	37.38	62.78	52.54	45.75	31.87	38.02
J	16.38	40.55	25.61	30.65	56.95	38.77	25.02	33.21	11.93	31.01
J	4.37	4.12	5.99	8.11	5.52	4.73	1.44	6.64	3.04	4.88
A	74.01	56.44	48.09	70.75	67.35	38.05	76.14	17.04	17.13	51.67
S	16.07	29.59	28.96	37.31	17.47	18.54	27.66	19.89	11.55	23.00
O	18.14	23.71	31.06	27.76	31.10	39.28	42.98	52.96	31.21	33.13
N	13.95	17.44	21.80	21.52	26.88	32.62	41.27	46.63	25.83	27.55
D'10	14.22	13.01	16.77	22.32	32.36	38.50	57.04	71.55	27.70	32.61
J'11	9.50	15.60	17.58	14.47	17.20	20.08	23.79	15.39	18.57	16.91
F	19.25	23.60	29.16	21.71	31.68	39.83	39.44	44.46	35.11	31.58
M	16.55	21.71	23.36	21.42	22.94	34.11	34.29	40.57	36.06	27.89
A	12.81	14.25	19.06	20.19	19.44	41.43	44.31	43.27	32.25	27.45
M'11	17.60	27.28	21.87	22.37	17.71	21.09	19.13	33.98	40.82	24.65

Table 3.22.2 Mean seasonal variation of silicate-silicon in selected stations of Cochin estuary during 2009-11 period

Stations	**Monsoon period**		**Post-monsoon period**		**Pre-monsoon period**	
	Mean ± SD		**Mean ± SD**		**Mean ± SD**	
	2009-10	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**
1	40.65±6.59	27.71±31.37	18.14±5.47	13.95±3.53	19.26±3.39	16.55±2.73
2	53.96±2.98	32.68±22.00	23.72±10.45	17.44±4.56	23.60±4.00	21.71±5.48
3	59.11±10.38	27.16±17.24	31.07±19.56	21.80±6.55	29.16±8.73	23.36±4.26
4	62.51±16.96	36.71±25.91	27.76±10.66	21.52±5.46	21.71±4.95	21.42±0.91
5	58.50±0.83	36.82±29.95	31.11±19.74	26.89±6.87	31.69±11.68	22.94±6.22
6	45.64±8.76	25.02±16.46	39.28±18.31	32.62±8.87	39.84±16.01	34.12±9.23
7	38.28±7.78	32.57±31.35	42.99±18.67	41.27±13.63	39.45±13.25	34.29±10.90
8	47.15±9.11	19.20±10.94	52.97±21.65	46.63±23.36	44.46±4.28	40.57±4.69
9	20.50±5.74	10.91±5.83	31.22±14.44	25.83±5.33	35.12±4.51	36.06±3.56

Table 3.22.3 Mean station wise variation of silicate-silicon (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	**Surface**		**Bottom**	
	Min	**Max**	**Min**	**Max**
1	5.85	70.43	2.88	77.58
2	3.60	64.53	4.64	56.07
3	7.74	80.91	4.23	74.66
4	9.41	62.51	6.80	109.31
5	8.15	76.73	2.88	67.50
6	2.84	70.11	6.62	62.01
7	0.99	130.50	1.89	67.95
8	6.48	88.34	6.80	71.55
9	3.92	49.28	2.16	52.20

Table 3.22.4 ANOVA of silicate-silicon in selected stations of Cochin estuary during 2009-11 period

Source	**df**	**Mean Square**	**F**
Model	37	1175.745	4.904
Season	2	2686.596	11.205**
Station	8	1685.255	7.029**
Surface water, Bottom water	1	437.276	1.824
Season * Station	16	1463.780	6.105**
Station * Surface water, Bottom water	8	85.557	0.357
Season * Surface water, Bottom water	2	52.557	0.219
Error	394	239.767	
Total	432		
R^2= 0.315			

** Variation is significant at 1% level

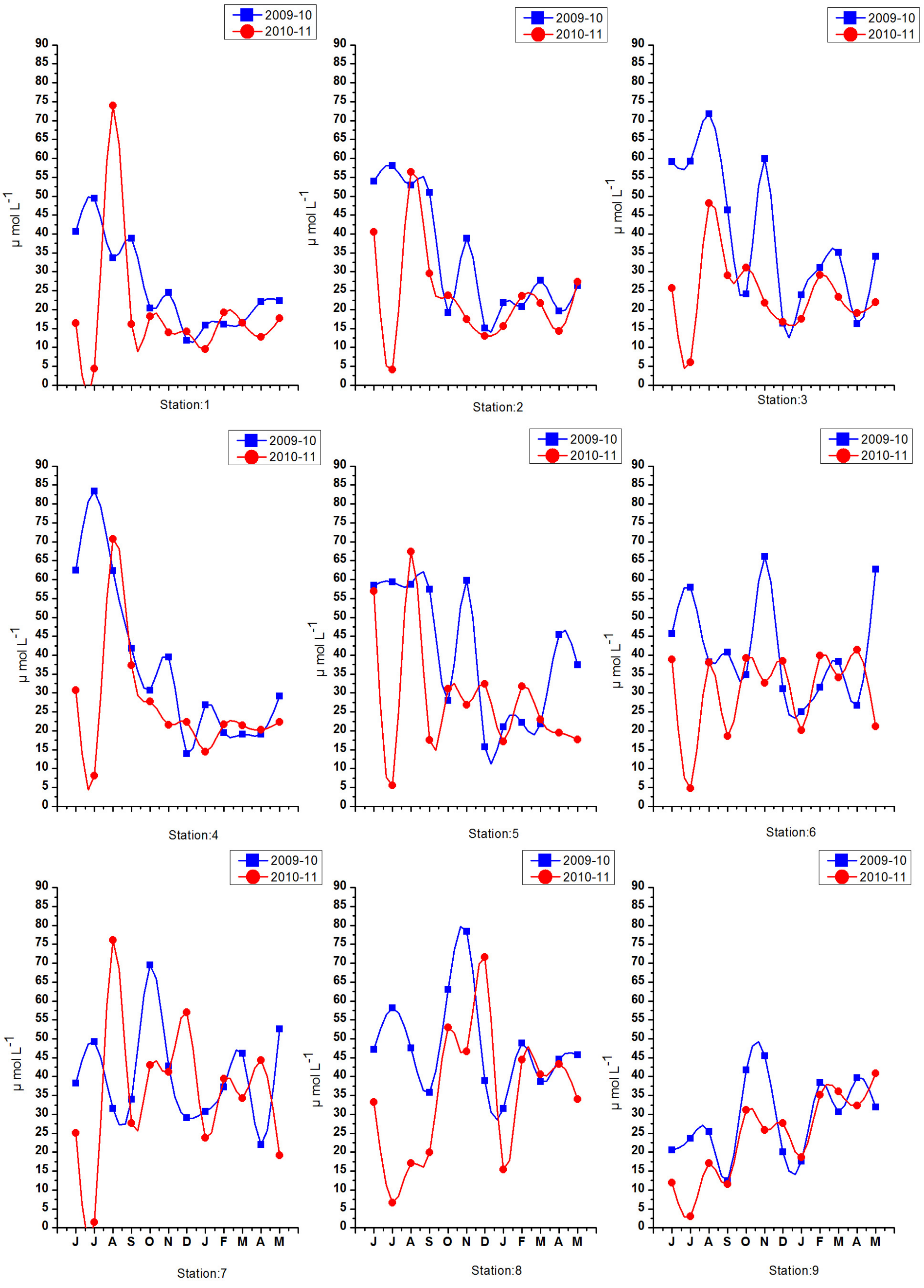


Fig. 3.22. Mean monthly variation of silicate-silicon in selected stations of Cochin estuary during 2009-11 period

3.4.3.12 Hydrogen Sulphide

The average sulphide concentration of the Cochin estuary was 20.84 µmol L^{-1}. The sulphide was found to be very high in the bottom waters of the estuary. Mean station-wise values ranged from 5.91 µmol L^{-1} at station 7 to 27.76 µmol L^{-1} in station 3. It was higher (22.77 ± 3.57 µmol L^{-1}) in the northern zone of the estuary and lower (16.40 ± 3.57 µmol L^{-1}) in the central zone of the estuary. In the central zone, the highest hydrogen sulphide concentration (23.41 µmol L^{-1}) was recorded at station 5 and the lowest (7 µmol L^{-1}) was observed at station 1. In the southern zone, the hydrogen sulphide concentration was higher (28.59 µmol L^{-1}) at station 3 compared to station 2 (18.19 µmol L^{-1}). In the northern zone, the sulphide values ranged from 6.41 µmol L^{-1} at station 7 to 68.12 µmol L^{-1} at station 6.

It was drastically high (50.18 ± 26.24 µmol L^{-1}) during the monsoon period. The season wise comparison of hydrogen sulphide in the study period showed nil values in all the seasons. In the monsoon period the highest value of 885.31 µmol L^{-1} was observed at station 6 in September 2010. The post-monsoon period recorded the highest value of 40.75 µmol L^{-1} in January 2010 at station 8. The pre-monsoon period showed the maximum (43.56 µmol L^{-1}) in April 2010 at station 7.

Mean monthly variation of sulphide ranged from zero to 885.31 µmolL^{-1} in September 2010 at station 6. It was higher (24.35 µmol L^{-1}) during the 2010-11 period. In 2009-10 periods the values ranged from zero in May 2010 to 64.72 in August 2009. In 2010-11 periods the range of hydrogen sulphide was 1.95 µmol L^{-1} in October 2010 to 108.98 µmol L^{-1} in September 2010 (Table 3.23.1 and Fig.3.23).

The variations of hydrogen sulphide between seasons was significant at 1% level whereas the interaction between seasons and stations ($p \leq 0.05$), and significant at 5% level between stations and surface and bottom waters ($p \leq 0.05$) and between seasons and surface and bottom waters ($p \leq 0.05$).

Table 3.23.1 Mean monthly variation of hydrogen sulphide in selected stations of Cochin estuary during 2009-11period

	Stations									
Months	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	7.73	33.26	58.79	41.45	45.44	152.94	0.00	8.43	6.56	39.40
J	6.32	101.88	147.55	98.37	113.83	3.51	0.00	1.41	0.00	52.54
A	12.65	0.00	24.59	18.27	11.24	449.68	1.41	28.11	36.54	64.72
S	4.22	2.81	4.22	8.43	11.24	7.03	9.84	4.22	4.22	6.25
O	7.03	8.43	8.43	4.22	4.22	4.22	7.03	4.22	2.81	5.62
N	12.65	0.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00	1.56
D'09	7.03	15.46	11.24	5.62	1.41	0.00	0.00	0.00	0.00	4.53
J'10	2.81	5.62	2.81	1.41	1.41	8.43	7.03	40.75	0.00	7.81
F	0.00	1.41	0.00	2.81	11.24	4.22	7.03	0.00	2.81	3.28
M	1.41	11.24	8.43	15.46	0.00	0.00	4.22	4.22	5.62	5.62
A	21.08	9.84	21.08	14.05	40.75	18.27	43.56	33.73	12.65	23.89
M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J	14.05	207.98	71.67	199.55	29.51	19.67	0.00	0.00	0.00	60.27
J	0.00	0.00	223.43	0.00	203.76	0.00	0.00	15.46	0.00	49.18
A	14.05	0.00	28.11	22.48	18.27	14.05	9.84	30.92	66.05	22.64
S	11.24	2.81	22.48	14.05	12.65	885.31	0.00	25.29	7.03	108.98
O	9.84	2.81	3.51	1.41	0.00	0.00	0.00	0.00	0.00	1.95
N	4.22	9.13	6.32	3.51	0.70	2.81	0.00	13.35	0.00	4.45
D'10	9.84	7.03	4.22	7.03	1.41	12.65	23.89	9.84	8.43	9.37
J'11	19.67	0.00	11.24	16.86	12.65	15.46	9.84	25.29	9.84	13.43
F	0.70	5.62	1.41	9.13	4.22	0.70	2.11	1.41	4.22	3.28
M	0.00	0.00	2.81	0.00	8.43	2.11	11.24	6.32	2.11	3.67
A	0.00	1.41	7.03	0.00	11.24	19.67	0.00	0.00	4.22	4.84
M'11	1.41	9.84	15.46	9.84	18.27	14.05	16.86	7.03	12.65	11.71

Table 3.23.2 Mean seasonal variation of hydrogen sulphidein selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean ± SD		Mean ± SD		Mean ± SD	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	7.73±3.58	9.84±6.69	5.62±5.50	9.84±8.03	5.27±10.54	0
2	34.49±47.39	52.70±103.53	3.51±4.22	2.46±3.32	4.92±5.79	3.86±4.78
3	58.79±63.32	86.07±94.24	2.81±3.97	4.74±4.71	7.38±9.96	6.67±6.32
4	41.45±39.95	59.02±94.14	1.41±1.99	5.97±7.98	8.08±7.81	4.74±5.48
5	45.44±48.36	62.53±90.84	1.41±1.99	3.51±6.13	13±19.25	10.36±6.16
6	152.94±209.84	229.76±437.11	3.16±4.04	7.03±8.19	5.27±8.77	8.43±10
7	2.46±4.92	2.46±4.92	3.51±4.06	8.43±11.30	11.59±21.32	7.03±7.87
8	10.19±12.43	17.21±13.79	11.24±19.77	8.78±11.94	9.49±16.28	2.99±3.55
9	11.83±16.69	24.36±36.27	0.70±1.41	4.57±5.30	3.86±6	3.34±6.22

Table 3.23.3 Mean station wise variation of hydrogen sulphide (minimum-maximum) in selected stations of Cochin estuary during 2009-11period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0	19.67	0	25.29
2	0	126.47	0	289.48
3	0	134.90	0	444.06
4	0	25.29	0	393.47
5	0	407.52	0	36.54
6	0	36.54	0	1770.62
7	0	33.73	0	64.64
8	0	61.83	0	44.97
9	0	56.21	0	75.88

Table 3.23.4 ANOVA of hydrogen sulphide in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	24479.761	2.520
Season	2	92688.702	9.542**
Station	8	17875.422	1.840
Surface water, Bottom water	1	31786.328	3.272
Season * Station	16	18241.823	1.878*
Station * Surface water, Bottom water	8	21600.300	2.224*
Season * Surface water, Bottom water	2	40456.246	4.165*
Error	394	9713.731	
Total	432		
R^2= 0.191			

* Variation is significant at 5% level

**Variation is significant at 1% level

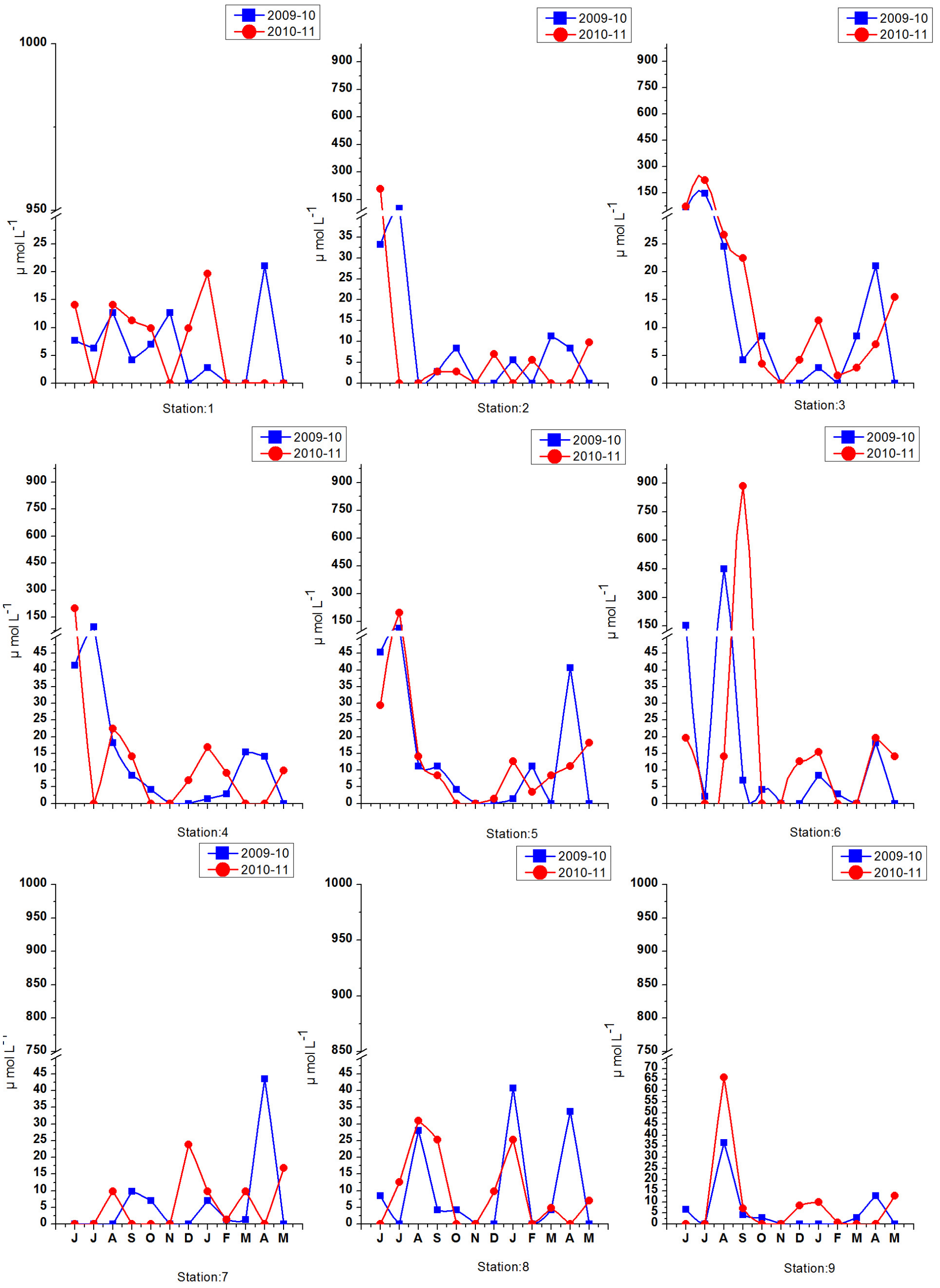


Fig. 3.23. Mean monthly variation of hydrogen sulphide in selected stations of Cochin estuary during 2009-11 period

3.4.4 Data analysis

3.4.4.1 Cluster analysis

The station wise dendrogram showed four clusters. The bottom waters of the first, second and fourth stations form a cluster, while the surface waters of these three stations form another cluster. These cluster formation is justified by the similar environmental conditions. The bottom water of station 6 was distinct compared to all the other stations. The surface waters of station 3 and 5 form a cluster and the bottom waters form another cluster. The solid line reflects significant differences between clusters and dotted line reflect no statistical evidence for the substructures within the group. The two solid lines in the dendrogram shows that the surface and bottom waters of the central and southern zones of the estuary forms one set of clusters, while the stations of the northern zone formed the other clusters.

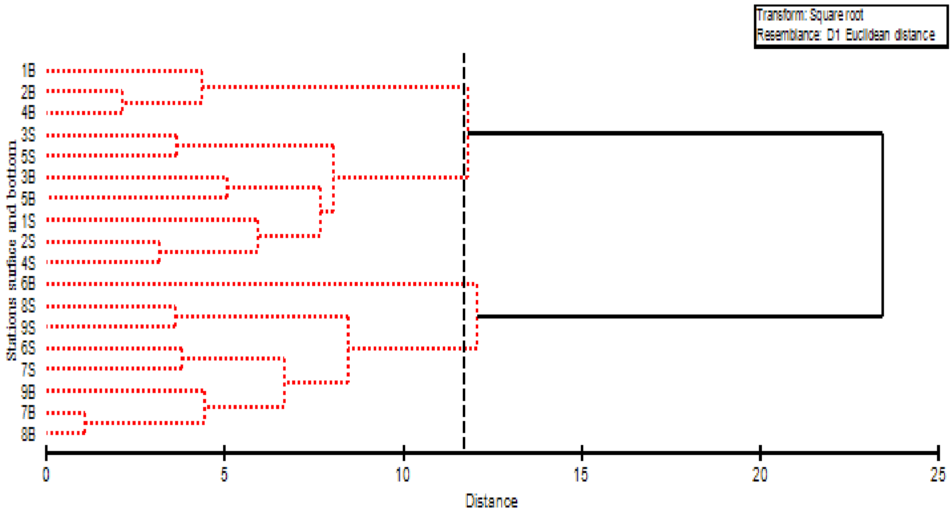


Fig. 3.24. Dendrogram showing mean station wise surface and bottom values of water quality parameters in Cochin estuary during 2009-11 period

Month wise water quality parameters of the Cochin estuary formed two clusters. The southwest monsoon months form a cluster, except June 2009. The post-monsoon period (summer) and pre-monsoon period (northeast monsoon period) form clusters together. The month wise variation of water quality parameters showed similarity in the pre-monsoon and post monsoon period.

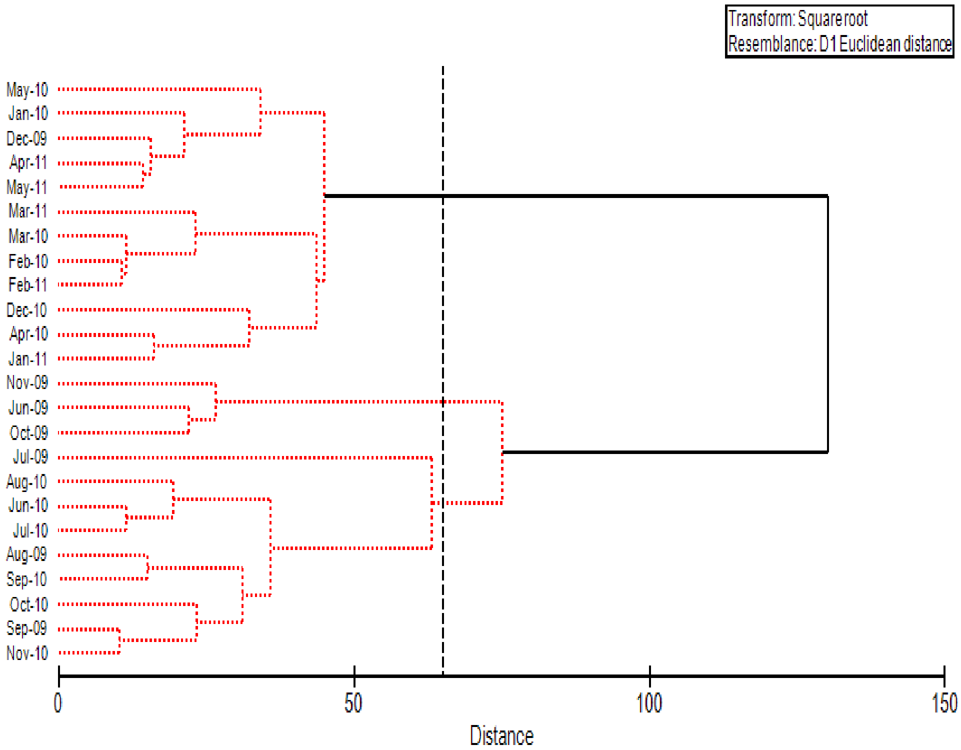
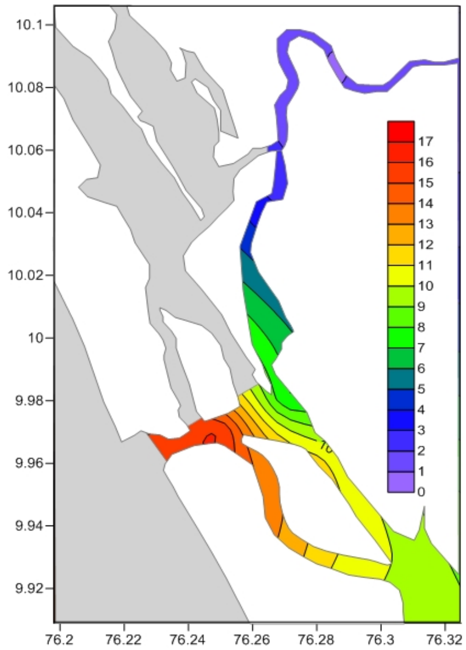
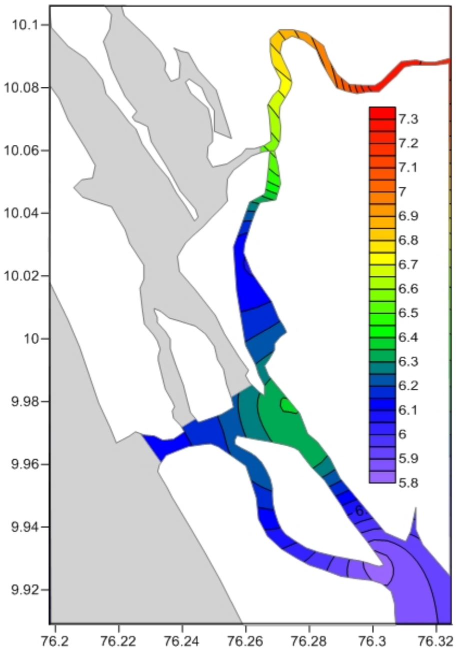


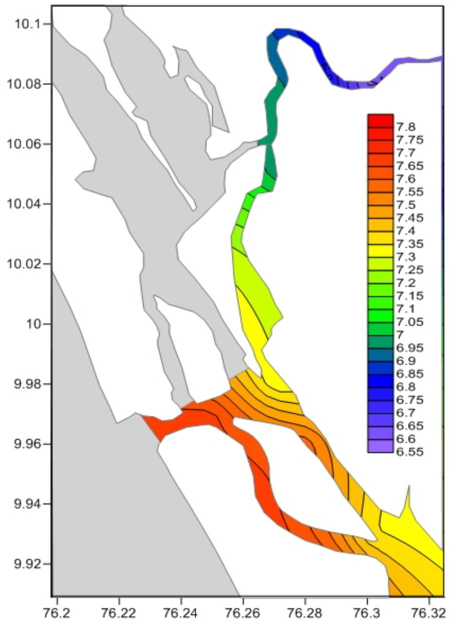
Fig. 3.25. Dendrogram showing mean monthly values of water quality parameters in Cochin estuary during 2009-11 period



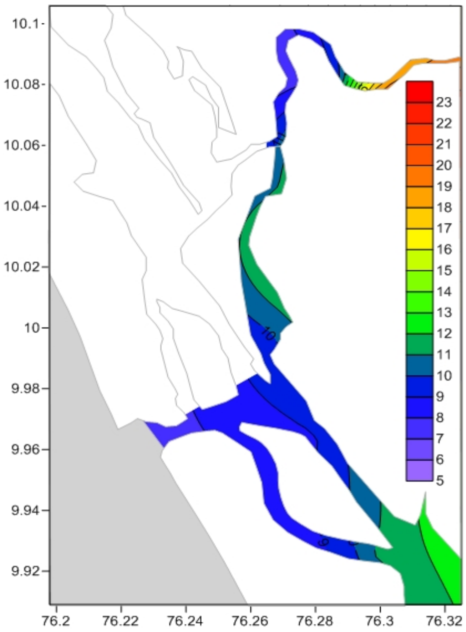
Salinity (ppt)



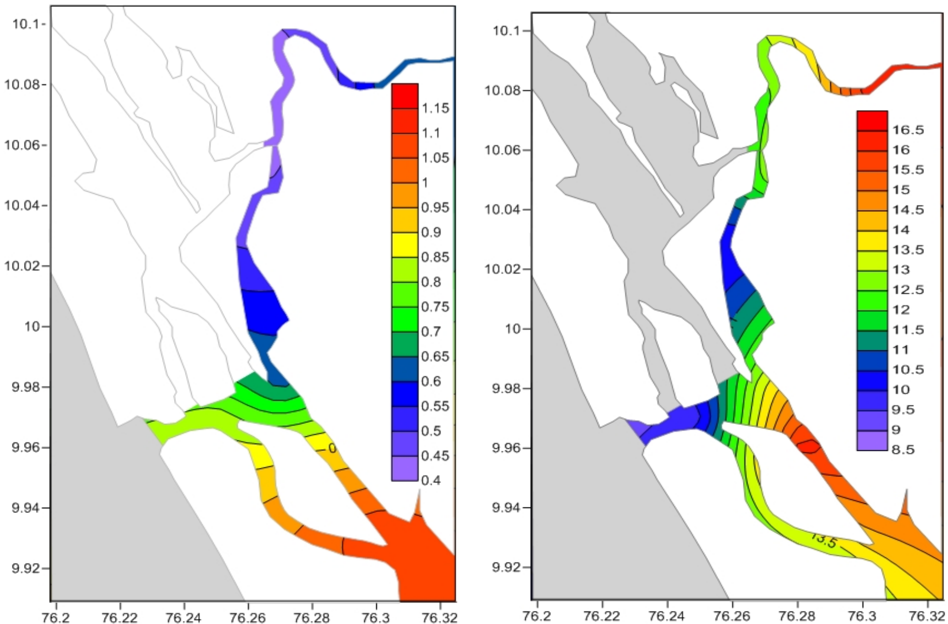
Dissolved oxygen (mg L^{-1})



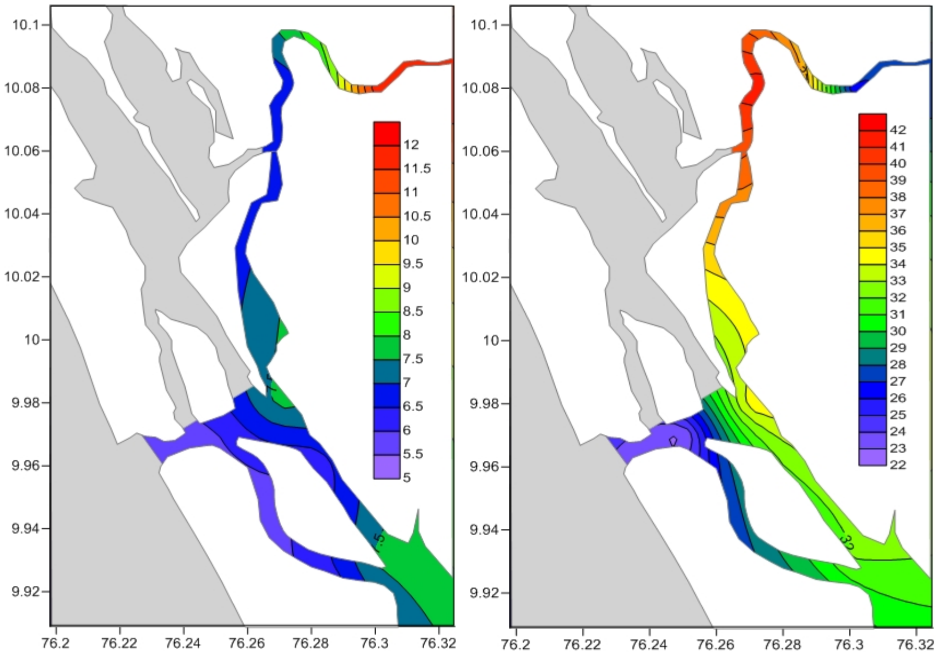
pH



$(NH_3^+\text{-}NH_4^+)\text{-}N(\mu mL^{-1})$



NO_2-N (µmL^{-1}) NO_3-N (µmL^{-1})



PO_4-P (µmL^{-1}) SiO_4-Si (µmL^{-1})

Fig. 3.26. Distribution of salinity, Dissolved oxygen, pH and dissolved nutrients in the Cochin estuary during the period 2009-11.

3.6 Discussion

Water is the primary medium for the transport of matter and energy in estuarine ecosystems. The composition of water varies considerably with varying local conditions. Freshwater enters the estuary either through precipitation or accumulation. The latter is driven by gravity, through streams and rivers travelling down slope to reach the estuary. Salt water enters the estuary from the sea via tidal forcing. The gradient of increasing salt concentration from freshwater to marine divides the estuary into zones of salt stress and subsequently into different pelagic systems (Jorgensen, 2009).

The mean annual rainfall and river discharge in the Cochin estuary showed that nearly 60-70% of all the rainfall occurs between June and September, while the least (6.82%) occurs between December and February. Annual precipitation in the seven rivers (Chalakudy, Periyar, Muvattupuzha, Achencoil, Pamba, Meenachil and Manimala) are which discharges into the Cochin estuary varied between 630 mm (Muvatupuzha river basin) and 916 mm (Meenachil river basin) (Revichandran et al., 2012). Josanto (1969) reported that the total rainfall in Cochin estuary area were 3502.66 and 3401.1mm in the years 1968 and 1969 respectively. The region received a mean annual precipitation of 3200 mm, based on an average of ten years from 1976-1993 (Balachandran, 2001; Qasim, 2003; Srinivas et al., 2004; Renjith, 2006). The average monthly rainfall for the years 1978-2002 at different physiographic zones of the river basin ranged from 0-3000 mm (Shivaprasad, et al., 2013b). The daily rainfall pattern in the Cochin estuary ranged from 0-120 mm day^{-1}

during the 2008-09 period, which is immediately prior to the period of this study (Vinitaet al., 2015). In the present study the total annual rainfall was higher during the 2010-11 period. Similar to the Cochin estuary, rainfall events have known to affect the salinity and nutrient distribution in the Obidos lagoon in Portugal (Pereira et al., 2009).The mean annual rainfall in the tropical and temperate estuaries are very similar. However larger runoff coefficients are observed in the temperate catchments (Eyre and Balls, 1999).

River discharge affects the geomorphology, salinity and turbidity of the estuaries, which in turn influences the distribution and abundance of fishes and other related food webs (Whitfield, 1996). During the peak monsoon period months, the discharge from southern rivers (Achancoil, Pamba, Manimala, Meenachil and Muvattupuzha) exceeds 3400 m^3s^{-1}, while the discharges from northern rivers (Periyar and Chalakudy) reach a value of 1500 $m^3\ s^{-1}$ (Josanto, 1969). Cochin estuary receives a freshwater input of 2×10^{10} $Mm^3\ yr^{-1}$from six rivers (Srinivas et al., 2003). A first order estimate of the annual drainage into the Cochin estuary can be obtained by summing up the annual discharge from the six rivers and the value arrived at is 22×10^3 $Mm^3\ yr^{-1}$(Revichandran et al., 2012). The highest annual river flow was recorded at Muvattupuzha and Pamba river basin. Mean monthly inflow into the Cochin estuary ranged from 49 m^3s^{-1} in March to 1000m^3s^{-1}in July (Vinita et al., 2015). River discharge and rainfall showed a positive correlation significant at 1% level (r^2= 0.899). The highly significant correlation between rainfall and river discharge might be due to the similar patterns of annual rainfall and the river runoff. In the present study mean annual rainfall and river discharge was high during 2010-11 period and the monthly values recorded the peak during monsoon and gradually declines during the pre-monsoon season. Balls et al. (1997) recorded that the mean annual flow of the Ythan estuary in Scotland is 6.96 m^3s^{-1}, which is a lower value compared to the Cochin estuary. The Devi estuary of the Mahanadi river basin in Orissa had the annual average rainfall of 1572 mm a peak discharge of 44,740 m^3 s^{-1} (Pradhan et al., 2009). The average annual rainfall in the Kodungallur-Azhikode estuary is 310 cm and fresh water input varied from 10 m^3 s^{-1} to 21 m^3 s^{-1} during pre-monsoon season and 123m^3s^{-1} to 387 m^3 s^{-1}during southwest monsoon season (Bijoy Nandan et al., 2014)

As the depth of the water column changes, the light penetration is affected, which in turn influences the primary production of the estuary. Gopalan et al. (1983) reported that the average depth of the Vembanad lake reduced from 6.7m to 4.4m in the past 50 years from the 1930s to 1980s. In the present study the depth was found to be further reduced to a value of 3.67m. The shallowness reduced the drainage capacity of the lake from 2.4 km^3 to 0.6 km^3, a decline of 75% (Krishnakumar and Rajan, 2012). The siltation caused by river discharge and the tidal influx has led to the decrease in the depth of the estuary. Large quantities of sediment from the river discharge settle to the bottom at the time of high tide, when the currents attain low speed. Further the flood current transports sediment into the river via the northerly littoral currents during monsoon period and post-monsoon period season. This type of sediment transportation deposits silt at the bottom and decreases depth (Kumari and Rao, 2009).The depth of barmouth region was maximum due to the continuous dredging for the deepening and widening of the ship channel. Dredging has affected the sedimentation features, salinity alterations, transparency and nutrient distribution of the estuary (Rasheed, 1997). In comparison, the mean depth of Bilbao estuary in Spain was 7m (Intxausti et al., 2012). Mandovi estuary in Goa had a depth ranging from 2-5m (Shetye, 2011). The Ashtamudi lake is the deepest among all the estuaries of Kerala, having a maximum depth of 6.4m. In the Vembanad lake, the depth ranged from 1.5-6m (Sujatha et al., 2009). Caffrey et al. (2014) studied three estuaries in the north east Gulf of Mexico (Weeks bay, Grand bay and Apalachicola) where the mean depth ranged from 1-2.5m. Water depth of the Cochin estuary was shallow in nature compared to the depth of Darwin harbour in Australia, which ranged from 5-30m (Duggn et al., 2008) and Ria de vigo, a coastal ecosystem in North West Spain having a depth of 45m during low tide (Cermeno et al., 2006).

Temperature is a critical water quality parameter influencing the chemical and biological process in an estuary. The water and air temperature showed comparable patterns of seasonal variation (Rao and George, 1959). The air temperature was higher during the 2009-10 period, which may be due to the lower rainfall and river discharge. Chandra and Ramamurthy (1984) stated that the annual temperature variations in tropical estuaries usually vary by less than 10^0C in comparison with the temperate estuaries. Similar results were obtained in the present study as well. Inter -station comparison of the air temperature distribution showed significant variations. This may be due to the change in the geomorphology of the estuary (Gouda and Panigrahy, 1993).

Ramamritham and Muthuswamy, 1986 observed that the surface water temperature of the Cochin-Azhikode region, i.e. the northern arm of the Vembanad Lake, varies between 24.5°C to 30.5°C.The annual maximum was observed in April and the minimum in July-August A similar pattern was observed in the Korapuzha estuary by Rao and George, 1959, in the Olippuramkadavu backwaters by Ramakrishna et al., 1987, in the Adimathala estuary by Anilakumary et al., 2007, in the Kodungallur –Azhikode estuary by Jayachandran et al., 2012, and in the Bilbao estuary in Spain by Intxausti et al., 2012. In the Krishna estuary located on the east coast of India, the maximum temperature was observed in the pre-monsoon period season and the minimum temperature in post-monsoon period (Kumari and Rao, 2009). The Cochin estuary is a tropical estuary .The variation in temperature over the months was minimal in the tropical region (Nair, 1983). In the present study the monthly variation of temperature was low may be due its tropical behaviour.

Joseph and Ouseph, 2009 recorded the water temperature of the Cochin estuary as fluctuating from 22 to 34°C. The present observation showed that the range of water temperature has changed to 25 to 34°C, representing an overall increase. Monthly variations of water temperature showed a decline in temperature as the southwest and northeast monsoon period progresses, which attain the peak in the months of October and

May. The same observation was made by Kunjukrishna Pillai et al., 1975; Balakrishnan and Shynamma, 1976 and Renjith, 2006. Sujatha et al., 2009 reported that the water temperature in the Ashtamudi estuary ranged from 26-32.5^{o}C whereas in Vembanad Lake the temperature range was 28.9-33^{o}C. Nair and Azis, 1987 recorded that the temperature of the Ashtamudi estuary ranged from 26.40- 35.50^{o}C. The higher water temperature in the Narmada estuary (29-30^{o}C) and Mahi estuary (28-30^{0}C) compared to Sabarmati estuary (27-30^{o}C) could be attributed to the release of industrial waste (Sonal et al., 2012). This statement was supported in the present study by the observations from Station 9 (FACT-Eloor).

A positive correlation significant at 1% level emerged between water temperature and atmospheric temperature (r^2=0.594). A strong negative correlation significant at 1% level between the water temperature and river discharge (r^2= -0.578).The drastic variations in the surface and bottom water temperatures may be due to the shallowness and large surface area of the estuary, which cause the water to heat up and cool down rapidly under prevailing atmospheric conditions. During the monsoon period season, the water temperature decreased due to influx of freshwater from heavy rains and increased river discharge (Sankaranarayanan and Qasim, 1969). During the pre-monsoon period months, solar radiation and warm weather resulted in the maximum water temperature in the tropical estuary (Qasim, 1979; Eyre and Balls, 1999).

Secchi disc depth is an indicator of relative primary production and pollution levels in the marine environment. The light penetration in the water is influenced by various physical factors such as currents, wind and turbidity, and biological factors such as plankton blooms. The transparency values show a direct relation with the southwest and northeast monsoon periods. The reduction in the values during the monsoon period season was due to the decrease in solar radiation and the increase in river runoff (Gouda and Panigrahy, 1993; Anilakumary et al., 2007; Patil and Anil, 2011; Jayachandran et al., 2012; Bijoy Nandan et al., 2014). The annual variation of transparency is directly related to rainfall and river discharge. The maximum transparency in several estuaries was recorded during the pre-monsoon period (Sheeba et al., 1996; Qasim et al., 1968; Gopinathan and Qasim, 1971). However; turbidity was more or less the same during the post-monsoon period and pre-monsoon periods. Aktan et al. (2005) reported that the mean annual transparency of the Izmit Bay in Turkey ranged from 1 to 6.5. In comparison, the transparency of the Cochin estuary was very low (0.61m). The zone-wise distribution of transparency in the Cochin estuary showed that the transparency was higher in the upstream regions, where the salinity was the lowest. The Secchi disc depth in the estuary (0.10 to 1.90m) was lower compared to the earlier records by Renjith (2008) in Cochin estuary (0.5 to 2m). A similar value was observed by Biancalana et al. (2012) in the Bahia Blanca estuary in the south-western Atlantic Ocean (0.26 to 1.15m).It showed a strong negative correlation significant at 1% level between the rainfall (r^2= -0.542) and river discharge (r^2= -0.531). Simier et al. (2006) made a similar observation in the Gambia River estuary in West Africa, that transparency was positively correlated with salinity, but became less correlated during the dry season, and inversely correlated in June.

Light attenuation is an important measure of the light available for photosynthesis and of the aesthetic qualities of water for human use. Good water quality corresponds to a light extinction coefficient value less than 1.387, which is equivalent to the transmission of 25% of the light incident on the water surface to a depth of 1m (Strobel et al., 1999). The range of light extinction coefficient in the Cochin estuary was comparable with the other estuaries (Williams et al., 1968; Chandran and Ramamoorthy, 1984; Upadhyay, 1988; Saisastry and Chandramohan, 1990; Gouda and Panigrahy, 1991; Misra et al., 1993; Gouda and Panigrahy, 1993). Light extinction coefficients were higher in the central zone of the estuary, which is nearer to the sea, and increased towards the riverine side of the northern zone. This was due to the brown stain of the freshwater influx and the change in the character of the bottom sediments from sand and shell near the sea to increasingly muddy sediment toward the freshwater side (Williams et al., 1968). Light attenuation coefficient showed a positive correlation (r^2=0.455) with rainfall significant at 5% level and a negative correlation (r^2=-0.449) with depth significant at 5% level. It also showed a strong positive correlation (r^2=0.541) with river discharge significant at 1% level.

Salinity is the amount of salt dissolved in water. It controls the types of species that can live in an estuary. Salinity also influences the physical and chemical processes such as flocculation and amount of dissolved oxygen in the water. The gradual increase in salinity from the head towards the mouth of the system is a typical estuarine character (Manikoth and Salih, 1974; Stickney, 1984; Dauvin and Desroy, 2005;

Martin et al., 2011). This characteristic was observed in the Cochin estuary from the southern zone to the northern zone. Higher salinity in the bottom water compared with the surface water was due to sea water intrusion from the Arabian Sea (Joseph and Ouseph, 2009). The vertical stratification in salinity due to density changes was observed in the lower reaches of the estuarine stations (Sujatha et al., 2009). The homogenous nature of the upper estuarine stations may be due to the shallowness offer little resistance to mixing and therefore the stratification remains less sharp (Sankaranarayanan and Qasim, 1969). George, 1958; Joseph, 1974;UdayaVarma et al., 1981; Sarala Devi et al., 1983; Balachandran et al., 1999; Renjith, 2006; Martin et al., 2008; John, 2009; Kaladharan et al., 2011;Revichandran et al., 2012; Shivaprasad et al., 2013; Haridevi, 2013; Vineetha et al., 2015 in the Cochin estuary; Rao and George, 1959 in Korapuzha estuary; Gouda and Panigrahy, 1993 in Rushikulya estuary; Macauley et al., 1995 in the Perdido bay; Ramdani et al., 2009 in the North African coastal lagoon; Wooldridge and Deyzel, 2009 in Great berg estuary; Sarma et al., 2010 in Godavari estuary; Satpathy et al., 2010 in the coastal waters of Kalpakkam; Carrasco and Perssinotto, 2011 in the Station Lucia estuary in South Africa; Patil and Anil, 2011 in the Zuari estuary; Cleetus et al., 2015 in Vembanad estuary showed a remarkable seasonal fluctuation with high values in non monsoon period season (dry season) and low during monsoon period season (wet season). In contrast to the earlier observation the maximum peak in salinity was observed in last phase of post-monsoon period month (January) with a remarkable seasonal variation in the Cochin estuary. The Thannermukkom barrage (a salinity barrier) which is located near to the southern zone of our study region remain closed during dry season (January April). It weakens the river runoff from Meenachil, Manimala, Achankovil and Pamba to the estuary. This factor also attribute to the increase in salinity during the post-monsoon and pre-monsoon period.

According to George and Kartha, 1963, the salinity of surface water in the estuary is comparable to the inshore waters during the January-May period. At the end of the post-monsoon period, a reduction in the runoff from the canals and rivers as well as increased evaporation causes the surface water to be replaced gradually by sea water through the increased tidal flow. The salinity in the central zone of the estuary was higher due to its proximity towards the sea. The water was homogeneous during the pre-monsoon period in the study region, which may be due to weakened river runoff during these months. Jyothibabu et al., 2006 reported salinity stratification during the pre-monsoon period; Renjith, 2006 reported a homogeneous condition during the pre-monsoon period in the Cochin estuary. The salt transport was balanced between the seaward flux induced by river runoff and the tidally induced diffusive landward flux. The latter dominated in almost all sections along the estuary except at the upstream end, increasing the salt content of the estuary (Vinita et al., 2015). The surface and bottom waters of the study region exhibited a salt wedge condition to a partially mixed condition in the monsoon period and post-monsoon period months, respectively.

The salinity of the estuary is influenced by the wind pattern and the currents. In the present study, the annual mean salinity was higher during the 2009-10 period compared to the 2010-11 period, which is associated with the rainfall and river discharge data during the study period. The annual rain fall and river discharge was high during 2010-11 period (4109.10 mm and 285050.517 m^3s^{-1}) compared to 2009-10 period (3314.20mm, 217606.792 m^3s^{-1}). A positive correlation (r^2= 0.523) significant at 1% level between transparency and salinity and a strong negative correlation (r^2= -0.430) with turbidity significant at 5% level were established. Simieret al. (2006) studied the estuarine fish assemblages with environmental parameters in the Gambia estuary in West Africa. In the factor plot analysis of environmental variables, salinity showed a positive relation with transparency, while turbidity also was an important factor. Canonical correspondence analysis of environmental variables in the three estuaries (Grand Bay, Weeks Bay, Apachicola Bay) of Gulf of Mexico showed a negative correlation between salinity and turbidity (Cafferey et al., 2014).

Total dissolved solids (TDS) are defined as the amount of dissolved substances in water, such as salts or minerals, remaining after evaporating the water and weighing the residue. It is an essential quality of any water body, resulting from the imbalance between dissolution and precipitation. In our study, TDS was higher during the monsoon period season and lower during thepre-monsoon period season. This may be due to the heavy rain and freshwater runoff. Total dissolved solids established a strong positive correlation significant at 1% level between river discharge (r^2 = 0.525), conductivity (r^2 = 0.962). A positive correlation significant at 5% level between rainfall (r^2= 0.504) and turbidity (r^2= 0.416) was observed. A negative correlation significant at 5% level emerged between the TDS and depth (r^2= -0.458) as well as between TDS and alkalinity (r^2= -0.490).

Conductivity is the measure of the ability of water to conduct an electrical current, based on its ion content. It is a good estimator of the amount of total dissolved solids or total dissolved ions in water. Salinity of the estuarine water was previously found to be proportional to its electrical conductivity (Gopinathan and Qasim, 1972), but this relationship was not established in the present study. Conductivity showed positive relationship with river discharge (r^2=0.425) significant at 5% level; a negative correlation (r^2= -0.495) significant at 5% level was with alkalinity.

Turbidity is a measure of light scattering caused by suspended solids in a fluid (Davies-Colley and Smith, 2001). Turbidity and water temperature determine the metabolic balance of an estuary (Shen et al., 2015). The highest turbidity of the estuary occurs during times of maximum river flow and heavy rainfall. Turbidity was low near the mouth of estuary, with its excess sea water, and increased toward inland with distance (Nair et al., 1984; Nybakken and Bertness, 2005; Lueangthuwapranit et al., 2011). In the present findings, the southern zone, which is the estuarine region, was the maximum turbidity zone. This observation was supported by Kessarkar et al. (2010) in the Mandovi estuary. The maximum turbidity zone in estuaries is typically the region near the seaward edge. However, this was not observed in the present study, because the position of the turbidity maximum varies with the strength of the river flow and with the timing of the tidal excursion (Nienhuis, 1993).

The southwest monsoon period results in a turbulent condition, favouring the resuspension of the bottom sediment bytidal stirring action. This may be the reason for high turbidity in the bottom waters (Qasim et al., 1968; Nixon, 1988; Acha et al., 2008; Sathpathy et al., 2010). In the study region, water was more turbid during the monsoon period. The same observation was made by Renjith (2006); John(2009) in Cochin estuary; Bijoy Nandan et al.(2014) in Kodungallur-Azhikode estuary; Lad and Patil (2014) in the Ulhas river estuary, Thane in Maharashtra. An enormous increase in the Turbidity level during the monsoon periodcould be due to high influx of silt content, agricultural runoff, sewages and other allochthonous organic matters (Jayachandran et al., 2013). Mean station-wise turbidity in the Cochin estuary ranged from 4.25 to 13.51 NTU. The turbidity of temperate estuaries washigher, ranging from 220-143 NTU as in the case of the Great Berg estuary (Wooldridge and Deyzel, 2009). Turbidity showed a strong positive correlation with rainfall (r^2= 0.730) and river discharge (r^2=0.677) significant at 1% level. A negative correlation (r^2= -0.450) with 5% level of significance emerged between alkalinity and turbidity. According to Lueangthuwapranit et al., (2011), turbidity in the Na Thap river estuary varied inversely with salinity and water transparency.

Sufficient dissolved oxygen (DO) in estuarine waters is a basic requirement for the health of aquatic organisms. Fish kills, benthic defaunation, and decreased diversity of fish and benthic invertebrates have often been attributed to hypoxia (insufficient DO to support biological processes) or anoxia (absence of DO) (Engle et al., 1999). It varies according to a number of factors like seasons, temperature, salinity and time of the day. The higher oxygen concentration during post-monsoon period season was due to the higher primary production occurring in the surface layers during this period. The DO values during the post-monsoon periodmight be due to the higher solubility of oxygen in colder and less saline water (Anilakumary et al., 2007). The salinity and water temperature were the lowest during monsoon period, but the dissolved oxygen was slightly higher during the post-monsoon period (6.89 mg L^{-1}) as compared to the monsoon period(6.48 mg L^{-1}). Qasim et al. (1969), Haridas et al. (1973) and Pillai et al. (1975); Jyothibabu et al. (2006); Madhu et al. (2007); John (2009);Haridevi(2013); Vineetha et al. (2015a) recorded the seasonal peak during the monsoon period season from the same estuary. Dehadri(1969) recorded the peak during the northeast monsoon period season in the Mandovi-Zuari estuaries and Janakiraman et al. (2013) in the Adayar estuary. Jayachandran et al. (2013) and Bijoy Nandan et al. (2014) observed the peak during the monsoon period season in the Kodungallur-Azhikode estuary.

Babu et al.(2010) reported that surface water has higher DO than the bottom water, which might be due to the increased organic inputs from the urban area as well as the industrial effluents into the Ashtamudi estuary. Similar observations were observed in the present study, supported by the findings of Shivaprasad et al. (2013) in the Cochin estuary and Patil and Anil (2011) in the Zuari estuary. Breitburg et al. (1997) observed that the depletion of dissolved oxygen in the bottom layers of the Chesapeake Bay resulted from a combination of excess nutrient loadings from anthropogenic sources, deforestation and possibly the substantial decrease in top down control of primary production due to overharvesting and disease mortality of oysters. Aktan et al., 2005 reported that DO in the surface waters were generally oversaturated, due to the exchanges with the atmosphere and algal productivity.

The solubility of oxygen in water decreases with increased temperature and salinity. The high amount of DO in the northern zone might be due prevalence of the low saline conditions, attributed to the high solubility of oxygen. The inverse relationship of salinity and temperature with DO was observed by several authors, such as Qasim and Gopinathan, 1969; Sankaranarayanan and Qasim, 1969; Marichamy and Sirimeethan, 1979; Sankaranarayanan and Panampunnayil, 1979; Marichamy et al., 1985; Eyre and Balls, 1999; Sujatha et al., 2009. The high amount of organic matter and high bacterial population of the sediment lowers the amount of dissolved oxygen in the water column. Mean station wise variation and low DO at the bottom clearly support the above theory. The organic matter of the sediment was very high in Station 9 and low in Station 3, upon which the resulting decomposition of organic matter lowers oxygen in the deeper layers of the water body (Department of Environment and Climate change- project report, 2013).

No clear trend in DO was observed with respect to the months and the average DO (6.35 mg L^{-1}) of the estuary was high in the present study (Sankaranarayanan and Qasim, 1969; Nair, 1983; Ouseph, 1992, Thomson, 2002; Sathpathy et al., 2010). A comparative analysis of the distribution of dissolved oxygen in 1966 and 1992 shows that the dissolved oxygen content has been more or less stable over the last three decades in the selected locations of the study areas (Ouseph, 1992). In the present study also the inter annual variation of the DO was not observed, it was 6.10 mg L^{-1} during 2009-10 period and 6.29 mg L^{-1} in 2010-11 period.

Aquatic organisms survive and carry out their normal life functions when DO concentration meets or exceeds 5 mg L^{-1}. Problems generally arise when DO falls below 3 mg L^{-1}, though most organisms can survive at this level for at least limited periods (Stickney, 1984). Water quality will allow the passage of fishes at all the states of tide, if the water quality is greater than 5mg L^{-1} (Whitfield and Elliott, 2002). In aquatic systems, oxygenation is the result of an imbalance between the processes of photosynthesis, degradation of organic matter, reaeration (Granier et al., 2000), and the physico-chemical properties of water (Aston, 1980). In the present study, approximately16% of the samples exhibited a DO concentration $\leq$5mg L^{-1}, indicating a biologically stressed condition in the estuary. Depletion of dissolved oxygen was due to the upwelled propagation of high saline water mass and its increased residence time in the lower estuary (Martin et al., 2010). DO showed a negative correlation with the light attenuation coefficient at 5% level (r^2= -0.436).

Jhingran (1982) reported that in 1966, the level of pH in the Cochin backwaters varied between 7.0 and 8.4. The northern zone was slightly acidic, while the southern zone and central zone were alkaline in nature. Streams and rivers transporting large quantities of humic materials in colloidal suspension are frequently of a slightly acidic nature. Upon meeting sea water, the colloidal particles coagulate and the pH shifts towards the alkaline side. Another reason might be the discharge of industrial effluents. High pH in the marine zone was on account of the intrusion of sea water and low values in riverine zone that could be due to the influence of freshwater and effluents introduced through various sources (Nair and Azis, 1987).

The surface and bottom water pH in the study region showed variation. It was low in the bottom waters, which may be due to the oxidation of organic matter. The same results have also been reported from the Vellar estuary (Chandran and Ramamoorthi, 1984), the Kali estuary (Bhat and Neelakandan, 1988), the Mahanadi estuary (Upadhyay, 1988), the Uppnar backwaters (Murugan and Ayyankannu, 1993) and the Rushikulya estuary (Gouda and Panigrahy, 1993). Due to the extensive buffering capacity of sea water, the variations in pH lie within the narrow limit (Riley and Chester, 1971). Similar findings were recorded from the Cochin estuary by Sankaranarayanan and Qasim (1969); Balachandran (2001); Joseph and Ouseph (2010), from the Ashtamudi estuary by Babu et al. (2010), and from the Kodungallur-Azhikode estuary by Jayachandran et al. (2012).

Addition of CO_2 to water will cause the pH to decrease due to the formation of hydrogen ions by ionisation of carbonic acid. Similarly, the removal of carbon dioxide from the system would lead to a rise in pH. The pH was high during the post-monsoon period due to the high photosynthetic activitywhich removes CO_2 from water and the low solubility of gases due to high water temperature. The low pH during monsoon period was due to the opposite conditions, namely low photosynthetic activity and high solubility of gas due to low salinity and low water temperature. The rainwater fed into the estuaries during monsoon period has a slightly acidic naturedue to the presence of industrial effluents and oxidation of organic matter. A positive correlation significant at 1% level was observed between transparency (r^2= 0.564; r^2= 0.613) and salinity, while a negative relation significant at 5% level between pH and turbidity (r^2= -0.415).

Carbon dioxide is the product of respiration, the substrate in photosynthesis and an important factor in controlling the pH of sea water. Free carbon dioxide present in trace amounts is good for aquatic health.But at high concentrations, it becomes harmful for the system (Pathak et al., 2004). Ramakrishana et al. (1987) observed that the trend of oxygen and carbon dioxide followed a mirror image-like pattern in the Olippuramkadavu backwaters. However, the present results do not support this observation for the Cochin estuary. Jayachandran et al. (2012) reported high carbon dioxide values from the Kodungallur-Azhikode estuary. High values of carbon dioxide were due to increased human activities and this has lead to ecosystem stress. For good fish production, a free carbon dioxide concentration level less than 5 mg L^{-1} is recommended (Ellis, 1937). In the Cochin estuary, carbon dioxide values were high with an average of 8.19 mg L^{-1}.

The consequences of global climate change include elevated levels of carbon dioxide and decrease in pH affect the equilibrium of inorganic carbon complexes in the estuary such as carbonates, bicarbonates. The shift in CO_2:HCO_3^- ratio may benefit species able to utilise only CO_2 by diffusive uptake, but most phytoplankton species have an active uptake system for inorganic carbon (Beardall et al., 2015). In the present study the carbon dioxide values were found to be elevated but the pH is shifting towards an alkaline side.

Alkalinity or acid combining capacity of water is another important factor which can be correlated with productivity. It is generally caused by the carbonates and bicarbonates of calcium and magnesium, which along with dissolved carbon dioxide in the water, form an equilibrium system $CO_2+CO_3+H_2O \leftrightharpoons (HCO_3)_2$ which play a very important role in the ecology of the environmentt. This equilibrium also acts as a buffer system for limiting the fluctuation of pH (Pathak et al., 2004). Moyle (1949), based on the study of a large number of lakes and ponds, showed that alkalinity ranging from 40 to 90 mg L^{-1} gives medium productivity whereas highly productive waters have alkalinity values more than 90 mg L^{-1}.Additionally, alkalinity measurements help to understand the estuary's ability to neutralize acid pollution from rainfall and waste water discharge.

The average alkalinity of the Cochin estuary (36.26 ± 14.32 mg L^{-1}) was comparable with the Kodungallur-Azhikode estuary, 35.1 ± 18.4 mg L^{-1} (Jayachandran et al., 2012; Bijoy Nandan et al., 2014). Zone-wise variation of alkalinity and carbon dioxide are related. The relationship might be due to the fact that the uptake or release of carbon dioxide changes the proportion of carbonates and bicarbonate ions in water (Boyd, 1984). The alkalinity values fluctuate rapidly during the monsoon season, while small changes were observed during the pre-monsoon period in the Cochin estuary (Qasim, 1971).From the present observations; the seasonal fluctuations are very significant in all the seasons. Alkalinity showed a positive correlation (r^2=0.405) significant at 5% level between the depth.

The hardness of water depends mainly on the presence of dissolved calcium and magnesium salts. It affects the distribution of aquatic organisms and toxicity of trace metals. The decrease in hardness during the monsoon season in the second year was attributed to the increased rainfall and the river discharge. The hardness showed a two to three fold increase in the pre-monsoon and post-monsoon seasons, which might be due to the high rate of evaporation and reduction in the freshwater runoff. The same observation was made by Bijoy Nandan et al., 2014 in the Kodungallur-Azhikode estuary and by Lad and Patil, 2014 in the Ulhas river estuary of Thane, Maharashtra. Station -wise and zone-wise distribution of hardness showed an increase in hardness due to salt water intrusion. Pearson correlation analysis showed a negative relationship between rainfall (r^2= -0.412) and river discharge (r^2= -0.475) at 5% level; where as a positive relationship with water temperature (r^2= 0.542) at 1% level.

BOD was high during the monsoon season in the Cochin estuary as well as the Kodungallur-Azhikode estuary (Jayachandran et al., 2012).Organic pollution in the Cochin estuary is attributed to the high BOD values. According to BIS (ISI) standards, the permissible level of BOD_3 in the inland surface waters is 20 mg $L^{-}1$ whereas the ICMR standard permit is 5 mg L^{-1} (Meera and Bijoy Nandan, 2010; Krishna Kumar and Rajan, 2012. The BOD values in the Kadinamkulam backwaters ranged from 4.96 mg L^{-1} to 24.39 mg L^{-1} (Bijoy Nandan and Azis, 1990). In the present study, the mean BOD values mostly lie within the range of 0 to 10.68 mg $L^{-1.}$ Occasionally, the surface and bottom water samples exceeded the limit of 5 mg L^{-1}. BOD level in the Muvattupuzha River ranged from 0.5 to 3 mg L^{-1}. At the industrial discharge points, the BOD level was significantly higher, ranging from 1.5 to 5000 mg L^{-1} (Balchand, 1984). BOD showed a positive correlation (r^2= 0.561) significant at 1% level with dissolved oxygen. Theoretically, a high amount of BOD leads to depletion of DO in the water bodies. This exerts stress on the aquatic organisms in turn, leading to their suffocation and death.

Ammonium is a primary decomposing product from organic matter. Nitrification is a two-step process: oxidation of ammonia to nitrite and of the latter to nitrate under oxic conditions. Under anoxic conditions, NO_3 and NO_2 can be further transformed to nitrogen gas (N_2) by denitrification. Nitrification rate is high at intermediate salinities. Salinity and the concentration of ammonium are directly related (Miranda et al., 2008). Temperature, salinity, substrate concentration, suspended particulate matter, dissolved oxygen and pH have been shown to exercise an influence on nitrification at one time or the other.Their relative importance as controlling factors may vary between different estuaries or even between different segments of an estuary (Berounsky and Nixon, 1993).Miranda et al., 2008 reported that the nitrification in the Cochin estuary increases with increase in the concentration of ammonium and pH in the non-monsoon months.

Seasonal variation of ammonium in the study region exhibited the maximum during the pre-monsoon period, followed by the post-monsoon period and monsoon period. In the present study, the average concentration of ammonia (11.48 µmol L^{-1}) was very high compared to the earlier observation by Joseph and Ouseph, 2010 (0.34± 0.30 µmol/L). The presences of higher levels of ammonia indicate the increased sewage input and agricultural runoff into the surface waters (Anirudhan et al., 1987; Lakshmanan et al., 1987). The ammonia content is also supplemented by the discharge from the Periyar River and its associated tributaries such as Chitrapuzha, which flow through the industrial zone. Ammonium concentration was high in the surface waters of central zone of the estuary, which may be due to the influx of inorganic nitrogen into organisms, which results from the assimilation of ammonia and nitrate. These reactions predominate in the surface waters and are mediated primarily by phytoplankton (Conway, 1977; Balachandran, 2001).In most coastal environments; the majority of the recycled nitrogen is released from sediments to the water in the form of ammonium ions (Kemp et al., 1990). This may be the reason for high ammonium concentration in the bottom waters of southern and central zone of the estuary. Apart from industrial waste, regeneration and excretion are the other sources of ammonia into the estuary. The high concentration of ammonia during the pre-monsoon period is contributed by the excretion of zooplankton and the members of higher trophic levels (Kiefer and Atkinson, 1984). A positive correlation significant at 1% level emerged between ammonia and total hardness (r^2= 0.529).

The average ammonium concentration during 2009-11 period was 11.48 μmol L^{-1}, whereas that of nitrite is 0.72 μmol L^{-1} in the Cochin estuary. No correlations were also found between ammonium and nitrate, reflecting complex processes associated with the cycle of nitrogen (Pereira et al., 2009). Ammonium oxidation rate is higher than the nitrite oxidation rate (Wada and Hattori, 1971). Ammonium oxidizers are also known to be more adaptable than nitrite oxidizers: they have half-saturation constants for substrate uptake and oxygen thresholds for inhibition of oxidizing activity that are several times lower, while the affinity for particles is much higher (Helder and de Vries, 1983; Morris et al., 1985; Owens, 1986).

The distribution of nitrite suggests that the riverine inputs are very low. Additionally, localised effects appeared to increase nitrite concentration. Possible input sources include sewage discharge and waste from the fisheries industries (Lakshmanan et al., 1987).Gupta and Pylee, 1964 have reported higher planktonic growth attributed by high chlorophyll a in this estuary, suggesting a depletion of nutrients during the post-monsoon period. This observation is also valid for the present study. The values recorded during this study are lower than the earlier reports, which reflect the unstable nature of nitrite (Lakshmanan et al., 1987; Manikoth and Salih, 1974; Sathpathy et al., 1996, 2010). Nitrite-N is a transitory stage in the nitrogen cycle of the system, formed by the oxidation of ammonia or by the reduction of nitrate and is most unstable transient species of dissolved inorganic nitrogen. The progressive decrease of ammonia from the bottom to the top may suggest its possible conversion into nitrite. A similar trend was observed in our study.

The reactivity of nitrite is very high, leading to a lower concentration of nitrite in the aquatic system compared to ammonia and nitrate. The spatio-temporal variation of nitrite showed a trimodal cycle, with the peaks occurring when the system remains dominated by freshwater. The peak obtained during the pre-monsoon period indicates that the hydrodynamic processes associated with sea water intrusion control the nitrite concentration (Sankaranarayanan and Qasim, 1969;Anirudhan, 1988; Patil and Anil,2011; Bijoy Nandan et al., 2014). Higher nitrite concentrations in station 3 are indicative of effluent discharge and are often associated with the unsatisfactory microbiological quality of water. Krishna

KrishnaKumar and Rajan, 2012 reported high nitrite concentration less than 0.55 mg L^{-1} in the Vembanad Lake due to the persistent use of agricultural fertilizers. According to Domingues et al., 2005, Nitrite concentration was usually less than 1.00 μ mol L^{-1} throughout the sampling period in the temperate Guadiana estuary in Spain. Most of the nitrite concentration values lie within the same range for our study area. Dissolved nitrite-N showed a negative correlation (r^2= 0.511) significant at 5% level with dissolved oxygen. According to Miranda et al., 2008 nitrification is influenced by dissolved oxygen. However, the nitrification process can still function at very low concentrations of dissolved oxygen.

Nitrate-N is the most abundant and most stable inorganic form of Nitrogen. The concentration of nitrate-N was highest during the monsoon period because the concentration entirely depends upon the freshwater discharge and land runoff (Ewins and Spencer, 1967). The concentration was influenced slightly by the intrusion of saline water. It also showed a clear positive correlation with river discharge. The average nitrate-N retained in this estuary is at more or less the same concentrations, as compared to the earlier observations (Sankaranarayanan and Qasim, 1969; Manikoth and Salih, 1974; Sheeba et al., 1996; Renjith, 2006). White et al. (2006) reported that the abnormally higher nitrate concentration (15.3 ± 5.41µmol l^{-1}) and phosphate concentration (40.9±9.2µmol l^{-1}) in the Vishakhapatanam harbour that were due to eutrophication, caused by the discharge of fertilizer factory waste and domestic sewage. In the Cochin estuary, the mean concentration for nitrite was 13.12 ± 10.54 µmol l^{-1} and that of phosphate was 7.38 ± 8.18 µmol l^{-1}. The zone-wise distribution of nitrate was very similar to the distribution observed with nitrite in the estuary. The higher monsoonal values attributed to the nitrate leaching leads to higher primary production in this estuary (Lakshmanan et al., 1987). During the pre-monsoon period, the nitrite-N values were minimum indicating that the influx of nitrogen from the sea water is very little (Manikoth and Salih, 1974). Babu et al. (2010) reported that nitrate was higher during the non-monsoon period months than the monsoon period months. Nitrification is most likely restricted to the bottom sediments, which have been suggested as a major source of nitrate to the water column of other tropical estuaries (Sankaranarayanan and Qasim 1969; Eyre 1994; Eyre and Balls, 1999). This restriction may also be the reason for higher concentration of nitrate in the bottom waters. The mean annual nitrite+nitrate (dissolved inorganic nitrogen (DIN) = (nitrite + nitrate) + ammonium) concentration accounts for approximately 55% of DIN, whereas ammonia contributes the remaining 45% in the estuary. Sarma et al. (2010) reported that ammonia accounts for approximately 36% of the DIN in the Godavari estuary. Seasonal variations of DIN were similar to that of nitrate.

Nitrate-N showed a strong positive correlation significant at 1% level between rainfall (r^2= 0.597), river discharge (r^2= 0.660), turbidity (r^2= 0.572), conductivity (r^2 = 0.760) and TDS (r^2=0.810). Aweak positive correlation was established with the light attenuation coefficient (r^2= 0.460). A negative correlation significant at 1% level was observed with water temperature (r^2= 0.500) and transparency (r^2= 0.518). Water column nitrification is influenced by temperature (Eyre and Balls, 1999), ammonium concentration (Berounsky and Nixon 1993) and suspended sediments (Owens 1986; Balls et al. 1996). The relation was observed in the present study as well. Nitrate values showed a correlation significant at 5% level with transparency (Seechi disc depth) in the Bahia Blanca estuary, south Atlantic (Biancalana et al., 2012).

Phosphate is a major inorganic nutrient which limits primary production in the coastal marine ecosystems. The concentration of phosphate was very high during the pre-monsoon period. According to Martin et al. (2008) and Shivaprasad et al. (2013), the high nutrient concentration during pre-monsoon period might be due to the anthropogenic activities (industries) and sediment re-suspension, which substantially alter the nutrient stoichiometry. The surface phosphate concentration was moderately higher in stations with high salinity, whereas a decreased phosphate concentration was observed in low saline regions. However in the present study the phosphate was higher in the northern zone containing low saline regions.The industrial effluent discharge and domestic sewage containing detergents and fertilizers used in the agricultural fields in this zone significantly influenced the nutrient concentration. The same observation was reported by Biancalana et al. (2012) from the Bahia Blanca estuary in Argentinawhile studying the effects of sewage pollution on mesozooplankton.

The nutrient concentration in the bottom waters were generally higher, compared tothe surface waters. Sankaranarayanan and Panampunnayil(1979) reported higher concentrations of nitrogen and phosphorus in the sediments of Cochin estuary, due to the disposal of domestic waste. Dredging releases nutrients from the sediment, which explains the high nutrient concentration in the bottom waters (Joseph and Ouseph, 2009). Phosphate is released from the sediments due to the stirring action of strong tidal waves. This phenomenon has been reported for the Cochin estuary (Rajagopal et al., 1974; Martin et al., 2007) as well as the coastal waters of Kalpakkam (Sathpathy et al., 2010). Mean station-wise values clearly suggest that concentration of phosphorus in the estuary was mainly controlled by external sources, such as land drainage and freshwater runoff (Sankaranarayanan and Qasim, 1969). Seasonal observations in the present study support the earlier observations (Lakshmanan et al., 1987, Joseph, 1974).

The heavy rainfall and the increased surface runoff during the monsoon period contributed to the higher values of silicate in the surface waters during the monsoon period. The same observation was reported by Balls et al. (1997); Jyothibabu et al. (2006); Sathpathy et al. (2010); Patil and Anil (2011); Shivaprasad et al. (2013).The silicate concentration was higher during the monsoon period.High silicate values are associated with low salinity of water and vice versa. The spatio-temporal distribution of silicate observed in the present study is similar to the observations in earlier works (Sankaranarayanan and Qasim, 1969; Sankaranarayanan et al., 1984; Anirudhan et al., 1987; Renjith, 2006; Jayachandran et al., 2012). In the present study the silicate concentration was high during monsoon period and low during pre-monsoon period, while the variation of phosphate showed the opposite pattern. High values of silicate were always associated with the low values of phosphate and this might result in a diatom bloom (Joseph, 1974).The substantial removal of dissolved silicate during the pre-monsoon period in the estuary might be due to the enhanced biological utilization caused by the development of null zones (a body of water column with a high residence time compared to other sections of the estuary) in the middle areas of the estuary (Balachandran et al., 1999). Silicate values were higher in the central zone of the estuary, which is influenced by the coastal processes due to its proximity to the barmouth. Silicate showed a positive correlation significant at 1% level with conductivity (r^2= 0.673); TDS (r^2= 0.606); nitrate (r^2=0.550).

Hydrogen sulphide is highly toxic to marine life. Lower dissolved oxygen values, high BOD and higher values of hydrogen sulphide are indicators of sewage discharge (Unnithan et al., 1975; Chapman et al., 1996).

But this was not observed in the present study. The high amount of sulphide in the bottom layers may be due to the anaerobic bacterial decaying of organic matter. The high amount of sulphide in the bottom waters are due to sulphate reduction taking place in the Cochin estuary (Martin et al., 2010). The equilibrium between hydrogen sulphide, hydrosulphide and sulphide is determined by the pH. If the pH is less than 10, it is not detrimental to the ecosystem (Chapman et al., 1996). Sulphide showed a positive correlation significant at 1% level between rainfall (r^2= 0.562), river discharge (r^2=0.535) and turbidity (r^2= 0.594) and weak correlation with attenuation coefficient. It also showed a negative correlation significant at 5% level with atmospheric temperature (r^2= 0.448); water temperature (r^2= 0.514); transparency (r^2= 0.477) and total hardness (r^2= 0.495).

The N:P ratio of Redfield has long been used to estimate which of these nutrients is limiting the growth of algae in aquatic systems. The station-wise mean values of Redfield ratios ranged from 0.01 at Station 5, 6 and 7 to 5.10 in station 8. The mean Redfield ratio was found to be higher during monsoon period (0.65) and lower during post-monsoon period (0.40). The maximum photosynthetic activity during post-monsoon period resulted in a low Redfield ratio. The large influx offreshwater added nitrate to the system. A Redfield ratio less than one indicatesthe complete exhaustion of nitrate. The Redfield ratio of Vellar estuary showed high values during monsoon period and post-monsoon period, and a low value in summer (Venugopalan et al., 1981). A similar result was observed in the present study. The ratios of inorganic N:P (by atoms) ranged from 1:1 to 99:1 during the year (Sankaranarayanan and Qasim,1969). Jayachandran et al., (2012) reported that the average N:P ratio of the Kodugallur-Azheekode estuary was 21.91. Additionally, the estuary was phosphorus-limited during monsoon period and nitrogen-limited during post and pre-monsoon periods. In the Cochin estuary the season wise, zone wise and year wise analysis of Redfield ratio showed a nitrogen limiting condition. This means N:P<10 and Si:N>1,indicating N limitation (Parsons et al., 1961; Healey and Hendzel, 1979; Brezezinski, 1985; Levasseur and Therriault, 1987). The direct application of the Redfield ratio in estuarine systems is problematic. The measurements of limiting nutrients are typically problematic due to the rapid regeneration of nutrients and short turnover times in an estuarine system. (Pickney et al., 2001).

The enrichment of nitrogen and phosphorus in the estuaries can lead to undesirable disturbances in the equilibrium of the organism and in the quality of water body as a whole (Zhang et al., 2010). Many indicators were created to evaluate the intensity and evolution of eutrophication in estuary and coastal environments. Abnormal levels of nitrate (15µ mol L^{-1}) and phosphate (greater than 40 mol L^{-1}) suggesting a high level of eutrophication was observed during the present study. The same observation was made by Saraladevi et al. (1983) in the Cochin estuary and by Lad and Patil (2014) in the Ulhas river estuary. White et al. (2006) reported the high level of eutrophication in the Visakhapatanam harbour, caused by the discharge of fertilizer factory waste and domestic sewage.

Strobel et al., (1999) studied the current status of the Virginian province estuaries and used biotic, abiotic and habitat indicators to measure the ecosystem stress. The effects of such ecosystem stress can be classified into three categories: eutrophication, impacted benthos and contaminated sediments. Eutrophication conditions are defined as: dissolved oxygen less than 5 mg L^{-1} or sediment total organic carbon concentration greater than 3%. Impacted benthos can be defined as a benthic index value less than zero. Contaminated sediment can be defined as the percent amphipod survival less than 80% of control or any chemical analyte present in excess of the ER-M (Effects, Range-Median) concentration. In the present study DO sagging (less than 5 mg L^{-1}) and increase in organic carbon in the sediments (greater than 3%) were observed in most of the stations. Low transparency and high turbidity are the other observable effects of eutrophication. Hence the Cochin estuary exhibited the signs of eutrophication.

According to EU-Crouzet et al., 1999 method, all the stations were classified as bad based on phosphate concentration. Based on the nitrate + nitrite concentration, stations 4 and 9 were rated as bad while the other sites were observed to be of the poor category. So this index pointed to an extreme deterioration of water quality in the estuary. In the light of this finding, a particularly relevant challenge is to establish scenarios, eventually supported by models, in order to predict changes and spatial variability on nutrient availability and its implications on phytoplankton, macro algae, zooplankton and benthic macro invertebrates, which are key biological elements to define the quality of coastal and transitional waters (Pereira, 2009).

Table 3.24 The Pearson correlation analysis of water quality parameters in Cochin estuary during 2009-11 period.

	Rainfall	River discharge	Atm. temperature	Wat. temperature	Depth	Attenuat	Transparency	Alkaliinity	Turbidity	Total hardness	Conductivity	Salinity	pH	TDS	DO	CO_2	BOD	Nitrite-N	Nitrate	Phosphate-P	Silicate-Si	Ammonia-N	H_2S
Rainfall	1																						
River discharge	0.899**	1																					
Atm.temperature	-0.115	-0.199	1																				
Wat.temperature	-0.399	-0.578**	0.594**	1																			
Depth	-0.251	-0.237	0.012	0.137	1																		
Attn.co efficient	0.573**	0.589**	-0.296	-0.377	-0.317	1																	
Transparency	-0.542**	-0.531**	0.373	0.356	0.231	-0.875**	1																
Alkaliinity	-0.356	-0.31	-0.356	-0.16	0.405*	-0.323	0.238	1															
Turbidity	0.730**	0.677**	-0.299	-0.467*	-0.367	0.793**	0.838	-0.450*	1														
Total hardness	-0.412*	-0.475*	0.271	0.542**	0.169	-0.309	0.354	-0.098	-0.334	1													
Conductivity	0.403	0.425*	0.011	-0.249	-0.398	0.003	0.007	-0.495*	0.298	-0.197	1												
Salinity	-0.382	-0.303	-0.171	-0.188	0.076	-0.406*	0.523**	0.285	-0.430*	0.176	0.37	1											
pH	-0.288	-0.229	0.093	0.026	-0.135	-0.569**	0.564**	0.164	-0.415*	0.325	0.29	0.613**	1										
TDS	0.504*	0.525**	-0.069	-0.316	-0.458*	0.208	-0.15	-0.490*	0.416*	-0.2	0.962**	0.015	0.26	1									
DO	0.027	0.088	0.2	-0.072	0.3	-0.436*	0.283	-0.067	-0.136	-0.02	0.188	-0.185	0.121	0.017	1								
CO_2	0.127	0.012	0.079	0.293	0.276	-0.027	-0.193	-0.234	0.068	-0.074	0.319	-0.187	-0.2	0.258	0.055	1							
BOD	0.087	0.218	0.194	-0.072	0.141	0.059	-0.013	-0.101	-0.021	-0.05	-0.027	-0.4	-0.2	-0.054	0.561**	-0.106	1						
Nitrite-N	-0.091	-0.184	0.092	0.277	-0.328	-0.006	0.142	-0.162	0.071	0.151	0.146	0.058	0.143	0.146	-0.511*	0.029	-0.292	1					
Nitrate-N	0.597**	0.660**	-0.216	-0.500**	-0.315	0.460*	-0.365	-0.518**	0.572**	-0.397	0.760**	-0.206	-0.15	0.810**	0.073	0.169	0.101	0.05	1				
Phosphate-P	-0.374	-0.294	0.035	0.243	0.125	-0.175	0.251	0.156	-0.326	-0.041	-0.111	0.178	-0.06	-0.134	-0.188	0.173	0.089	0.11	-0.184	1			
Silicate-Si	0.252	0.286	0.238	-0.033	-0.151	0.142	0.009	-0.351	0.038	-0.194	0.673**	-0.234	0.08	0.606**	0.188	0.328	0.03	0.13	0.550**	0	1		
Ammonia-N	-0.098	-0.178	0.256	0.266	-0.235	-0.203	0.366	-0.172	-0.77	0.529**	-0.078	0.041	0.276	-0.072	-0.098	-0.352	-0.223	0.36	-0.109	-0.287	-0.062	1	
H_2S	0.562**	0.535**	-0.448*	-0.514*	-0.129	0.413*	-0.477*	0.142	0.594**	-0.495*	0.231	-0.271	-0.28	0.281	0	0.105	0.113	0.04	0.39	-0.254	0.03	-0.249	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

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Chapter 4

PRIMARY PRODUCTION AND MICROPHYTOPLANKTON

Contents

4.1 Introduction

The synthesis of organic matter from inorganic constituents by the photosynthetic activity of organisms is termed primary production. Almost the entirety of primary production is accounted for by autotrophic production – photosynthesis by green plants. In the process of photosynthesis, solar energy is transformed into chemical energy. This is achieved through conversion of inorganic carbon in the air (CO_2) into the carbohydrate glucose ($C_6H_{12}O_2$), a form of organic carbon. Gross primary production is the energy or carbon fixed via photosynthesis over a specific period of time. Reducing the energy or carbon lost via respiration during the same time period, gives the net primary production. The components of the ecosystem that make up a trophic level, are quantified in terms of biomass (the weight or standing crop of organisms). Ecosystem dynamics such as the flow of energy and materials among system components are quantified in terms of rates. (Jorgenson, 2009).

The dynamics of primary production varies across different tropical marine ecosystems, such as mangroves, coastal waters, coral reefs and sea grass beds. Mangroves found near estuarine regions have higher productivity than the backwaters and the estuaries themselves, due to the presence of vegetation in addition to the phytoplankton. Considering only the phytoplankton in a mangrove ecosystem, the values of production are comparable to that of estuarine and near-shore ecosystems. The value of phytoplankton production ranges from 1-2 gC m^{-2} d^{-1}, whereas leaf addition contributes to production as detritus, with a value of 25 gC m^{-2} d^{-1}. Coastal regions are five times more productive than oceanic realms. Phytoplankton account for at least half of primary production in a coastal ecosystem. Coral reef ecosystems have typical values of production ranging from 2 to 12 gC m^{-2} d^{-1}. In a reef ecosystem, benthic algae contribute the major share of primary production. For a sea grass ecosystem, the gross primary production is approximately 11.97 gC m^{-2} d^{-1}. (Qasim and Bhattathiri, 1971; Bhattathiri, 1992).

Phytoplankton is unicellular microscopic algae which comprised of several taxonomic groups, such as chlorophytes, chrysophytes, cryptophytes, cyanobacteria, diatoms and dinoflagellates. According to size, phytoplankton are classified into picoplankton (<2µm), nanoplankton (2-20µm) and microplankton (>20µm). The compositional makeup of a community of phytoplankton with each of these sub-groups exerts considerable influence by way of fuelling energy to higher trophic levels organisms with the product of their photosynthesis. Communities dominated by large-sized phytoplankton have a large potential to export organic matter to upper trophic levels, through a short, classical food chain, and to adjacent systems. By contrast, communities dominated by small-sized phytoplankton are characterized mainly by complex microbial food webs that favour the recycling of organic matter within the euphotic layer (Cermeno et al., 2006). Additionally, quality of water is also influenced by the composition of the phytoplankton community (Goercike, 2011). Phytoplankton dynamics are regulated by bottom-up controls (light, nutrients) as well as top-down controls (grazing). The interactions between these controls are influenced by flushing rate and residence time.

Phytoplankton dynamics have been affected by man-made as well as climatically-induced environmental changes in coastal ecosystems. These changes have also affected trophic states, biogeochemical cycles, quality of water as well as the overall condition of the habitat. (Paerl and Justic, 2011). Composition of phytoplankton and rates of photosynthesis have been affected by the increased emission of CO_2 and greenhouse gases due to industrialization. Stratification of the water column due to global warming prevents replenishment of nutrients in the surface waters. (Beardall et al., 2009). In the Cochin estuary, man-made and natural disturbances has significantly affected the patterns of primary productivity as well as the compositional structure of the phytoplankton community.

4.2 Review of literature

The history of productivity in the Indian waters starts with John Murray expedition (1933) followed by Danish Galathea Deep sea expedition in 1950-52, introduced carbon isotopes in the study of marine photosynthesis on the western parts of the Indian Ocean (Steemann Nielsen, 1952; Steemann Nielsen and Jensen, 1957). Galathea was followed by R.V. Vityaz in 1956-60 and International Indian Ocean Expedition (IIOE) in 1962-1965. The expedition has provided a detailed picture of hydrography, productivity and the resources of the Indian Ocean.

In the recent decades, coastal waters and estuaries around the world have been active area of ecological studies of primary production and phytoplankton. A considerable amount of knowledge has been gained in recent years on the seasonal distribution of phytoplankton (Ostenfeld, 1913; Jhonstone et al., 1924; Cupp, 1937; Dakin and Colefax, 1940). Pescod, 1969 estimated the oxygen production in the lower reachesof the Chao Phya estuary in Bangkok. Thayer, 1974 studied the nutrient limitation and phytoplankton production in the Beaufort estuaries of North Carolina. Estuarine primary production was studied in detail by Joint and Pomroy, 1981. Cloern et al., 1985, conducted a survey throughout the San Francisco Bay over an annual cycle to study the dynamics of estuarine phytoplankton. Malone et al., 1988 reported seasonal variations in the phytoplankton biomass of the mesohaline reach of the Chesapeake Bay. Maximum productivity during summer in the mesohaline reach of the Bay is a consequence of the recycling of nitrogen delivered to the system during the previous spring. Alpine and Cloern, 1992 observed that the seasonal and inter annual fluctuations in estuarine phytoplankton biomass and primary production can be regulated jointly by direct physical effects and trophic interactions. Mallin et al., 1994 studied the phytoplankton ecology of North Carolina estuaries in the United States. Mallin and Paerl, 1994 investigated the diel, seasonal and community structure effects on planktonic trophic transfer in the Neuse River estuary, North Carolina.

Kromkamp and Peene, 1995 observed the phytoplankton primary production in the turbid Schelde estuary in Netherlands. Doering et al., 1995 set up an experimental design to study the phosphorus and nitrogen limitation on primary production in a simulated estuarine gradient. Macauley et al., 1995 gave an assessment of the Perdido Bay, a northern Gulf of the Mexico estuary. On a seasonal basis the productivity and chlorophyll a concentration of phytoplankton in Perdido Bay are controlled by temperature. Nutrients, standing crop and primary production in the western coastal waters of the Adriatic Sea were measured by Zoppini et al., 1995.

Yin et al., 2000 and 2001; Yin, 2002 conducted field experiments to determine the nutrient that limits phytoplankton biomass in the Pearl River estuary of Hong Kong, during the summer and monsoon seasons. Wasmund et al., 2001 compared the trophic status of the coastal waters and open sea regions of the South-Eastern Baltic Sea. Gailhard et al., 2002 studied the microalgal population along the French coast. Mackey et al., 2002 recorded that the grazing of picophytoplankton by macrograzers may make an important contribution to the "biological pump". The monthly changes of chlorophyll a, phytoplankton abundance and nutrient concentrations at two stations, one inshore and other at the deep waters, of the northern part of Iskenderun Bay were investigated by Polat, 2002. Huang et al., 2004 attempted the comparison of the composition, abundance and spatial distribution of phytoplankton in the rainy and dry seasons of Pearl River estuary. The abundance of phytoplankton in the rainy season was higher than that of the dry season.

Domingues et al., 2005 and Lopes et al, 2007 studied the relationship between phytoplankton succession and nutrient dynamics in the Guadiana estuary and the Ria de Aveiro estuary respectively. Thomas et al., 2005 observed that Mhlaga and Mdloti estuarine waters were eutrophicated but the short residence time limits the phytoplankton blooms. Azevedo et al., 2006 studied the pelagic metabolism of the Douro estuary in Portugal. A decreasing trend in water column primary production related with higher nitrogen concentrations and phytoplankton biomass from riverine origin was observed. Community respiration was higher in the more urbanised stretch of the estuary and heterotrophy dominated in the entire estuary.

Coelho et al., 2007 studied the community succession of phytoplankton density in the Foz de Almargem estuary. The seasonal relationship between phytoplankton production, nutrient distribution and freshwater flow were examined by Murrel et al., 2007 in a subtropical estuary. The flood caused high turbidity and rapid flushing, severely reducing phytoplankton production and biomass accumulation. Following the flood, phytoplankton biomass and productivity sharply increased. Buford et al., 2008 reported that anthropogenic nutrient inputs had an effect on the primary production in Darwin harbour, Australia. Cymbola et al., 2008 demonstrated that sediment-derived phosphorus stimulates phytoplankton growth, but that its effect on phytoplankton dynamics is modulated by other factors, such as light. Gle et al., 2008 studied the seasonal and spatial variability of nutrients and primary production in the Arcachon Bay, France.

Costa et al., 2009 observed that phytoplankton functional groups in the estuary of the Paraiba do Sul River were represented by fresh water organisms, indicating the strong influence of the river. Farrell et al., 2009 attempted to study the dynamic effect of free floating plants on phytoplankton ecology. The field experiments revealed that persistent free floating plants cuts light penetration resulted in the lose of species and low biomass, yet high diversity and productivity is maintained. The lack of free floating plants resulted in the nitrogen limiting condition. The fluctuating free floating plant covers help to maintain the diversity and richness of the shallow lakes. Muylaert et al., 2009 studied the phytoplankton diversity and community composition in the Schelde river estuary. Ramadani et al., 2009 studied the effect of environmental parameters on the qualitative and quantitative composition of phytoplankton and zooplankton in the coastal lagoons of North Africa. The major environmental parameters influencing the hydrological regimes are the salinity, suspended sediment dynamics and excess of nutrients.

Distribution of phytoplankton density and their relationships to physicochemical variables in the Na Thap River, Thailand were investigated by Lueangthuwapranit et al., 2011. Cloern et al., 2014 gave a detailed review on the phytoplankton primary production in the world's estuarine-coastal ecosystems. Jiang et al., 2014 attempted to study the response of the summer phytoplankton community towards drastic environmental changes in the Changjiang estuary, during the past 50 years. The dominant species shifted from temperate-subtropical/ eurythermal to subtropical-tropical/eury thermal taxa in the warmer water caused by global warming and hydrographic changes. Jiang et al., 2015 conducted studies to understand the factor which influences the phytoplankton community structure in the Changjiang estuary. Shen et al., 2015 attempted to study the aquatic metabolism response towards hydrologic alterations in the Yellow river estuary in China. Aquatic metabolism is an integrative measurement of aquatic system functioning and can be used to assess the impairment. Aquatic metabolism includes gross primary production, ecosystem respiration and net ecosystem production. Turbidity and water temperature were the important factors influencing the rate of metabolism in estuaries.

A detailed work done on the plankton and hydrology of the Indian coastal waters along the coastal waters of India was done by Menon, 1931; Aiyar et al., 1936; Bal and Pradhan, 1945 and Subrahmanyan, 1946. Ganapathi and Rao, 1958 reported that phytoplankton production in the coasts was stimulated by nutrient regeneration caused by dredging. The first attempt to study the production of organic matter along with their relation to fish landings from the southwest coast of India was done by

Subrahmanyan, 1959. Subramanyan and Sarma, 1959 gave a detailed account on the seasonal distribution of various phytoplankton. Prasad and Nair, 1963 investigated the organic production in the Gulf of Mannar. Dehadrai and Bhargava, 1972 noted the two different patterns of seasonal changes in the environmental features, in relation to high and low tide in the Mandovi and Zuari estuaries. Bhargava, 1973 conducted a detailed study on the diurnal variation in phytoplankton pigments of Mandovi estuary. A brief account on the productivity of the tropical seas was given by Ganapathi, 1973. Balasubramaniam, 1974 studied the seasonal variations in chlorophyll a in three environments: sea grass bed, coral reef and estuary. Bhargava and Dwivedi, 1976 studied the seasonal distribution of phytoplankton pigments in the estuarine system of Goa. Bhattathiri et al., 1976 reported production at different trophic levels in the estuarine system of Goa.

Gajbhiye et al., 1984 observed the plankton of the Narmada estuary and adjacent creeks. Venu and Seshavatharam, 1984 reported that physical factors such as water depth, percentage light transmission, turbidity and a few nutrient factors such as chlorides, sulphates and magnesium showed significant relationship with the plankton production in the Kondakarla Lake in Vishakhapatanam. Marichamy et al., 1985 investigated the primary and secondary production in relation to hydrography in the inshore waters of Tuticorin. Silas, 1986 studied the ecology and production of a saline lagoon at Mandapam. Devassy and Goes, 1989 determined the seasonal patterns of phytoplankton biomass and productivity in the Mandovi- Zuari estuarine complex. Edward and

Ayyankavu, 1992 studied the phytoplankton distribution in the Kollidam estuary in the southeast coast of India. The maximum plankton density was recorded in the summer season whereas the minimum was noted in the monsoon season.

Gopinathan and Rodrigo, 1991 investigated the primary production in the inshore waters of Tuticorin and indicated three peak periods first during March-April, second during July and the third during September-October. Bhattathiri, 1992 gave a brief description on the primary production in tropical marine ecosystems. Ram and Goswami, 1993 conducted studies on the phytoplankton biomass in terms of chlorophyll a and reported that temperature, salinity and nutrients influence the distribution of phytoplankton. Gopinathan et al., 1994 reported the annual variation of primary production and chlorophyll a in the inshore area of Tuticorin indicated three peak periods during March-April, June-July and September-October. The multiple regression analysis indicated significant levels of correlation by chlorophyll a and nitrates with primary production. Among the nutrients only nitrate and phosphate had influence on primary production.

Sathpathy and Nair, 1996 studied the phytoplankton blooms occurring in coastal ecosystems and stated that high nutrient concentration permit seasonal phytoplankton bloom and it will result in lowest dissolved oxygen values and highest suspended matter. Nair et al., 1998 correlated the selected water quality parameters such as DO, salinity and nutrients with chlorophyll a, phaeophytin, primary productivity, zooplankton and benthos in the Vasishti River. Spatio-temporal variations of phytoplankton pigments in Talapady lagoon, a shallow coastal lagoon near Manglore on the south west coast of India was studied by Nair and Gowda (1999). Gowda et al. (2002) observed the primary production in relation to chlorophyll a and phytoplankton in theGurupur estuary. Kumari et al. (2002) investigated primary production, phytoplankton biomass, particulate organic carbon and particulate organic nitrogen in the Mandovi-Zuari estuaries of Goa. Manjappa et al. (2002) reported that chlorophyll a values exhibited a significant positive correlation with benthic phytoplankton biomass, whereas it was inversely related with sediment nitrogen and phosphorus. Tiwari and Nair (2002) reported that industrialisation along the banks of the Dharmatar creek resulted in the loss of biodiversity in the phytoplankton and zooplankton community. Madhav and Kondalrao(2004) recorded the endemic phytoplankton groups in the southeast (34 species) and the northeast (29 species) coastal regions of India. Vijayakumaran et al. (2005) estimated the production in relation to hydrography of the inshore surface waters off Visakhapatnam. Monthly variability of chlorophyll and associated physical parameters in the south west Bay of Bengal water using remote sensing data was recorded by Sarangi et al. (2008).

Naik et al. (2009) made an attempt to study the seasonal variations of phytoplankton in the Mahanadi estuary a positive correlation between phytoplankton population, with chlorophyll a and dissolve oxygen were recorded in all three sampling seasons. Panigrahi et al. (2009) studied the variability of nutrients and phytoplankton biomass in Chilka lagoon in Odisha. They reported that hydrodynamics of the lagoon, weed coverage, input of urban sewage through tributaries and agricultural runoff are probably the key factor controlling the trophic conditions of lagoon. Manna et al. (2010) studiedthe eutrophicated status and toxic algal blooms in the Sunderbans estuary. Kadam and Tiwari (2011) reported about 52 genera of phytoplankton from the Dahanu-creek on the west coast of India. Patil and Anil (2011) reported that the phytoplankton community shifted from the low saline adapted forms to high saline forms and vice versa in the Zuary estuary. Chaudhuri et al. (2012) explored the estuarine metabolism in the Sundarbans as a function of both physico-chemical and biological processes. Sahu et al. (2012) studied the variations in the community structure of phytoplankton in relation to the physico-chemical properties of coastal waterson the southeast coast of India. They observed a threefold increase in the phytoplankton species composition compared to the earlier findings. Salinity and nitrate influenced the phytoplankton species composition and its growth. Seasonal variation of phytoplankton community in Gopalpur creek in Odisha was done by Baliarsingh et al. (2013). According to Jyothibabu et al. (2013) the picoplankton and nanoplankton carbon biomass was in the Gulf of Mannar (av. 62.2 mgC/m^3) as compared to the Palk Bay (av.47.6 mgC/m^3). The carbon biomass in the Gulf of Mannar and Palk Bay was mainly contributed by nanoplankton (>70%) signifying their trophic preference in the study area. Shruthi and Rajashekhar (2014) observed the species composition, abundance and diversity of phytoplankton in theNethravati-Gurupur estuary.

The primary production and distribution of phytoplankton in the estuarine waters of Kerala is one of the major areas of ecological research in the region.Chidambaram and Menon(1945) attempted to correlate the quantity of fish landed on the Malabar Coast with the total plankton volumes, limiting the studies only to the post-monsoon months. George(1953) examined the marine plankton in the coastal waters of Calicut in terms of the hydrological conditions.

Qasim and Reddy(1967) reported that the phytoplankton crop of the Cochin backwater during the monsoon period months (June-September) was largely made up of diatoms and dinoflagellates. No constant relation between chlorophylls a, b and c, and plant carotenoids, was obtained and it is suggested that high values of chlorophyll c and carotenoids obtained in the present investigation may be because the extract contained a substantial quantity of dead chlorophyll and their derivatives coming from dertritus and stirred up sediment. Qasim et al.(1968)studied the solar radiation, its penetration and compensation depth in the Cochin backwaters. Qasim et al. (1969) had accounted the organic production of the Cochin estuary. Qasim et al.(1972) conducted a series of experiments to demonstrate the problems related with the measurement of primary production using radiocarbon technique. It was concluded that bottle size had no appreciable effect on the measurement of primary production.Qasim et al. (1972); Devassy and Bhattathiri(1974) found that salinity controls the species composition and succession of phytoplankton. It has apparently no influence on primary production in the Cochin estuary. Gopinathan et al. (1972,1974,1984) studied the various aspects phytoplankton and its production in the Cochin estuary. Primary production of VembanadLake was studied by Nair et al. (1975), and Pillai et al.(1975).

Kumaran and Rao (1975) are of the opinion that the concentration of nanoplankton, largely composed of diatoms, is relatively high throughout the year.Most of them are marine forms, which renders the area near the barmouth the most productive. The environmental conditions immediately after or following a break in the monsoon period are favourable for the sudden spurts in plankton abundance. Primary productivity and related aspects in the Vizhinjam Bay and the adjacent Arabian Sea were investigated from April 1983 to March 1984 by Jacob and Kumar (1984). Nair et al.(1984) conducted a detailed study on the primary production of Ashtamudi estuary. Jayalakshmi et al. (1986) attempted to study the seasonal distribution of phytoplankton. Selvaraj(2000) studied the validity of net primary productivity estimation techniques in shallow coastal waters of the intertidal surf zone of the sea at Cochin from July 1996 to June 1999.Akram(2002) studied the phytoplankton community based on the distribution of size in the coastal waters of Cochin. Generally, the size groups of planktonic algae greater than 53 um are dominated by filamentous- chain forming and colonial diatoms; while the size groups smaller than 53 um usually formed of small and unicellular pinnate and centric diatoms, dinoflagellates and some other flagellates and blue-green algae.

Selvaraj et al. (2003) gave a comparative account on the seasonal variation of phytoplankton and productivity in the surf zone and backwaters of Cochin. The study revealed that the surf zone was relatively more productive in terms of cell density and species diversity as compared to the Cochin backwater. Balachandran et al. (2008) evaluated the abiotic factors controlling the production of phytoplankton in a coastal marine region of Cochin. The processes were assessed using multiple regression models. The model explains 77% of variability for chlorophyll a production is indicative of preconditioning of the coastal waters. The phytoplankton production was found to be sensitive to the environment, which varies seasonally. Further the study suggests that supply of organic matter and grazing of zooplankton would improve the model efficiency. According to Gupta et al., 2009, the Cochin estuary was a previously autotrophic (CO_2 sink) system, has transformed into a heterotrophic (CO_2 source) system due to rapid urbanization and industrialization in the region.

Madhu et al., 2010a found that short term variations in water quality play a significant role on thevariability of phytoplankton in the Cochin estuary. The predominant nanoplankton communities during the pre-monsoon perform as active converters of inorganic nutrients into phytoplankton biomass, whereas during the post monsoon due to the limited growth of nanoplankton populations, the inorganic nutrients could not be efficiently fixed into organic form and sustains heterotrophy due to high bacterial respiration. According to Madhu et al., 2010b the nanoplankton community formed the major part of chlorophyll a concentration and primary production, both in the Cochin estuary and the coastal waters. Meera and Bijoy Nandan, 2010 reported that the chlorophyll pigments in the Valanthakad backwaters showed a negative correlation with phosphate- phosphorus and nitrite-nitrogen. The water quality and productivity of the backwaters is impacted due to hospital waste discharge and decaying slaughter house waste. Haridevi, 2013 studied the spatio-temporal variation of phytoplankton and its growth limiting factors in Cochin estuary. Bijoy Nandan et al., 2014 studied the primary production of the Kodungallur-Azhikode estuary. Annual nutrient and carbon supply in the KAE increased due to a range of impacts such as catchment degradation caused by intensive sand mining, aquaculture, pollution, fish processing wastes discharge, artificial breaching, urban encroachment and harbour development. Sooria et al., 2015 described the seasonal planktonic food web in the Cochin estuary. The study showed that significant changes in the abundance and dynamics of plankton food web components were governed mostly by the spatial and seasonal changes in hydrography rather than short-term changes induced by tide.

4.3 Materials and Methods

4.3.1 Primary productivity- (Gross and Net production) and community respiration

The primary productivity (gross and net production) was estimated by using the *in situ* incubation method, employing the Light and Dark bottle method (Strickland and Parsons, 1972). This method is based on the principle that photosynthesis of phytoplankton is accompanied by the release of oxygen. The amount of oxygen so liberated is considered as a measure of primary production. These rates were converted to carbon units, assuming a photosynthetic quotient (PQ) of 1.3 based on the C:N:P molar elemental composition of phytoplankton (Redfield et al., 1963), and a respiratory quotient (RQ) of 1 (Hopkinson and Smith, 2005).

Productivity is defined as the rate at which inorganic carbon is converted to an organic form. Photosynthesis results in the formation of organic compounds, release of oxygen and reduction of carbon dioxide. The productivity is calculated based on the assumption that one atom of carbon is assimilated for each molecule of oxygen released. The advantage of this method is that it estimates gross (GPP) and net (NPP) productivity along with community respiration (CR).The bacterial population is very active in estuaries and consume a significant quantity of oxygen during the nitrification process. Thisoxygen consumption should be included to avoid overestimation of community respiration (APHA, 2005; Chaudhuri et al., 2012). The nitrate interference is effectively removed by the azide modified oxygen method.

The water samples were collected from the surface and at a pre-determined depth (on the basis of light availability), each in three bottles (initial, light and dark bottles). The light and dark bottles are normally incubated for 3 hours (between dawn and midday) at the respective depths where the water samples were taken for the experiment (APHA, 2005). The control bottle containing water samples were immediately fixed with 1 ml of manganese sulphate and 1 ml of alkaline iodide (fixatives normally used in the determination of oxygen by Winkler's method).After the incubation period, the bottles were taken out and fixed similar to control bottles. All the bottles were brought to the laboratory in cold condition for analysis. The oxygen content in the different bottles was determined by Winkler's method with manganous sulphate ($MnSO_4$), alkaline iodide and sulphuric acid (H_2SO_4).

In the dark bottle, respiration of plants, animals and bacteria consumes oxygen. The difference between the oxygen concentration in the control bottle and the dark bottle provides the community respiration. In the light bottle, photosynthesis, respiration and nitrification occur simultaneously. The difference in oxygen concentration between the light bottle and the dark bottle as well as the light bottle and the control bottle provides gross and net productivity respectively.The productivitywas expressed in the unit gC $m^{-3}day^{-1}$ (APHA, 2005).

4.3.2 Annual Water Column production

For the estimation of water column production, the average euphotic zone depth of the estuary was calculated and the photoperiod was taken as 12 hours. This is based on the assumption that light penetrates about 70-80% of the water column. The euphotic zone depth of the Cochin estuary ranged from 2-6m (Strickland, 1965; Qasim et al., 1968; Josanto, 1971; Renjith et al., 2004). The euphotic zone is taken as roughly three times the Secchi disc depth (Nair et al., 1970). But the shallowness of the estuary allows the light to penetrate upto the bottom, resultingin high benthic productivity. So, we consider the euphotic zone depth as 80% of the Secchi disc depth. The gross primary productivity (in terms of area) was converted to column productivity (in terms of volume) by multiplying it with the euphotic depth. From this, the annual column production was calculated (APHA, 2005).

4.3.3 Photosynthetic efficiency

The photosynthetic efficiency of the estuary was calculated from the column production as well as the solar radiation data(source: European centre for median range weather forecasts) (Qasim et al., 1969).

4.3.4 Estimation of Biomass

Assessment of biomass (standing crop) of phytoplankton is important in ecological studies because the level of biomass indicates the fertility and fishery resources, directly or indirectly. It was measured by following methods-chlorophyll measurements, algal biomass, phytoplankton carbon and cell count method.

4.3.4.1 Chlorophyll measurements

The chlorophyll a, b, c and the accessory pigments like phaeophytin, carotenoids and active chlorophyll 'a' were estimated by the Vacuum filtration –acetone extraction method, using the membrane filter assembly (Santhanam et al., 1976; Parsons et al., 1984; APHA, 2005).The technique is chiefly employed to estimate the standing crop of phytoplankton.

For the estimation of chlorophyll a, b, c and the accessory pigments like phaeophytin and carotenoids, one litre of surface water was filtered through whatman GF/C glass fibre filters (pore size-1µm) with 47 mm diameter, extracted with 90% acetone for 24 hours in the dark and the optical density was measured in a spectrophotometer (Systronics, UV-VIS spectrophotometer, Model No.117) before and after acidification. The filter retained all the size fractions of phytoplankton (pico, nano and micro plankton). The chlorophyll a, b, c and the accessory pigments, phaeophytin and carotenoids were expressed in mg m^{-3} (APHA, 2005).

Total chlorophyll (chl 'a'+ chl 'b'+ chl 'c'), total pigments (chlorophylls+ carotenoids+ pheophytin) and ratios of chlorophyll 'b/a', chlorophyll 'c/a' and total phytoplankton chlorophyll 'a' to total phytoplankton chlorophyll ‘a’ + phaeopigments concentration was calculated. These ratios indicate the state of phytoplankton population and for a healthy state of phytoplankton assemblages it is less than unity (Bhargava and Dwivedi, 1976; Bidigare et al., 1986; Thomas et al., 2005).

4.3.4.2 Algal biomass

Chlorophyll ‘a’ is used as an algal biomass indicator. Assuming that chlorophyll ‘a’ constitutes, on an average, 1.5% of the dry weight of the organic matter (ash-free weight) of algae, algal biomass can be estimated by multiplying the chlorophyll content by a factor of 67 (APHA, 2005). The wet weight of algal biomass was expressed in g m^{-3} and dry weight as ml dry $weight^{-1}$.

4.3.4.3 Phytoplankton carbon

The chlorophyll ‘a’ concentration was converted to equivalent organic carbon biomass by using suitable conversion factors. A factor of 50 was used to convert the chlorophyll ‘a’ into equivalent carbon biomass (Antia et al., 1963; Jonge, 1980; Shiomoto, 1997). The values obtained had accuracy greater than 90% when compared with the results obtained by the biovolume estimation method (Jyothibabu et al., 2013). Phytoplankton carbonwas expressed in mgC m^{-3}.

4.3.5 Microphytoplankton

Samples for microphytoplankton were collected by filtering~50 litres of sub-surface water through conical plankton net made of thin finest bolting silk of mesh size 20 µm. The resulting concentrated microphytoplankton was transferred to a 100 ml bottle and preserved in

3% buffered formalin and neutralized formaldehyde solution. The samples were allowed to stand in a 25 ml measuring cylinder for about 24 hours and the settling volume was noted.

The total number of phytoplankton cells per litre is one of the measures of biomass of phytoplankton in the study area (Verlenkar and Desai, 2004). Quantitative estimation of phytoplankton was done using the drop count method. A common glass slide is mounted with a drop of the concentrated phytoplankton sample in glycerol and covered with a square-shaped cover slip. All the phytoplankton present in the drop was counted.

The number of drops which form 1ml has to be counted by adding drops of the water into the graduated centrifuge tube. The total number of phytoplankton in 1ml of the sample was calculated by counting each drop. The total number of planktonic algal species present in one litre of the water sample was calculated using the formula proposed by Santhanam et al., 1989; Verlenkar and Desai, 2004). The identification of phytoplankton was done using a binocular microscope- Leica DM 500 and standard identification keys (Allen and Cupp, 1935; Subrahmanyan, 1946, 1959; Davis, 1955; Tomas, 1997).

4.3.6 Trophic index (TRIX)

The use of TRIX is to evaluate the degree of anthropogenic influence on estuarine eutrophication. TRIX is a combination of four state variables that directly express productivity: chlorophyll 'a' (mg m^{-3}), oxygen as absolute (%) deviation from saturation [abs|100-% 0|= aD%0], and nutritional factors available: dissolved inorganic nitrogen (mg m^{-3} N), and dissolved inorganic phosphorus (mg m^{-3} P) (Jayachandran and Bijoy Nandan 2012; Coelho et al., 2007 Vollenweider et al., 1998).The oxygen-saturation was calculated using temperature, salinity and dissolved oxygen values (Benson and Crause 1984).

It is calculated as follows:

TRIX= (Log10 (Chl-a X aD%O X DIN X DIP) +k) m

The parameters k=1.5 and m=12/10=1.2, are scale coefficients, introduced to fix the lower limit value of the index. Numerically, the index is scaled from 0 to 10, covering a wide gap of trophic condition from oligotrophy to eutrophy. TRIX point values assign an immediate measurement to the trophic level of coastal waters. Values exceeding 6 TRIX units are typical of highly productive coastal waters. Values lower than 4 TRIX units are associated with scarcely productive coastal waters.TRIXvalues lower than 3 are usually found in the open sea.

Table 4.1 List of values and the designations of the TRIX scale (Vollenweider et al., 1998)

Scale TRIX	State water quality	Level of eutrophication
0-4	High	Low
4-5	Good	Medium
5-6	Bad	High
6-10	Poor	Elevated

4.3.7 Efficiency coefficient

The efficiency coefficient is defined as:

Eff. Coeff= Log10 (Chl a X a D%O) (minN X DIP)

Numerically, values are usually negative. Low values would indicate low nutrient utilization and vice versa (Jayachandran and Bijoy Nandan 2012; Vollenweider et al., 1998).

4.3.8 Data analysis

The standard deviation, two way ANOVA (Analysis of Variance) was calculated using SPSS.22. By using PRIMER v6 multivariate analysis-Cluster analysis with SIMPROF was done, as mentioned in materials and methods of the chapter 3 - water quality of the Cochin estuary.

4.3.8.1 Univariate methods

Univariate analysis uses diversity indices, which attempt to combine the data on abundance within a species in a community into a single number. The state of the community can then be understood from this number.

4.3.8.1.1 Species richness- Margalef's index (Margalef, 1958)

$d = (S-1) / \log N$

Where

d = species richness
S = total number of species
N = total number of individuals

4.3.8.1.2 Species evenness- Pielou's index (Pielou, 1966)

$j' = H'/\log_2 S$ or $H'/\ln S$

Where

J' = evenness,

H' = species diversity

S = total number of species

4.3.8.1.3 Species diversity- Shannon-Weiner index (Shannon Weiner, 1949)

$H' = -\Sigma S\ Pi \log 2\ Pi.....$

$i = 1$

Where

H' = the species diversity

S = the number of species

pi = the proportion of individuals of each species belonging to the i^{th} species of the total number of individuals (number of individuals of the i^{th} species)

4.3.8.1.4 Species dominance- Simpson's index (Simpson 1949)

$D = 1/\lambda$

Where

$\lambda = \Sigma Pi^2$

$Pi = ni/N$

Where

Ni = number of individuals of i, i^2 etc.

N = total number of individuals.

4.3.8.2 Multivariate methods

4.3.8.2.1 MDS Plots (Non-metric multi dimensional scaling)

The primary outcome of MDS is a spatial configuration in which the objects are represented as points. The points in this spatial representation are arranged in such a way that their distances correspond to the similarities of the objects. Similar objects are represented by points that are close to each other and dissimilar objects by points that are far apart. In metric multi dimension scaling developed by Shepard (1962) and Kruskal (1964), the ordinal information in the proximities is used for constructing the spatial configuration (Clarke and Gorely, 2006).

4.3.8.2.2 BEST analysis

BIO-ENV procedure is used to link biological community analyses to environmental variables or to examine the extent to which environmental data, such as physico-chemical data, is related to the observed biological pattern (Clarke and Gorely, 2006). The BIO-ENV procedure calculates a measure of agreement between the two similarity matrices: the fixed biotic similarity matrix (using Bray- Curtis similarity on the biotic data) and each of the possible abiotic matrices (PCA on combinations of the abiotic data). This is done by using the Spearman rank correlation, which ranks the subsets of variables that best 'matches' the biological patterns.

4.4 Results

4.4.1 Gross primary productivity

The gross primary productivity (GPP) showed an average of 2.27 ± 0.46 $gCm^{-3}d^{-1}$ during the study period. Highest GPP was observed during the post-monsoon period (2.57 ± 0.26 gC m^{-3} d^{-1}) followed by the monsoon period (2.12 ± 0.26 gC m^{-3} d^{-1}) and pre-monsoon period (2.11± 0.26 gC m^{-3} d^{-1}). The values of GPP were identical in the study region during the monsoon periods of 2009-10 and 2010-11.

Station wise mean values of GPP were highest at station 8 (2.51± 0.23 gC m^{-3} d^{-1}) and lowest at station 1 (1.87 ± 0.23 gC m^{-3} d^{-1}). The recorded GPP was maximum in the northern zone (2.40± 0.15 gC m^{-3} d^{-1}) and minimum in the central zone (2.11± 0.15 gC m^{-3} d^{-1}). The surface waters were found to be more productive than the bottom waters. The maximum GPP was observed at station 5 (2.50 gC m^{-3} d^{-1}) and minimum at station 1 (1.87 gC m^{-3} d^{-1}) in the central zone. Station 2 and 3 had similar values of GPP, 2.21 gC m^{-3} d^{-1}; 2.28 gC m^{-3} d^{-1} respectively. In the northern zone, the GPP ranged from 2.22 gC m^{-3} d^{-1}at station 9 to 2.51 gC m^{-3} d^{-1} at station 8.

The mean monthly variation of GPP in Cochin estuary during the study period is given in Table 4.1.1 and Fig. 4.1. Mean monthly values of recorded GPP were maximum in April 2011 at station 8 (4.28 gC m^{-3} d^{-1}) and minimum in February 2010 at station 3 (0.77 gC m^{-3} d^{-1}). The annual GPP was higher during the 2010-11 period (2.40 ± 0.49 gC m^{-3} d^{-1}) compared to the 2009-10 period (2.14± 0.41gC m^{-3} d^{-1}). During the 2010-11 period, GPP ranged from 1.74 gC m^{-3} d^{-1} in June 2010 to 3.05 gC m^{-3} d^{-1} in October 2010. In the 2010-11 period, the maximum GPP was 2.80 gC m^{-3} d^{-1} in December 2009 and minimum value was 1.50 gC m^{-3} d^{-1}in March 2010.

ANOVA result of gross primary production was significant at 1% level between seasons ($p \leq 0.001$) and between stations ($p \leq 0.001$) (Table 4.1.4).

Table 4.1.1 Mean monthly variation of gross primary productivity in selected stations of Cochin estuary during 2009-11 period.

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Mean
J'09	0.81	0.81	1.01	2.42	2.02	2.52	2.52	2.02	2.52	1.85
J	2.02	2.02	2.02	1.76	2.02	2.02	2.02	2.52	2.02	2.04
A	3.02	3.28	2.77	2.52	2.52	2.02	1.51	2.52	2.02	2.46
S	2.02	1.51	3.53	2.52	2.52	2.02	1.51	3.02	2.02	2.30
O	2.52	3.78	2.77	3.53	3.28	1.01	2.02	2.27	1.51	2.52
N	2.02	2.02	2.02	2.27	3.78	2.52	2.02	3.02	2.02	2.41
D'09	2.52	3.02	2.27	3.02	3.02	3.28	3.53	2.52	2.02	2.80
J'10	2.52	2.02	2.52	2.02	2.02	3.02	3.03	2.52	2.52	2.46
F	1.53	1.53	0.77	1.53	1.02	2.93	3.06	2.55	1.53	1.83
M	1.28	1.02	1.02	1.28	1.79	3.06	1.79	1.02	1.28	1.50
A	1.53	2.04	3.06	2.04	1.53	1.28	2.04	1.28	1.53	1.81
M	1.53	2.55	2.55	1.02	2.55	1.02	1.53	1.02	1.02	1.64
J	0.81	1.41	1.01	0.81	2.52	2.52	2.52	2.02	2.02	1.74
J	1.41	0.81	1.01	1.01	2.52	3.53	3.28	3.02	3.53	2.23
A	0.81	1.21	0.81	1.21	3.02	3.02	2.02	2.52	2.02	1.85
S	1.41	3.02	3.23	1.41	2.27	2.77	2.02	3.02	3.53	2.52
O	3.02	3.65	3.53	3.02	3.91	2.77	2.65	2.90	2.02	3.05
N	2.17	2.77	2.12	2.02	2.52	2.52	2.77	2.77	2.77	2.49
D'10	1.81	1.01	1.21	1.01	2.02	3.02	2.52	2.02	2.02	1.85
J'11	2.52	2.77	3.02	3.02	3.02	2.02	3.02	3.53	3.53	2.94
F	1.47	1.79	1.85	1.47	1.72	2.36	2.42	1.47	1.34	1.76
M	2.02	3.02	3.53	2.02	2.77	2.77	2.52	3.53	3.28	2.83
A	2.02	2.02	3.53	2.02	3.02	3.02	2.52	4.28	2.52	2.77
M'11	2.02	4.03	3.53	2.02	2.52	2.52	2.52	2.77	2.77	2.74

Table 4.1.2 Mean season wise variation of gross primary productivity in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	1.97±0.91	1.11±0.35	2.39±0.25	2.38±0.52	1.47±0.13	1.88±0.27
2	1.9±1.04	1.61±0.97	2.71±0.86	2.55±1.11	1.79±0.66	2.71±1.03
3	2.33±1.08	1.51±1.15	2.39±0.33	2.47±1.02	1.85±1.13	3.11±0.84
4	2.31±0.36	1.11±0.26	2.71±0.69	2.27±0.97	1.47±0.44	1.88±0.27
5	2.27±0.29	2.58±0.32	3.02±0.74	2.87±0.81	1.72±0.64	2.51±0.56
6	2.14±0.25	2.96±0.43	2.46±1.02	2.58±0.43	2.07±1.07	2.67±0.29
7	1.89±0.48	2.46±0.6	2.65±0.76	2.74±0.22	2.1±0.67	2.5±0.05
8	2.52±0.41	2.65±0.48	2.58±0.32	2.8±0.62	1.47±0.73	3.01±1.2
9	2.14±0.25	2.77±0.87	2.02±0.41	2.58±0.72	1.34±0.24	2.48±0.82

Table 4.1.3 Mean station wise variation of gross primary productivity (minimum- maximum) selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.81	3.28	0.81	3.02
2	0.81	4.03	0.81	4.54
3	0.51	4.08	0.81	4.03
4	0.81	4.03	0.81	3.28
5	1.02	4.03	0.51	3.78
6	1.01	4.03	1.01	4.03
7	1.01	3.57	1.01	4.03
8	1.02	4.03	1.02	4.54
9	1.01	4.03	1.02	4.03

Table 4.1.4 ANOVA of gross primary productivity in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	1.705	2.421
Season	2	9.624	13.667**
Station	8	2.593	3.682**
Surface water, Bottom water	1	0.039	0.056
Season * Station	16	1.003	1.425
Season * Surface water, Bottom water	2	0.464	0.659
Station * Surface water, Bottom water	8	0.757	1.075
Error	394	0.704	
Total	432		
R^2 = 0.185			

** Variation is significant at 1% level

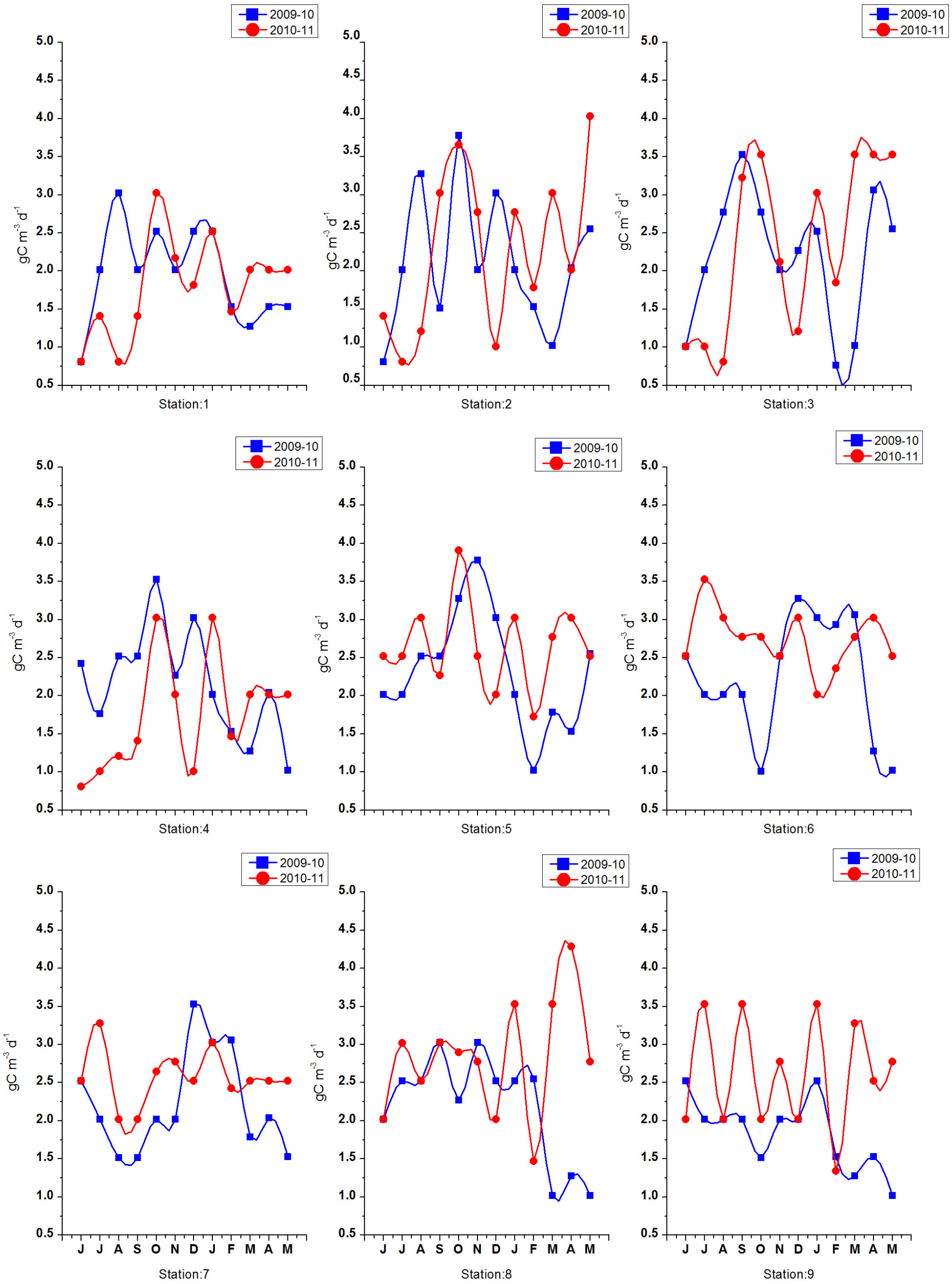


Fig. 4.1. Mean monthly variation of gross primary productivity in selected stations of Cochin estuary during 2009-11 period

4.4.2Net primary productivity

The average net primary production of Cochin estuary was 1.26 ± 0.30 gC m^{-3} d^{-1}. The NPP was higher in the southern zone (1.37± 0.14 gC m^{-3} d^{-1}) and low in the central zone of the estuary (1.11± 0.14 gC m^{-3} d^{-1}). The range of NPP was from 0.93 ± 0.30 gC m^{-3} d^{-1} at station 4 to 1.45 ± 0.30 gC m^{-3} d^{-1} at station 5 in the central zone of the estuary. The NPP was higher at station 3 (1.46 gC m^{-3} d^{-1}) compared to station 2 (1.28 gC m^{-3} d^{-1}) in the southern zone. The range of NPP varied from 1.17 gC m^{-3} d^{-1} at station 9 to 1.40 gC m^{-3} d^{-1} in the northern zone. The mean station wise values of NPP were maximum at station 3 (1.46±0.20 gC m^{-3} d^{-1}) and minimum at station 1 (0.95± 0.20 gC m^{-3} d^{-1}). The station wise variation of NPP was shown in Table 4.2.3.

The highest NPP values were observed in the post-monsoon period (1.44± 0.17 gC m^{-3} d^{-1}) followed by the pre-monsoon period (1.41± 0.17 gC m^{-3} d^{-1}) and monsoon period (1.10 ± 0.17 gC m^{-3} d^{-1}) periods. During the monsoon period, the highest NPP recorded was 3.39 gC m^{-3} d^{-1} in August 2010 and the lowest was 0.39 gC m^{-3} d^{-1} in June 2009. In the post-monsoon period, maximumNPP observed was 3.39 gC$m^{-3}d^{-1}$ in October 2009 and the minimum was 0.39 gC m^{-3} d^{-1} in December 2010. During the pre-monsoon period, NPP ranged from a maximum of 3.67 gC m^{-3} d^{-1} in February 2010 to a common minimum value 0.49 gC m^{-3} d^{-1} in all the pre-monsoon period months of 2010.

The mean monthly values of net primary production in Cochin estuary during 2009-11 period is shown in Table 4.2.1 and Fig.4.2. Mean monthly values of net primary production were maximum in January 2010 at station 7 (3.67 gC m^{-3} d^{-1}) and minimum during the monsoon period months (0.39gC m^{-3} d^{-1}) (June 2010, July 2010, August 2010 and September 2010 and December 2010 at stations 1, 2, 3 and 4 (0.39 gC m^{-3} d^{-1}). The mean annual values of NPP did not show any variation. The value was 1.26 gC m^{-3} d^{-1} for both the years. In the 2009-10 period, the highest NPP of 1.99 gC m^{-3} d^{-1}was recorded in October 2009 and the lowest value of 0.89 gC m^{-3} d^{-1} in June 2009. A maximum NPP of 1.63 gC m^{-3} d^{-1} in October 2010, to a minimum of 0.81 gC m^{-3} d^{-1} in June 2010 was recorded during the 2010-11 period.

ANOVA of net primary production was significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.001$), between the stations and surface and bottom waters ($p \leq 0.01$) (Table 4.2.4).

Table 4.2.1 Mean monthly variation of net primary productivity in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	0.39	0.39	0.39	1.55	0.97	0.97	0.97	0.97	1.45	0.89
J	0.97	0.97	0.97	0.97	0.97	0.97	0.97	1.45	0.97	1.02
A	1.45	0.97	1.94	0.97	1.94	0.97	0.97	1.45	0.97	1.29
S	0.97	0.97	1.45	1.45	0.97	0.97	0.97	1.45	0.97	1.13
O	2.90	3.39	2.90	0.97	2.90	0.97	1.45	1.45	0.97	1.99
N	0.97	0.97	0.97	0.97	2.42	0.97	0.97	1.94	0.97	1.24
D'09	0.97	0.97	2.42	1.45	1.94	2.42	2.42	1.45	0.97	1.67
J'10	1.45	0.97	1.94	0.97	0.97	1.45	1.94	1.45	1.45	1.40
F	0.49	0.98	0.73	0.49	0.97	3.43	3.67	1.47	0.73	1.44
M	0.49	0.49	0.49	0.49	1.22	2.45	1.22	0.49	0.73	0.90
A	0.98	1.47	2.45	1.22	0.73	0.49	0.98	0.49	0.98	1.09
M	0.73	1.71	1.96	0.49	1.96	0.49	0.98	0.49	0.49	1.03
J	0.39	0.58	0.58	0.39	0.97	1.45	0.97	0.97	0.97	0.81
J	0.39	0.39	0.58	0.39	0.97	1.45	0.97	1.45	1.45	0.89
A	0.39	0.77	0.39	0.77	3.39	1.94	0.97	1.45	0.97	1.23
S	0.77	2.32	2.52	0.39	1.94	2.42	0.97	1.45	0.97	1.53
O	1.57	2.06	2.06	1.09	2.06	1.45	1.69	1.57	1.09	1.63
N	0.97	1.16	1.02	1.26	0.97	1.21	1.21	1.69	1.21	1.19
D'10	0.97	0.39	0.58	0.58	0.97	1.45	0.97	0.97	0.97	0.87
J'11	0.97	1.94	1.45	1.94	0.97	0.97	1.45	2.42	1.45	1.51
F	0.67	1.16	1.41	0.67	1.10	1.71	1.71	0.73	0.73	1.10
M	0.97	1.94	1.94	0.97	1.21	0.97	0.97	2.66	2.18	1.53
A	0.97	0.97	2.42	0.97	1.45	0.97	0.97	2.42	1.94	1.45
M'11	0.97	2.90	1.45	0.97	0.97	0.97	0.97	0.97	2.42	1.40

Table 4.2.2 Mean season wise variation of net primary productivity in selected stations of Cochin estuary during 2009-11 period.

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	0.94±0.44	0.48±0.19	1.57±0.92	1.12±0.30	0.67±0.23	0.89±0.15
2	0.82±0.29	1.02±0.89	1.57±1.21	1.39±0.77	1.16±0.54	1.74±0.88
3	1.19±0.66	1.02±1.0	2.06±0.83	1.28±0.63	1.41±0.95	1.8±0.47
4	1.23±0.31	0.48±0.19	1.09±0.24	1.22±0.56	0.67±0.37	0.89±0.15
5	1.21±0.48	1.81±1.14	2.06±0.83	1.24±0.54	1.22±0.53	1.18±0.20
6	0.97±0	1.81±0.46	1.45±0.68	1.27±0.23	1.71±1.47	1.15±0.37
7	0.97±0	0.97±0	1.69±0.62	1.33±0.31	1.71±1.31	1.15±0.37
8	1.33±0.24	1.33±0.24	1.57±0.24	1.66±0.60	0.73±0.49	1.7±0.98
9	1.09±0.24	1.09±0.24	1.09±0.24	1.18±0.21	0.73±0.20	1.82±0.75

Table 4.2.3 Mean station wise variation of net primary productivity (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.39	1.94	0.39	3.87
2	0.39	2.90	0.39	3.87
3	0.39	4.84	0.39	3.10
4	0.39	2.71	0.39	1.94
5	0.49	4.84	0.49	2.90
6	0.49	3.92	0.49	3.87
7	0.49	2.94	0.97	4.41
8	0.49	1.96	0.49	4.35
9	0.49	3.87	0.49	2.90

Table 4.2.4 ANOVA of net primary productivity in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	1.234	2.110
Season	2	4.115	7.038**
Station	8	1.969	3.368**
Surface water, Bottom water	1	0.015	0.026
Season * Station	16	0.579	0.990
Season * Surface water, Bottom water	2	0.175	0.300
Station * Surface water, Bottom water	8	1.505	2.574**
Error	394	0.585	
Total	432		
R^2 = 0.165			

** Variation is significant at 1% level

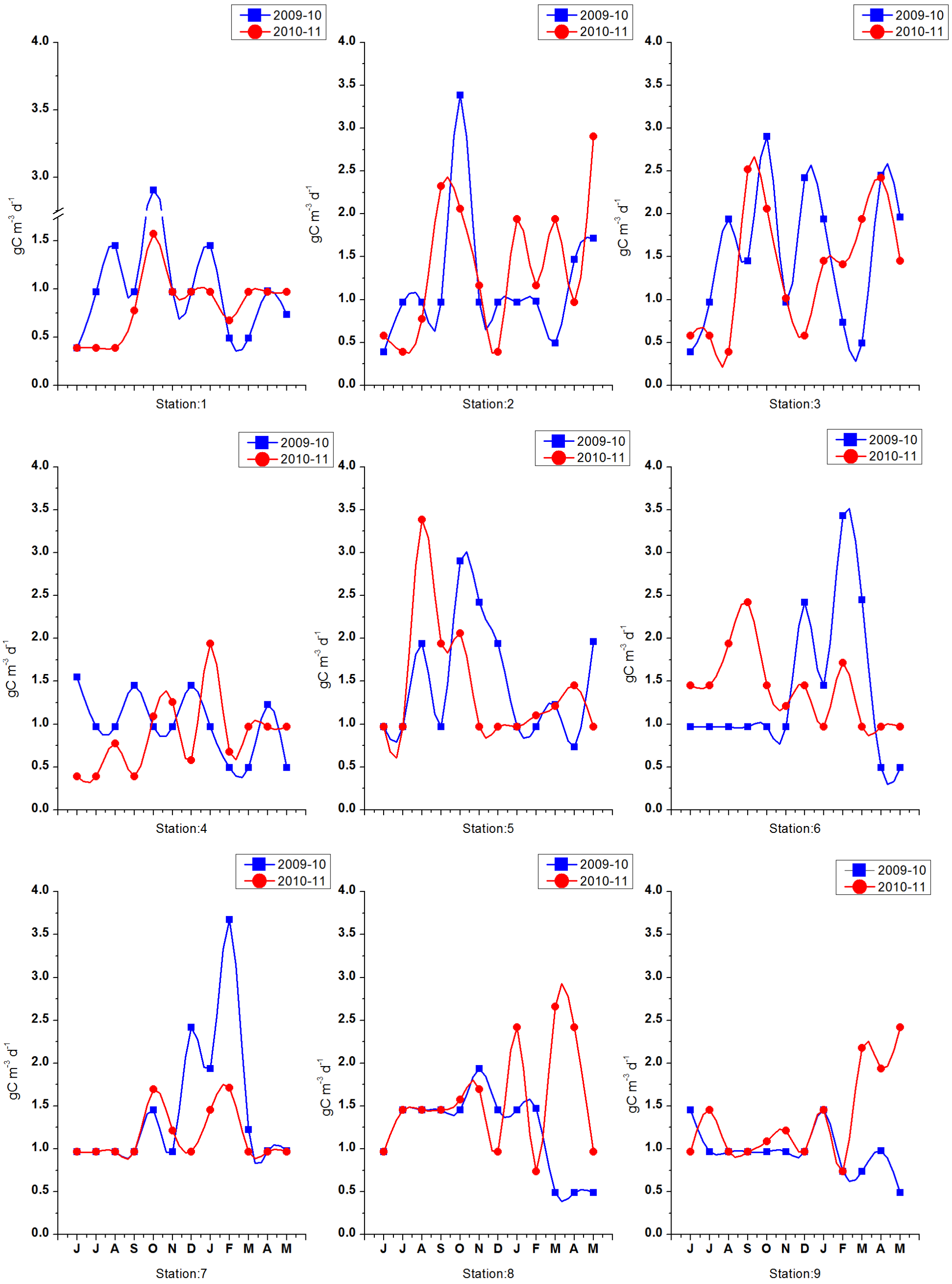


Fig. 4.2. Mean monthly variation of net primary productivity in selected stations of Cochin estuary during 2009-11 period

4.4.3Community respiration

The average respiration in the Cochin estuary is 0.28 ± 0.10 gC m^{-3} d^{-1}. Mean station wise values of respiration ranged from 0.31 ± 0.02 gC m^{-3} d^{-1} at stations6 and 9 to 0.25 ± 0.02 gC m^{-3} d^{-1} at station 1. The highest respiration values were recorded in the northern zone of the estuary (0.30 ± 0.02gCm^{-3} d^{-1}) while the southern and central zone (0.27 ± 0.02 gC m^{-3} d^{-1}) exhibited the same rate of respiration. The respiration was low at station 1 (0.25 gC m^{-3} d^{-1}) compared to stations 4 and 5 in the central zone of the estuary. Stations 2 and 3 in the southern zone of the estuary had similar values of respiration (0.28 gC m^{-3} d^{-1}; 0.26 gC $m^{-3}d^{-1}$). In the northern zone, higher values of respiration were observed at station 6 and 9 (0.31 gC m^{-3} d^{-1}) while lower values were recorded at station 7 (0.29 gC m^{-3} d^{-1}). The spatial variations of community respiration exhibited only small fluctuations during the study period.

Mean monthly values of respiration were maximum in August 2009 at station 2 (1.33 gC m^{-3} d^{-1}) and minimum in February 2010 at station 3 (0.05 gC m^{-3} d^{-1}) (Table 4.3.1 and Fig.4.3).The respiration of the estuary was higher during the 2010-11 period (0.30 ± 0.08 gC $m^{-3}d^{-1}$) as compared to the 2009-10 period (0.27 ± 0.12 gC m^{-3} d^{-1}).

During the post-monsoon period, respiration was the maximum (0.33 ± 0.05 gC m^{-3} d^{-1}) while it was minimum in the pre-monsoon period (0.23 ± 0.05 gC m^{-3} d^{-1}). The highest value of community respiration (1.33 gC m^{-3} d^{-1}) was observed in August 2009 while the lowest value of 0.10 was observed in June 2010, July 2010, August 2010 and June 2009. During the post-monsoon period, respiration ranged from 0.10 gC m^{-3} d^{-1}

in December 2010 to 0.73 gC m^{-3} d^{-1} in November 2009. During the pre-monsoon period, the values ranged from 0.05 gC m^{-3} d^{-1} in February 2010 to 0.73 gC m^{-3} d^{-1} in April 2011.

ANOVA of community respiration was significant at 1% level between seasons ($p \leq 0.001$) (Table 4.3.4).

Table 4.3.1 Mean monthly variation of community respiration in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	0.10	0.10	0.15	0.19	0.24	0.36	0.36	0.24	0.24	0.22
J	0.24	0.24	0.24	0.18	0.24	0.24	0.24	0.24	0.24	0.24
A	0.73	1.33	0.85	0.36	0.24	0.36	0.24	0.24	0.24	0.51
S	0.24	0.24	0.48	0.24	0.36	0.36	0.24	0.36	0.24	0.31
O	0.48	0.48	0.48	0.73	0.48	0.24	0.24	0.48	0.24	0.43
N	0.24	0.24	0.24	0.60	0.73	0.36	0.24	0.24	0.24	0.35
D'09	0.36	0.48	0.24	0.36	0.24	0.48	0.24	0.24	0.24	0.32
J'10	0.24	0.24	0.48	0.24	0.24	0.36	0.24	0.24	0.24	0.28
F	0.24	0.12	0.05	0.24	0.12	0.12	0.12	0.24	0.18	0.16
M	0.18	0.12	0.12	0.18	0.12	0.12	0.12	0.12	0.12	0.14
A	0.12	0.12	0.12	0.18	0.18	0.18	0.24	0.18	0.12	0.16
M	0.18	0.18	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.14
J	0.10	0.19	0.10	0.10	0.36	0.24	0.36	0.24	0.24	0.22
J	0.24	0.10	0.10	0.15	0.36	0.48	0.85	0.36	0.48	0.35
A	0.10	0.10	0.10	0.10	0.24	0.24	0.24	0.24	0.24	0.18
S	0.15	0.15	0.15	0.24	0.36	0.36	0.24	0.36	0.97	0.33
O	0.33	0.36	0.36	0.48	0.42	0.36	0.24	0.30	0.24	0.35
N	0.28	0.38	0.25	0.17	0.36	0.30	0.36	0.24	0.36	0.30
D'10	0.19	0.15	0.15	0.10	0.24	0.36	0.36	0.24	0.24	0.23
J'11	0.36	0.60	0.36	0.24	0.48	0.24	0.36	0.24	0.48	0.38
F	0.18	0.14	0.09	0.18	0.08	0.14	0.15	0.17	0.14	0.14
M	0.24	0.24	0.36	0.24	0.12	0.42	0.36	0.60	0.54	0.35
A	0.24	0.24	0.24	0.24	0.36	0.48	0.36	0.48	0.73	0.38
M'11	0.24	0.24	0.48	0.24	0.36	0.36	0.36	0.73	0.36	0.38

Table 4.3.2 Mean season wise variation of community respiration in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	0.33±0.27	0.15±0.07	0.33±0.12	0.29±0.07	0.18±0.05	0.23±0.03
2	0.48±0.57	0.13±0.05	0.36±0.14	0.37±0.19	0.14±0.03	0.22±0.05
3	0.43±0.31	0.11±0.02	0.36±0.14	0.28±0.10	0.10±0.04	0.30±0.17
4	0.24±0.08	0.15±0.07	0.48±0.22	0.25±0.17	0.18±0.05	0.23±0.03
5	0.27±0.06	0.33±0.06	0.42±0.23	0.38±0.10	0.14±0.03	0.23±0.15
6	0.33±0.06	0.33±0.12	0.36±0.10	0.32±0.06	0.14±0.03	0.35±0.15
7	0.27±0.06	0.42±0.29	0.24±0.00	0.33±0.06	0.15±0.06	0.31±0.10
8	0.27±0.06	0.30±0.07	0.30±0.12	0.26±0.03	0.17±0.06	0.50±0.24
9	0.24±0.00	0.48±0.34	0.24±0.00	0.33±0.12	0.14±0.03	0.44±0.25

Table 4.3.3 Mean station wise variation of community respiration (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.10	0.73	0.10	1.21
2	0.10	1.45	0.10	1.21
3	0.00	0.73	0.00	0.97
4	0.10	0.73	0.10	0.97
5	0.12	0.48	0.12	1.21
6	0.12	0.73	0.12	0.73
7	0.12	0.97	0.12	0.73
8	0.12	0.73	0.12	0.97
9	0.12	0.97	0.12	1.21

Table 4.3.4 ANOVA of community respiration in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	0.048	1.231
Season	2	0.337	8.727**
station	8	0.027	0.711
Surface water, Bottom water	1	0.009	0.225
Season * station	16	0.043	1.120
Season * Surface water, Bottom water	2	0.001	0.026
Station * Surface water, Bottom water	8	0.020	0.529
Error	394	0.039	
Total	432		
R^2= 0.104			

** Variation is significant at 1% level

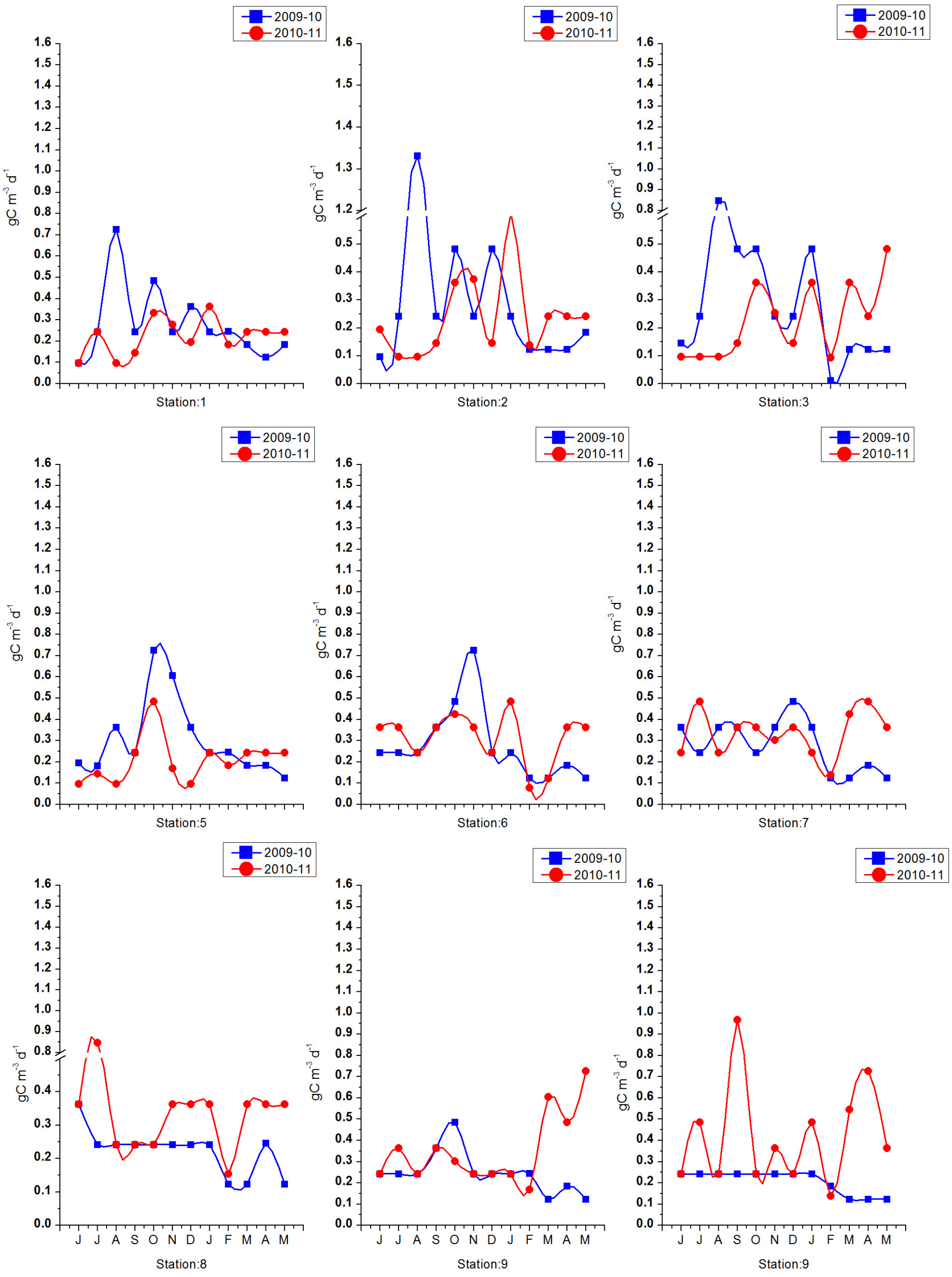


Fig.4.3. Mean monthly variation of community respiration in selected stations of Cochin estuary during 2009-11 period

4.4.4Chlorophyll ' a'

The mean chlorophyll ' a' value for all the nine stations in the estuary was 11.17 ± 8.01 mg m^{-3}.The variation was from 6.30 ± 3.11 mg m^{-3} at station 1 to 14.66 ± 3.11 mg m^{-3} at station 6. Chlorophyll 'a' was found to be higher in the bottom waters of the estuary in most of the stations. At stations 7 and 9, the chlorophyll values were three times higher than that of the other stations. The highest chlorophyll 'a' value (12.43 ± 1.31mg m^{-3}) was recorded in the northern zone of the estuary and the lowest (9.90 ± 1.31mg m^{-3}) in the central zone of the estuary. In the central zone, the values ranged from 6.30 mg m^{-3} at station 1 to 14.54 mg m^{-3} at station 5. The maximum value of chlorophyll 'a' in the southern zone of the estuary was reported from station 3(11.57 mg m^{-3}) while the minimum value was observed at station 2 (9.52 mg m^{-3}). The range of chlorophyll 'a' values in the northern zone varied from 8.10 mg m^{-3} at station 8 to 14.66 mg m^{-3} at station 6.

Relatively higher value of chlorophyll 'a' was observed during the post-monsoon period (15.08 ± 5.58 mg m^{-3}) which decreased to an average of 4.78 ± 5.58 mg m^{-3}during the monsoon period. During the monsoon period, the highest value was recorded in September 2009 (29.36 mg m^{-3}) and the lowest in August 2009 (0.18 mg m^{-3}). In the post-monsoon period, the values ranged from 1.65 mg m^{-3} in December 2010 to 88.86 mg m^{-3} in January 2010. During the pre-monsoon period, the values ranged from 1.41 mg m^{-3} in May 2010 to 64.98 mg m^{-3} in May 2011. Mean season wise variation of chlorophyll 'a' in Cochin estuary during 2009-11 period is given in Table 4.4.2.

Mean monthly values of chlorophyll 'a' were maximum in January 2010 (88.86 mg m^{-3}) at station 7 and minimum in August 2009 (0.18 mg m^{-3}) at station 9. The mean annual value of chlorophyll 'a' was higher during the 2009-10 period (11.74± 9.35 mg m^{-3}) as compared to the 2010-11 period (10.60± 6.78mg m^{-3}). The chlorophyll 'a' values in the Cochin estuary ranged from 2.47 to 35.33 mg m^{-3} during the 2009-10 period whereas in the 2010-11 period, the range of chlorophyll 'a' was from 2.93mg m^{-3} to 24.14 mg m^{-3} (Table 4.4.1 and Fig.4.4).

The ANOVA analysis of chlorophyll 'a' variations were significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.01$) and between seasons and stations ($p \leq 0.001$) (Table 4.4.4).

Table 4.4.1 Mean monthly variation of chlorophyll 'a' in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	7.82	11.87	7.12	5.07	3.64	2.21	1.04	1.70	5.08	5.06
J	1.31	1.00	2.07	1.07	1.04	2.04	0.22	1.36	12.07	2.47
A	2.46	5.24	7.16	5.62	3.58	1.51	0.39	1.21	0.18	3.04
S	19.69	29.36	12.14	8.52	6.32	3.09	2.52	2.54	2.99	9.69
O	24.37	35.06	17.56	33.82	48.96	7.77	9.86	9.80	1.84	21.01
N	4.82	4.63	14.88	15.94	16.74	19.91	12.06	12.57	6.07	11.96
D'09	3.41	4.06	10.63	6.30	21.03	9.05	10.22	3.92	2.56	7.91
J'10	5.04	6.20	9.96	9.25	26.71	76.16	88.86	24.63	71.16	35.33
F	3.21	5.40	12.08	4.60	12.14	30.11	26.06	11.20	29.38	14.91
M	2.48	10.30	21.43	4.70	31.23	33.49	25.59	8.23	7.81	16.14
A	7.14	6.33	18.09	7.25	14.79	7.11	14.15	3.46	4.03	9.15
M	1.83	5.66	8.88	4.29	6.77	2.75	3.21	2.82	1.41	4.18
J	6.83	7.61	5.59	6.36	2.21	1.50	0.81	1.97	1.32	3.80
J	4.10	5.47	6.83	4.59	2.04	1.26	0.43	0.68	0.95	2.93
A	4.96	6.00	5.38	6.91	5.40	2.57	1.47	0.87	0.80	3.82
S	6.44	18.25	10.18	13.00	9.86	7.12	1.41	0.37	0.61	7.47
O	9.41	12.49	13.26	16.33	28.36	28.22	30.25	12.73	20.41	19.05
N	5.24	6.85	8.71	10.04	14.59	16.66	17.79	8.58	11.51	11.11
D'10	2.32	3.19	3.09	4.19	3.94	3.26	2.24	1.65	3.30	3.02
J'11	3.99	4.89	9.79	9.61	11.46	18.51	20.87	11.37	10.81	11.26
F	6.54	9.71	14.22	10.77	22.30	23.29	23.75	9.58	15.54	15.08
M	5.30	8.05	14.29	8.60	16.54	17.53	19.22	15.79	19.52	13.87
A	5.91	6.72	16.66	9.23	25.05	13.66	11.03	10.25	6.94	11.72
M'11	6.50	14.12	27.78	7.04	14.16	23.19	22.48	37.02	64.98	24.14

Table 4.4.2 Mean season wise variation of chlorophyll 'a' in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	7.82±8.4	5.58±1.28	9.41±10.00	5.24±3.03	3.66±2.39	6.06±0.58
2	11.87±12.49	9.33±6.02	12.49±15.08	6.85±4.04	6.92±2.28	9.65±3.22
3	7.12±4.11	7.00±2.22	13.26±3.6	8.71±4.22	15.12±5.68	18.23±6.46
4	5.07±3.07	7.71±3.66	16.33±12.34	10.04±4.96	5.21±1.37	8.91±1.54
5	3.64±2.16	4.88±3.66	28.36±14.33	14.59±10.21	16.24±10.54	19.51±5.03
6	2.21±0.66	3.11±2.74	28.22±32.42	16.66±10.27	18.36±15.68	19.42±4.69
7	1.04±1.05	1.03±0.50	30.25±39.08	17.79±11.64	17.25±10.86	19.12±5.72
8	1.7±0.59	0.97±0.70	12.73±8.71	8.58±4.93	6.43±3.99	18.16±12.88
9	5.08±5.07	0.92±0.30	20.41±33.88	11.51±7.00	10.66±12.76	26.74±26.02

Table 4.4.3 Mean station wise variation of chlorophyll ' a' (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	1.87	14.33	0.66	34.41
2	0.66	52.49	1.35	40.86
3	2.84	31.60	1.31	45.78
4	1.39	37.60	0.76	30.04
5	0.53	48.11	1.54	49.81
6	0.85	75.76	1.15	76.56
7	0.03	72.06	0.24	105.65
8	0.03	44.70	0.44	33.87
9	0.10	75.31	0.27	119.03

Table 4.4.4 ANOVA of chlorophyll' a' in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	534.430	3.573
Season	2	4479.189	29.950**
Station	8	463.913	3.102**
Surface water, Bottom water	1	130.775	0.874
Season * Station	16	404.097	2.702**
Season * Surface water, Bottom water	2	0.349	0.002
Station * Surface water, Bottom water	8	63.399	0.424
Error	394	149.557	
Total	432		
R^2= 0.251			

** Variation is significant at 1% level

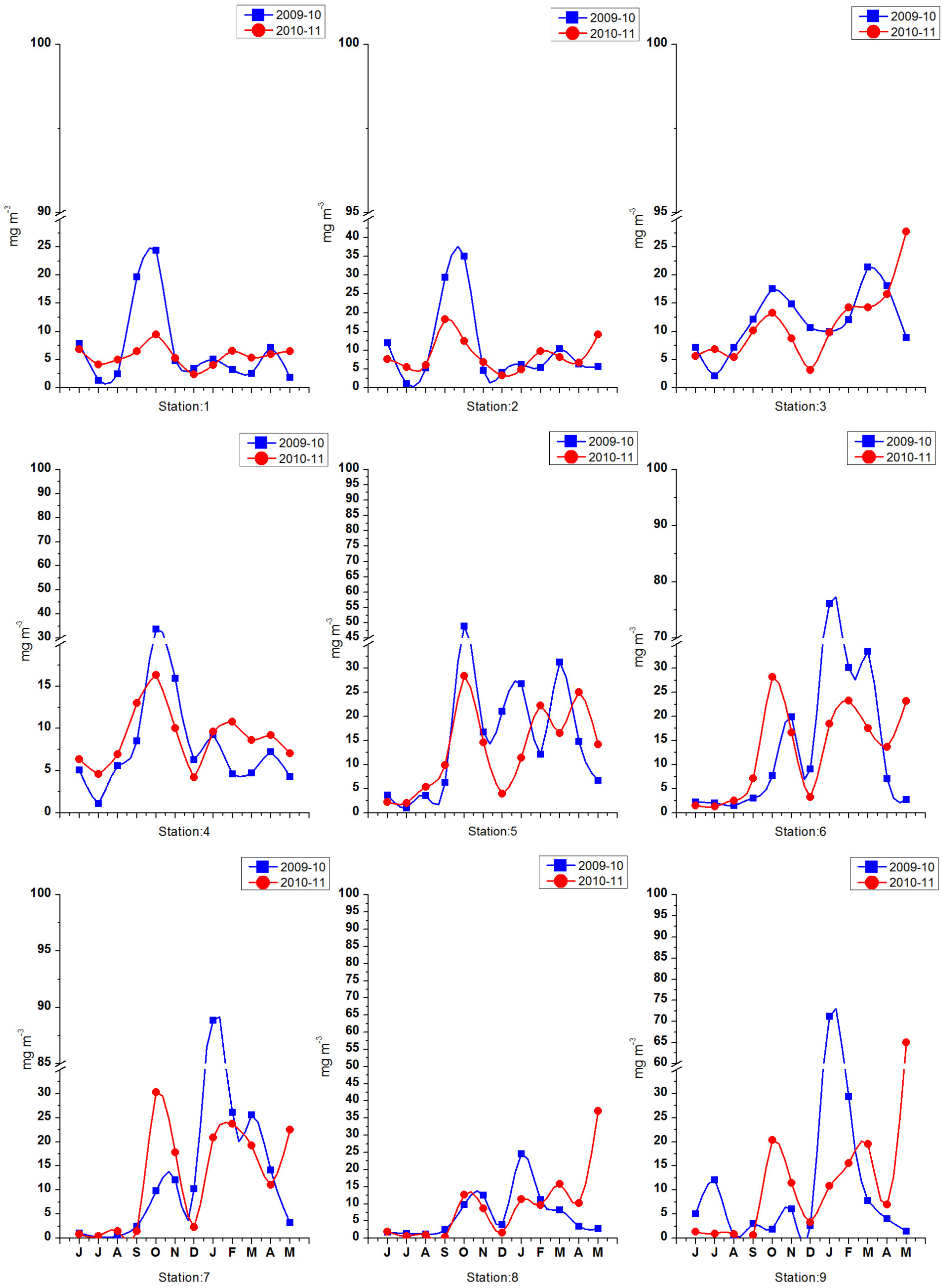


Fig. 4.4. Mean monthly variation of Chlorophyll ' a' in selected stations of Cochin estuary during 2009-11 period

4.4.5Chlorophyll 'b'

The average value of chlorophyll 'b' in Cochin estuary was 2.28±3.14mg m^{-3}. Mean station wise mean values were maximum at station 4 (3.49 ± 0.78 mg m^{-3}) and minimum at station 1(1.07 ± 0.78mgm^{-3}). The southern zone of the estuary had the lowest value of chlorophyll 'b' (1.61± 0.50mg m^{-3}) and the highest value was observed from central zone (2.51 ± 0.50 mgm^{-3}). The chlorophyll 'b' values in Cochin estuary ranged from 1.07 mg m^{-3}at station 1 to 3.49 mg m^{-3}at station 4 in the central zone. In the southern zone, the chlorophyll 'b' value at station 2 was 1.25 mg m^{-3} and at station 3, it was 1.97 mg m^{-3}. The range of chlorophyll 'b' values were from 2.00 mg m^{-3} at station 9 to 2.68 mg m^{-3} at station 6 in the northern zone.

The mean monthly values of chlorophyll 'b' varied from 0.04 mg m^{-3} in January 2011 at station 1 to 26.46 mg m^{-3}in September 2009 at station 4 (Table 4.5.1 and Fig.4.5). The mean annual value of chlorophyll 'b' was (3.03 mg m^{-3}) two times higher than the second year (1.52 mg m^{-3}). The minimum value of chlorophyll 'b' in the study region was 0.46 mg m^{-3} in August 2009 and the maximum of 14.11 mg $m^{-3}$was recorded in November 2009, during the 2009-10 period. During 2010-11 period, it ranged from 0.36 mg m^{-3} in April 2011to 5.93 mg m^{-3} in October 2010.

The post-monsoon period values of chlorophyll 'b' (4.12 ±1.61mg m^{-3}) were four times higher than the values in the monsoon period (1.53± 1.61mg m^{-3}) and pre-monsoon period (1.17± 1.61mg m^{-3}). During the monsoon period, the highest value of chlorophyll 'b' was 26.46 mg m^{-3}in September 2009 while the lowest value was0.05 mg m^{-3} in August 2010.

The range of chlorophyll 'b' during the post-monsoon period was 0.04 mg m^{-3} in January 2011 to 24.59 mg m^{-3} in November 2009. In the pre-monsoon the values ranged from 0.05 mg m^{-3} in April 2010 to 13.18 in May 2011.

The ANOVA result of chlorophyll 'b' suggested that the variations were significant at 1% level between seasons ($p \leq 0.001$) and significant at 5% level between seasons and stations ($p \leq 0.05$) (Table 4.5.4).

Table 4.5.1 Mean monthly variation of chlorophyll 'b' in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Mean
J'09	1.52	1.22	1.68	9.43	1.28	1.55	1.13	1.35	1.42	2.29
J	2.45	2.00	2.77	1.48	1.33	1.28	0.55	1.37	1.92	1.68
A	0.69	0.08	0.38	0.35	0.55	0.31	0.50	0.48	0.76	0.46
S	1.42	1.58	1.90	26.46	1.94	3.07	2.34	2.21	1.59	4.72
O	2.47	4.86	4.73	1.39	18.69	9.65	12.73	13.55	1.58	7.74
N	4.53	4.06	15.22	20.67	20.74	24.59	14.87	16.64	5.64	14.11
D'09	0.23	0.51	1.01	0.92	0.67	0.75	1.70	0.70	0.61	0.79
J'10	0.97	0.79	0.68	1.03	0.71	0.96	1.65	1.19	2.00	1.11
F	0.27	0.91	0.11	0.79	0.35	0.64	1.10	0.69	2.05	0.77
M	0.29	2.28	1.11	0.90	0.31	0.11	0.65	0.92	0.58	0.79
A	0.33	0.53	0.27	0.52	0.05	0.70	0.90	0.76	0.88	0.55
M	1.39	1.25	2.50	3.53	0.53	0.52	0.33	0.32	1.96	1.37
J	1.52	1.72	1.36	1.71	0.80	1.05	0.36	0.89	0.45	1.10
J	1.46	1.46	1.57	1.08	0.20	0.16	0.36	0.29	0.85	0.83
A	0.68	0.64	0.76	0.57	0.94	0.67	1.68	0.54	0.05	0.73
S	0.73	0.40	0.45	0.55	0.60	0.66	0.82	0.29	0.43	0.55
O	2.05	2.56	5.35	6.01	10.20	8.99	7.74	8.02	2.46	5.93
N	0.85	0.92	1.85	2.41	4.03	3.38	2.82	3.01	1.43	2.30
D'10	0.46	0.06	0.10	0.31	0.62	0.53	0.44	0.68	1.39	0.51
J'11	0.04	0.13	0.08	0.90	1.26	0.63	0.28	0.33	0.43	0.45
F	0.57	1.24	0.99	1.43	0.31	0.49	0.75	0.67	1.37	0.87
M	0.34	0.53	0.87	0.68	1.31	1.05	1.16	2.34	4.89	1.46
A	0.22	0.09	0.37	0.40	1.36	0.21	0.30	0.17	0.11	0.36
M'11	0.23	0.26	1.24	0.20	2.27	2.44	2.41	6.16	13.18	3.16

Table 4.5.2 Mean season wise variation of chlorophyll 'b' in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	1.52±0.72	1.1±0.45	2.05±1.9	0.85±0.87	0.57±0.55	0.34±0.16
2	1.22±0.83	1.05±0.64	2.56±2.22	0.92±1.16	1.24±0.75	0.53±0.51
3	1.68±0.99	1.03±0.52	5.41±6.79	1.85±2.48	0.99±1.09	0.87±0.37
4	9.43±12.05	0.98±0.55	6.01±9.78	2.41±2.56	1.43±1.41	0.68±0.54
5	1.28±0.57	0.64±0.32	10.2±11.02	4.03±4.37	0.31±0.19	1.31±0.8
6	1.55±1.14	0.63±0.37	8.99±11.2	3.38±3.97	0.49±0.27	1.05±0.99
7	1.13±0.86	0.81±0.62	7.74±7.05	2.82±3.48	0.75±0.33	1.16±0.91
8	1.35±0.71	0.5±0.28	8.02±8.27	3.01±3.55	0.67±0.25	2.34±2.72
9	1.42±0.49	0.45±0.33	2.46±2.2	1.43±0.83	1.37±0.75	4.89±5.89

Table 4.5.3 Mean station wise variation of chlorophyll 'b' (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.00	5.58	0.01	3.49
2	0.03	3.08	0.02	8.57
3	0.03	11.82	0.00	18.62
4	0.01	51.30	0.01	10.53
5	0.03	29.10	0.07	13.12
6	0.02	27.24	0.12	21.95
7	0.22	12.06	0.00	19.99
8	0.19	15.97	0.01	20.92
9	0.01	14.10	0.07	12.26

Table 4.5.4 ANOVA of chlorophyll 'b' in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	47.411	2.400
Season	2	371.522	18.811**
Station	8	29.552	1.496
Surface water, Bottom water	1	16.113	0.816
Season * Station	16	39.774	2.014*
Season * Surface water, Bottom water	2	2.806	0.142
Station * Surface water, Bottom water	8	14.580	0.738
Error	394	19.751	
Total	432		
R^2= 0.184			

** Variation is significant at 1% level

* Variation is significant at 5% level

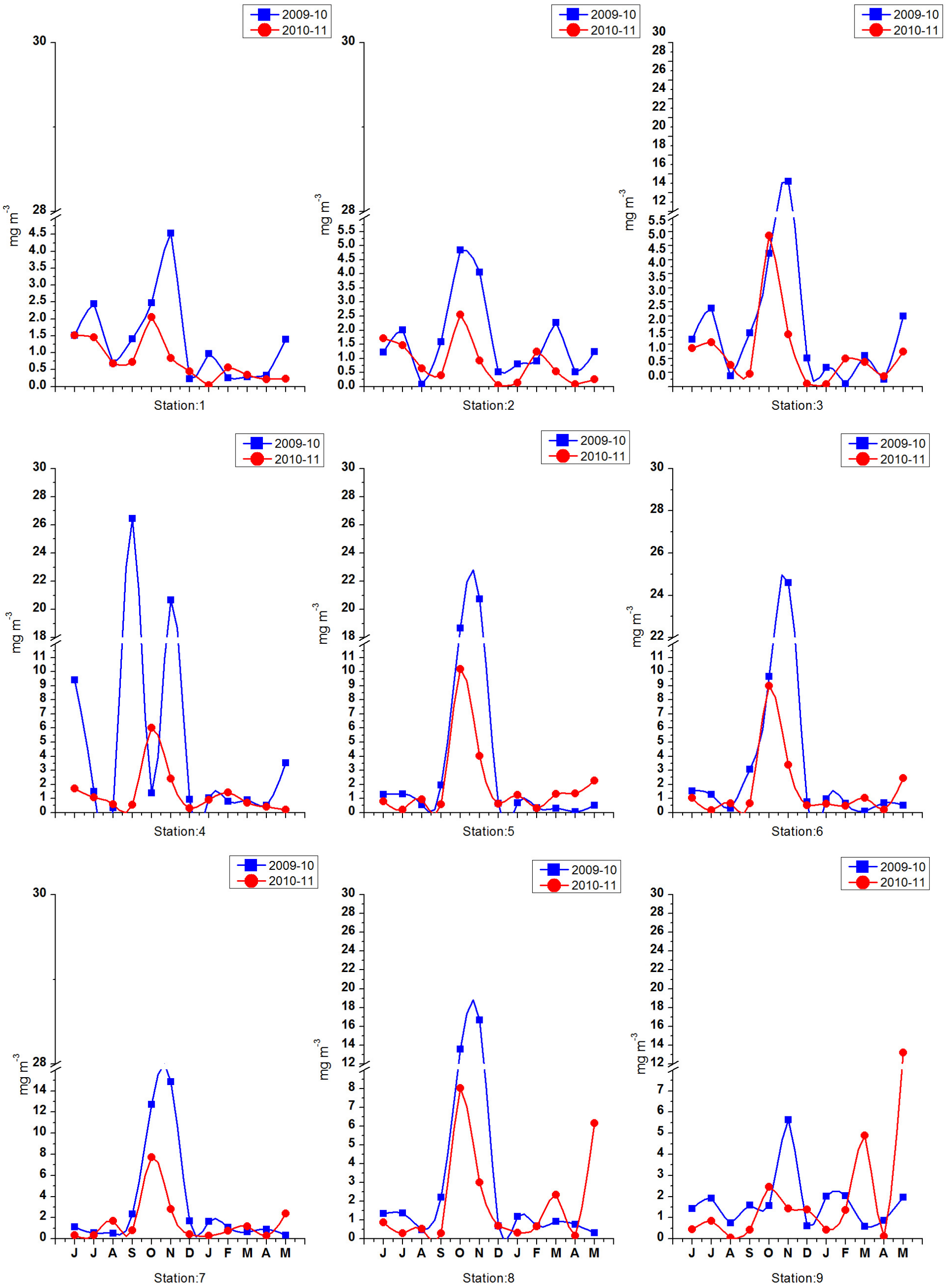


Fig. 4.5 Mean monthly variation of chlorophyll 'b' in selected stations of Cochin estuary during 2009-11 period

4.4.6 Chlorophyll 'c'

The mean value of chlorophyll 'c' in the estuary was 4.18 mg m^{-3} during the present study. The surface water recorded the maximum values of chlorophyll 'c' compared the bottom waters in the central zone of the estuary. Mean station wise values of chlorophyll 'c' varied from 5.89 ± 1.10 mg m^{-3} at station 5 to 2.69 ± 1.10 mg m^{-3} at station 1. The chlorophyll 'c' value was maximum in the central zone of the estuary (4.35 ± 0.22 mg m^{-3}) and minimum in the southern zone (3.92 ± 0.22mg m^{-3}). In the central zone, chlorophyll 'c' values were the maximum (5.89 mg m^{-3}) at station 5 and the minimum (2.69 mg m^{-3}) at station 1. In the central zone, station 3 (4.58 mg m^{-3}) showed higher values compared to station 2 (3.26 mg m^{-3}). In the northern zone, the value was higher at station 6 (5.19 mg m^{-3}) and low at station 9 (2.79 mg m^{-3}).

The post-monsoon period showed the highest values of chlorophyll 'c' (7.15 ± 2.57 mg m^{-3}) while in all the other seasons, the chlorophyll 'c' values were more or less the same. The chlorophyll 'c' values in the study region ranged from 0.04 mg m^{-3} in August 2010 to 18.93 in July 2009 during the monsoon period. During the post-monsoon period, the values ranged from 0.39 mg m^{-3} in December 2010 to 37.51 mg m^{-3} in November 2009. During the pre-monsoon period, the values ranged from 0.28 mg m^{-3} in February 2010 to 10.55 mg m^{-3} in February 2010. The mean monthly values of chlorophyll 'c' recorded lowest (0.04 mg m^{-3}) in August 2010 at station 6 and the highest (37.51 mg m^{-3}) in November 2009 at station 6.

The variations were significant at 1% level between seasons ($p \leq 0.001$) and between seasons and stations ($p \leq 0.01$) (Table 4.6.4).

Table 4.6.1 Mean monthly variation of chlorophyll 'c' in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Mean
J'09	7.94	8.38	7.97	8.03	4.36	1.55	1.46	1.83	1.68	4.80
J	18.13	18.16	18.93	15.52	9.96	2.62	0.51	1.83	2.68	9.81
A	0.75	0.94	1.67	0.23	0.25	0.20	0.63	1.08	0.94	0.74
S	4.95	6.04	3.32	8.34	2.88	1.85	3.23	2.57	1.42	3.84
O	7.05	11.63	8.81	6.35	31.50	13.31	18.73	18.67	0.68	12.97
N	7.06	6.83	22.29	31.82	31.31	37.51	21.67	24.58	9.28	21.37
D'09	0.53	0.86	1.64	1.64	2.46	2.01	2.44	1.54	1.06	1.58
J'10	1.31	1.48	2.21	2.07	4.17	8.34	11.09	3.47	9.76	4.88
F	0.45	0.28	1.83	1.29	3.80	9.11	8.68	3.93	10.55	4.44
M	0.99	2.20	3.81	1.68	4.53	5.38	4.39	2.20	1.76	2.99
A	1.60	1.54	2.85	1.26	3.03	1.93	3.38	1.19	1.20	2.00
M	0.51	1.65	1.39	2.35	0.40	0.61	0.44	0.86	0.63	0.98
J	1.00	1.15	0.76	1.32	0.87	1.70	0.70	1.15	0.81	1.05
J	0.96	0.41	0.51	0.48	0.21	0.09	0.20	0.06	0.54	0.38
A	0.75	0.20	0.94	0.40	0.04	0.57	2.29	0.22	0.22	0.63
S	0.11	2.57	1.11	1.55	0.16	0.86	0.65	0.71	0.50	0.91
O	3.99	5.20	8.74	10.47	17.36	15.29	13.48	12.07	5.20	10.20
N	1.80	2.16	3.49	4.22	6.47	6.02	5.63	4.71	2.46	4.11
D'10	0.56	0.52	0.40	0.43	0.39	0.64	0.53	0.86	1.47	0.64
J'11	0.86	0.75	1.32	1.77	1.66	2.12	2.88	1.20	0.70	1.47
F	0.89	1.42	2.47	1.65	2.94	4.26	4.22	2.05	3.53	2.60
M	0.84	1.30	3.99	1.47	3.88	3.19	3.24	2.56	3.37	2.65
A	0.86	0.67	2.37	1.31	5.38	1.22	1.82	1.67	1.05	1.82
M'11	0.77	1.81	7.14	1.44	3.32	4.08	3.69	3.96	5.54	3.53

Table 4.6.2 Mean season wise variation of chlorophyll 'c' in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	7.94±7.40	0.71±0.41	3.99±3.55	1.8±1.55	0.89±0.53	0.84±0.05
2	8.38±7.22	1.08±1.07	5.20±5.05	2.16±2.15	1.42±0.81	1.3±0.48
3	7.97±7.78	0.83±0.26	8.74±9.60	3.49±3.73	2.47±1.08	3.99±2.23
4	8.03±6.25	0.94±0.58	10.47±14.39	4.22±4.45	1.65±0.51	1.47±0.14
5	4.36±4.10	0.32±0.37	17.36±16.23	6.47±7.72	2.94±1.8	3.88±1.07
6	1.55±1.01	0.81±0.68	15.29±15.52	6.02±6.59	4.26±3.81	3.19±1.39
7	1.46±1.25	0.96±0.92	13.48±8.61	5.63±5.63	4.22±3.41	3.24±1.03
8	1.83±0.61	0.53±0.49	12.07±11.33	4.71±5.21	2.05±1.38	2.56±1.00
9	1.68±0.73	0.52±0.24	5.2±5.00	2.46±1.97	3.53±4.70	3.37±1.84

Table 4.6.3 Mean station wise variation of chlorophyll 'c' (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.11	23.87	0.11	12.38
2	0.13	12.87	0.13	23.44
3	0.10	25.88	0.12	25.84
4	0.08	46.44	0.11	17.21
5	0.01	44.90	0.04	20.26
6	0.07	41.39	0.01	33.62
7	0.02	16.33	0.09	29.08
8	0.05	21.48	0.05	31.28
9	0.09	9.45	0.20	19.26

Table 4.6.4 ANOVA of Chlorophyll 'c' in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	107.909	2.988
Season	2	952.702	26.381**
Station	8	57.789	1.600
Surface water, Bottom water	1	0.002	0.000
Season * Station	16	88.081	2.439**
Season * Surface water, Bottom water	2	3.817	0.106
Station * Surface water, Bottom water	8	25.998	0.720
Error	394	36.113	
Total	432		
R^2=0.219			

** Variation is significant at 1% level

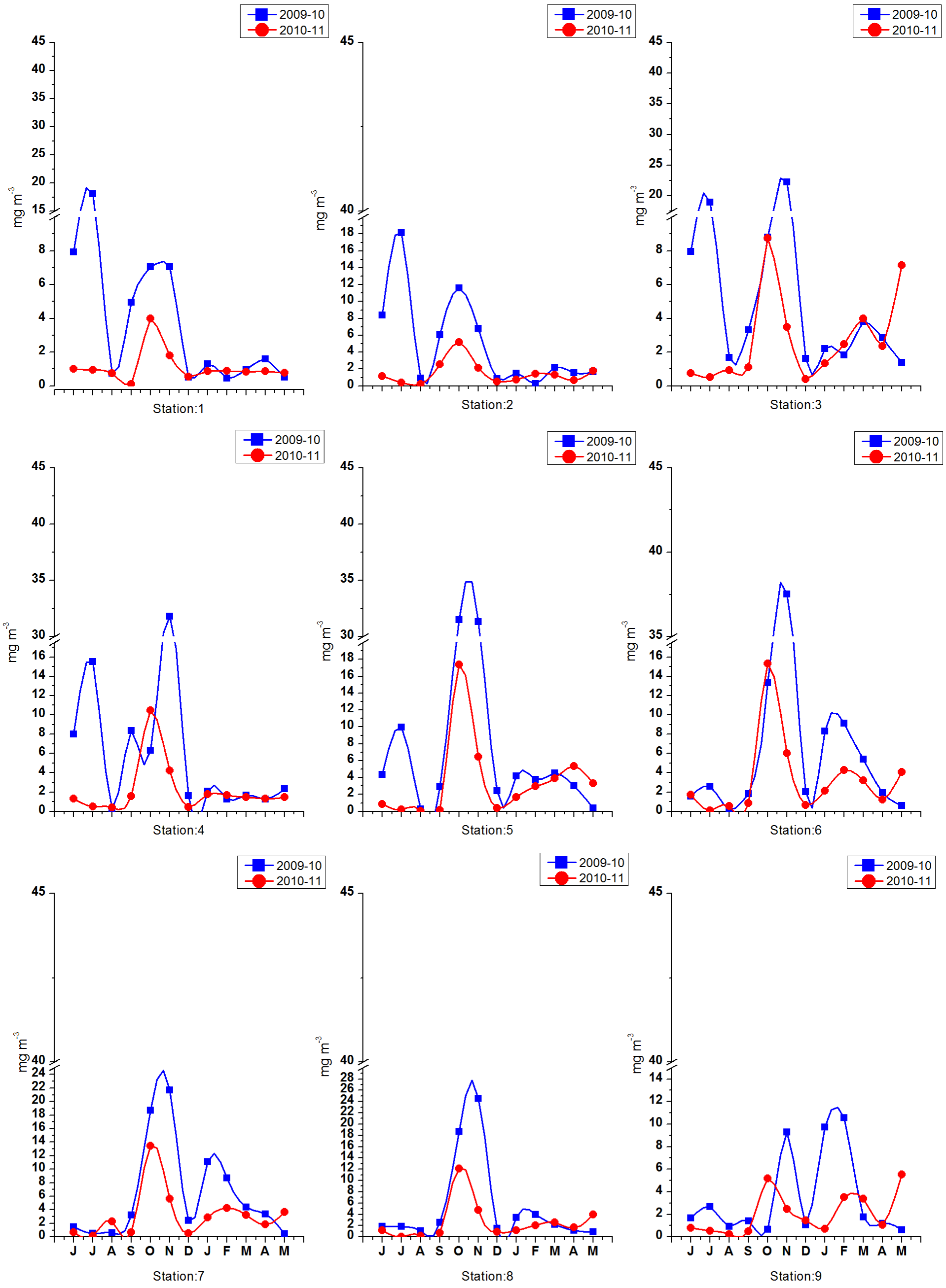


Fig. 4.6. Mean monthly variation of chlorophyll 'c' in selected stations of Cochin estuary during 2009-11 period

4.4.7 Carotenoid

The average carotenoid values of Cochin estuary was 9.36 ± 7.13 mgm^{-3}. Mean station -wise values of carotenoid recorded the highest at station 5(12.45 ± 1.88 mg m^{-3}) and lowest at station 1 (6.55 ± 1.88 mg m^{-3}). The carotenoid values were high in the southern zone (9.60 ± 0.23 mg m^{-3}) and low in the central zone (9.13 ± 0.23 mg m^{-3}) of the estuary. The maximum value of carotenoid in the central zone was recorded at station 5(12.45 mg m^{-3}) and the minimum value was recorded at station 1(6.55 mg m^{-3}). The carotenoid values at stations 2 and 3 were 8.56 mg m^{-3}and 10.53 mg m^{-3} respectively. In the northern zone, the carotenoid value ranged from 7.89 mg m^{-3} at station 8 to 11.03 mg m^{-3} at station 6.

The carotenoid values were high during the post-monsoon period (14.63 ± 5.18mg m^{-3}) and low during the monsoon period (4.28 ± 5.18mg m^{-3}). The carotenoid values ranged from 0.26 mg m^{-3} in September 2010 to 19.74 mg m^{-3} in September 2009 during the monsoon period. In the post-monsoon period, the highest carotenoid value was observed in December 2010 (1.16 mg m^{-3}) and the lowest in October 2009 (51.53 mg m^{-3}). In the pre-monsoon period, the values lie within the range from 1.87 mg m^{-3} to 33.28 mg m^{-3}.

Mean monthly values of carotenoid were maximum in September 2009 (51.53 mg m^{-3}) at station 5 and minimum in September 2010 (0.26 mg m^{-3}) (Table 4.7.1 and Fig.4.7). The annual variation of carotenoid showed the peak during the 2009-10 period (10.73±8.32mg m^{-3}). In the 2009-10 period, the highest carotenoid value of 28.23 mg m^{-3} was observed in November 2009 and the lowest value of 3.47 mg m^{-3} was recorded in August 2009. In the 2010-11 period, the values ranged from 2.24 mg m^{-3} to 20.32 mg m^{-3}.

ANOVA results of carotenoid showed that the variations were significant at 1% level between seasons ($p \leq 0.001$) and between seasons and stations ($p \leq 0.001$). It was significant at 5% level between stations ($p \leq 0.05$) (Table 4.7.4).

Table 4.7.1 Mean monthly variation of carotenoid in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Mean
J'09	7.99	11.19	6.63	6.71	5.24	2.98	1.51	2.62	3.94	5.42
J	8.02	7.19	8.12	6.29	6.41	4.61	1.23	3.90	8.40	6.02
A	2.54	6.65	6.34	4.64	3.49	2.13	0.90	3.58	0.97	3.47
S	13.41	19.74	6.68	9.21	5.82	2.20	2.40	1.36	2.45	7.03
O	21.31	32.62	22.24	24.47	51.53	19.40	23.27	24.33	2.07	24.58
N	12.72	13.33	33.67	37.28	40.57	42.50	28.17	30.17	15.70	28.23
D'09	2.15	3.12	7.11	4.66	13.44	5.75	6.33	2.71	1.73	5.22
J'10	3.65	4.75	7.25	6.36	14.22	34.12	40.62	12.97	36.24	17.80
F	2.30	4.80	8.37	4.34	7.22	16.20	15.29	7.31	17.56	9.26
M	2.54	9.61	18.32	5.62	17.95	18.52	13.96	7.17	6.35	11.12
A	5.36	5.21	11.30	5.73	9.79	5.50	9.47	3.93	3.78	6.67
M	3.59	4.67	6.41	3.80	5.66	2.71	3.09	3.00	1.87	3.87
J	5.47	5.93	4.69	5.38	2.42	2.12	1.31	1.77	1.40	3.39
J	3.46	4.48	5.50	3.76	1.26	0.69	0.47	0.47	1.24	2.37
A	3.28	3.60	3.37	4.20	3.37	1.76	1.41	1.19	0.52	2.52
S	3.51	11.15	6.13	6.83	4.52	2.57	0.70	0.26	0.27	3.99
O	22.19	13.46	17.56	18.19	29.94	25.44	24.60	17.54	13.94	20.32
N	9.46	7.10	9.21	9.61	13.86	13.22	13.62	8.94	7.67	10.30
D'10	1.86	2.91	2.45	3.33	3.24	2.03	1.78	1.16	1.43	2.24
J'11	4.33	4.93	7.61	7.29	8.39	12.18	14.48	8.12	7.64	8.33
F	4.49	7.25	14.05	5.95	12.63	12.02	11.86	11.59	15.47	10.59
M	3.45	6.07	11.10	4.87	10.16	10.73	10.45	5.35	7.39	7.73
A	5.05	5.68	10.70	6.97	15.77	7.50	7.54	6.32	5.73	7.92
M'11	4.98	10.00	20.34	6.01	11.97	17.81	17.58	23.10	33.28	16.12

Table 4.7.2 Mean season wise variation of carotenoid in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**
1	7.99±4.44	3.93±1.03	9.96±8.89	9.46±9.06	3.45±1.39	4.49±0.74
2	11.19±6.05	6.29±3.38	13.46±13.54	7.10±4.57	6.07±2.37	7.25±1.95
3	6.94±0.80	4.92±1.19	17.56±12.87	9.21±6.27	11.1±5.22	14.05±4.45
4	6.71±1.89	5.04±1.37	18.19±15.56	9.61±6.28	4.87±0.95	5.95±0.86
5	5.24±1.26	2.89±1.38	29.94±19.13	13.86±11.56	10.16±5.47	12.63±2.34
6	2.98±1.15	1.78±0.8	25.44±16.23	13.22±9.59	10.73±7.79	12.02±4.3
7	1.51±0.64	0.97±0.46	24.6±14.2	13.62±9.34	10.45±5.5	11.86±4.22
8	2.87±1.14	0.92±0.69	17.54±12.2	8.94±6.72	5.35±2.21	11.59±8.15
9	3.94±3.21	0.86±0.55	13.94±16.23	7.67±5.10	7.39±7.02	15.47±12.62

Table 4.7.3 Mean station wise variation of carotenoid (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	**Max**	**Min**	**Max**
1	1.64	22.19	1.07	29.14
2	2.68	36.92	2.83	28.33
3	1.24	26.51	2.83	40.82
4	3.53	49.69	2.80	24.90
5	1.13	57.04	1.40	46.01
6	0.85	47.67	0.52	37.33
7	0.27	29.77	0.67	51.47
8	0.18	27.63	0.33	33.15
9	0.33	38.21	0.21	57.20

Table 4.7.4 ANOVA of carotenoid in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	340.022	5.040
Season	2	3861.314	57.238**
Station	8	169.760	2.516*
Surface water, Bottom water	1	55.763	0.827
Season * Station	16	200.377	2.970**
Season * Surface water, Bottom water	2	0.651	0.010
Station * Surface water, Bottom water	8	29.629	0.439
Error	394	67.461	
Total	432		
R^2= 0.321			

** Variation is significant at 1% level

* Variation is significant at 5% level

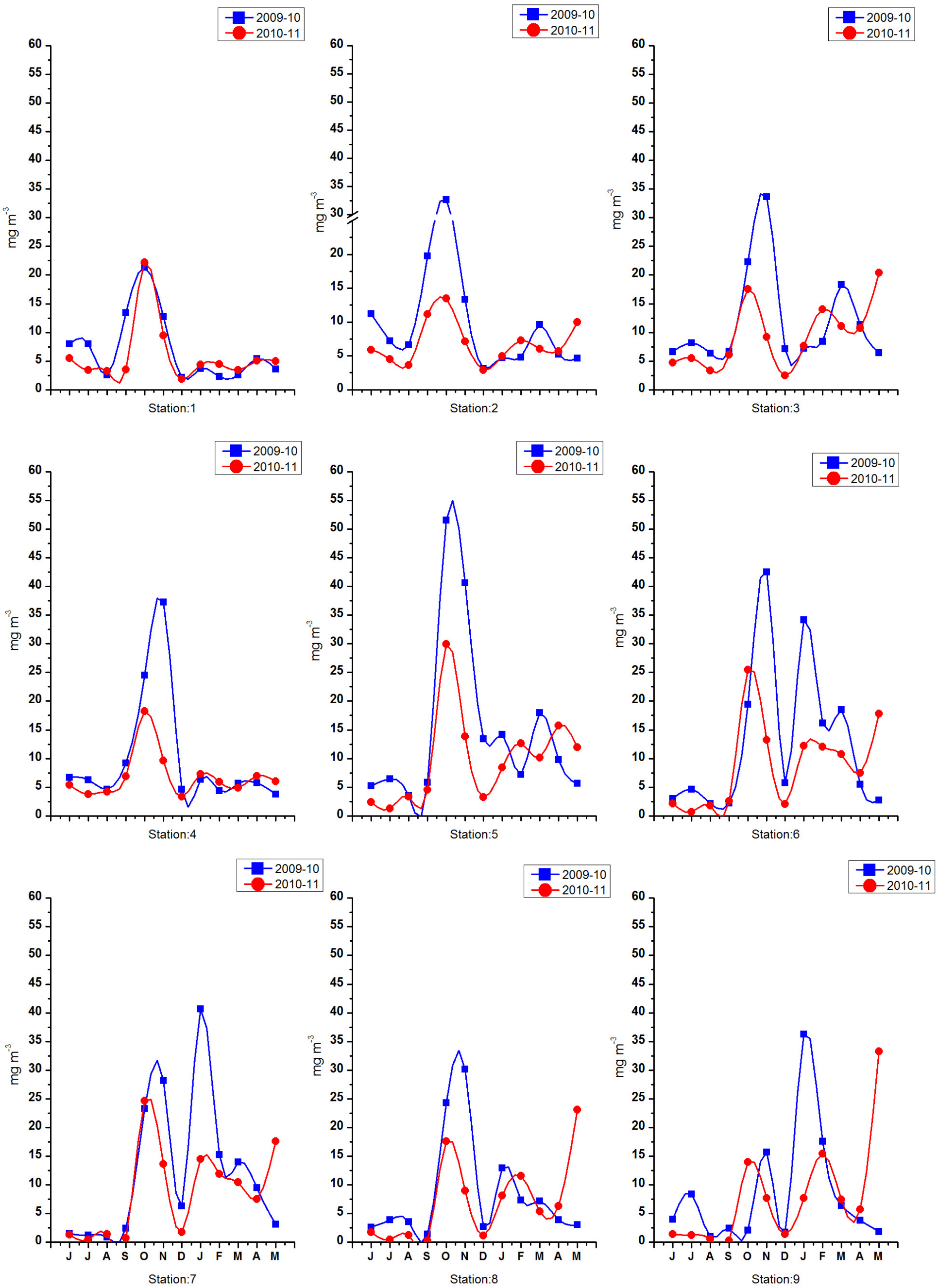


Fig. 4.7. Mean monthly variation of carotenoid in selected stations of Cochin estuary during 2009-11 period

4.4.8 Phaeophytin

The values of phaeophytin pigments revealed the dominance of dead photosynthetic pigments in the estuary. Station wise mean values of phaeophytin showed the highest value at station 3 (24.76 ± 5.45 mg m^{-3}) and lowest at station 8 (11.55 ± 5.45 mg m^{-3}). The phaeophytin pigmentswere found to be very high in the southern zone of the estuary (20.58 ± 4.09 mg m^{-3}) and low in the central zone (13.11 ± 4.09 mg m^{-3}). In the central zone, the phaeophytin values ranged from 12.40 mg m^{-3} at station 1 to 14.27 mg m^{-3} at station 5. In the central zone, phaeophytin was higher at station 3 (24.76 mg m^{-3}) compared to station 2 (16.40 mg m^{-3}).In the northern zone, the highest value was observed at station 9 (24.07 mg m^{-3}) and lowest at station 8 (11.55 mg m^{-3}).

The phaeophytin values peaked during the post-monsoon period (26.39 ± 9.23 mg m^{-3}). Mean monthly values of phaeophytin were maximum in May 2011 at station 3 (152.06 mg m^{-3}) and minimum in August 2009 at station 8 as well as in September 2010 at station 9(0.45 mg m^{-3}). It was high during the 2009-10 period (22.10 mg m^{-3}). In the 2009-10 period, the highest value of phaeophytin (55.48 mg m^{-3}) was observed in November 2009 and the lowest was in June 2009 (3.27 mg m^{-3}). In the 2010-11 period, the highest value was recorded in May 2011 (45.64 mg m^{-3}) and the lowest in July 2010 (3.18 mg m^{-3}).

The variations were significant at 1% level between seasons ($p \leq 0.001$) and 5% level of significance between stations ($p \leq 0.05$) and between seasons and stations ($p \leq 0.05$) (Table 4.8.4).

Table 4.8.1 Mean monthly variation of phaeophytin in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	4.69	8.78	0.61	2.87	2.27	3.78	2.57	3.33	0.49	3.27
J	23.60	24.51	21.79	18.61	14.07	4.54	5.45	3.18	3.52	13.25
A	2.27	4.99	5.90	7.26	3.63	1.36	3.63	0.45	1.82	3.48
S	39.04	45.84	14.07	2.72	3.63	13.62	1.36	11.80	4.99	15.23
O	30.87	41.30	71.72	79.89	17.25	73.08	64.45	24.06	87.60	54.47
N	69.90	98.04	66.27	43.57	28.60	34.50	8.17	37.67	112.57	55.48
D'09	2.27	3.63	10.44	8.17	25.42	11.80	14.07	6.81	5.90	9.83
J'10	8.62	8.62	12.26	13.62	39.04	112.57	131.18	33.13	95.32	50.48
F	2.27	5.45	12.71	2.72	14.98	125.73	50.38	12.26	37.67	29.35
M	2.27	6.35	12.26	1.82	32.23	33.59	21.79	4.99	8.62	13.77
A	9.99	8.17	29.50	8.17	20.43	7.72	20.88	3.18	4.99	12.56
M	6.81	5.45	5.45	2.72	5.45	0.91	0.91	3.18	5.45	4.03
J	8.62	8.17	7.72	9.08	4.09	7.72	3.18	6.35	2.72	6.41
J	4.99	3.18	7.72	4.99	2.72	1.36	1.36	0.91	1.36	3.18
A	9.99	18.16	8.62	16.79	7.26	6.35	5.45	7.26	4.09	9.33
S	7.72	29.05	12.71	15.43	10.44	9.08	3.63	1.36	0.45	9.99
O	22.47	25.42	28.82	17.70	15.77	8.96	28.82	13.16	25.87	20.78
N	4.61	7.57	5.98	0.76	8.43	10.86	15.51	5.60	3.48	6.98
D'10	1.82	3.63	3.63	4.99	3.18	5.45	2.27	1.82	8.62	3.93
J'11	6.81	4.54	7.26	10.44	6.35	18.16	15.43	6.35	6.81	9.13
F	6.81	0.91	7.26	10.44	6.35	18.16	15.43	1.82	6.81	8.22
M	5.79	8.70	64.15	5.60	22.28	22.70	18.35	23.60	30.01	22.35
A	5.90	5.90	25.42	4.09	33.59	11.35	9.99	9.99	21.33	14.17
M'11	9.53	17.25	152.06	11.35	14.98	31.77	21.79	54.92	97.13	45.64

Table 4.8.2 Mean season wise variation of phaeophytin in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	17.4±17.29	7.83±2.11	27.91±30.56	8.93±9.26	5.33±3.77	7.01±1.74
2	21.03±18.58	14.64±11.45	37.9±43.44	10.29±10.23	6.35±1.28	8.19±6.85
3	10.59±9.29	9.19±2.38	40.17±33.36	11.42±11.7	14.98±10.24	62.22±64.42
4	7.87±7.46	11.57±5.53	36.31±32.96	8.47±7.32	3.86±2.91	7.87±3.57
5	5.9±5.48	6.13±3.45	27.57±9.01	8.43±5.35	18.27±11.18	19.3±11.54
6	5.83±5.37	6.13±3.37	57.99±44.32	10.86±5.36	41.99±57.58	20.99±8.57
7	3.25±1.73	3.4±1.68	54.47±57.04	15.51±10.84	23.49±20.35	16.39±5
8	4.69±4.92	3.97±3.3	25.42±13.64	6.73±4.72	5.9±4.32	22.58±23.36
9	2.71±1.97	2.16±1.59	75.35±47.46	11.2±10.01	14.18±15.74	38.82±40.04

Table 4.8.3 Mean station wise variation of phaeophytin (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.91	90.78	0.00	53.56
2	0.91	86.24	0.91	109.84
3	0.61	147.06	0.61	157.05
4	0.76	25.42	0.76	139.80
5	1.82	62.64	0.91	47.21
6	0.00	185.19	0.00	115.29
7	0.00	100.77	0.91	197.90
8	0.00	69.90	0.91	45.39
9	0.49	114.38	0.00	150.69

Table 4.8.4 ANOVA of phaeophytin in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	1620.048	2.430
Season	2	12264.545	18.395**
Station	8	1424.352	2.136*
Surface water, Bottom water	1	231.049	0.347
Season * Station	16	1266.216	1.899*
Season * Surface water, Bottom water	2	310.319	0.465
Station * Surface water, Bottom water	8	363.340	0.545
Error	394	666.731	
Total	432		
R^2= 0.186			

** Variation is significant at 1% level

* Variation is significant at 5% level

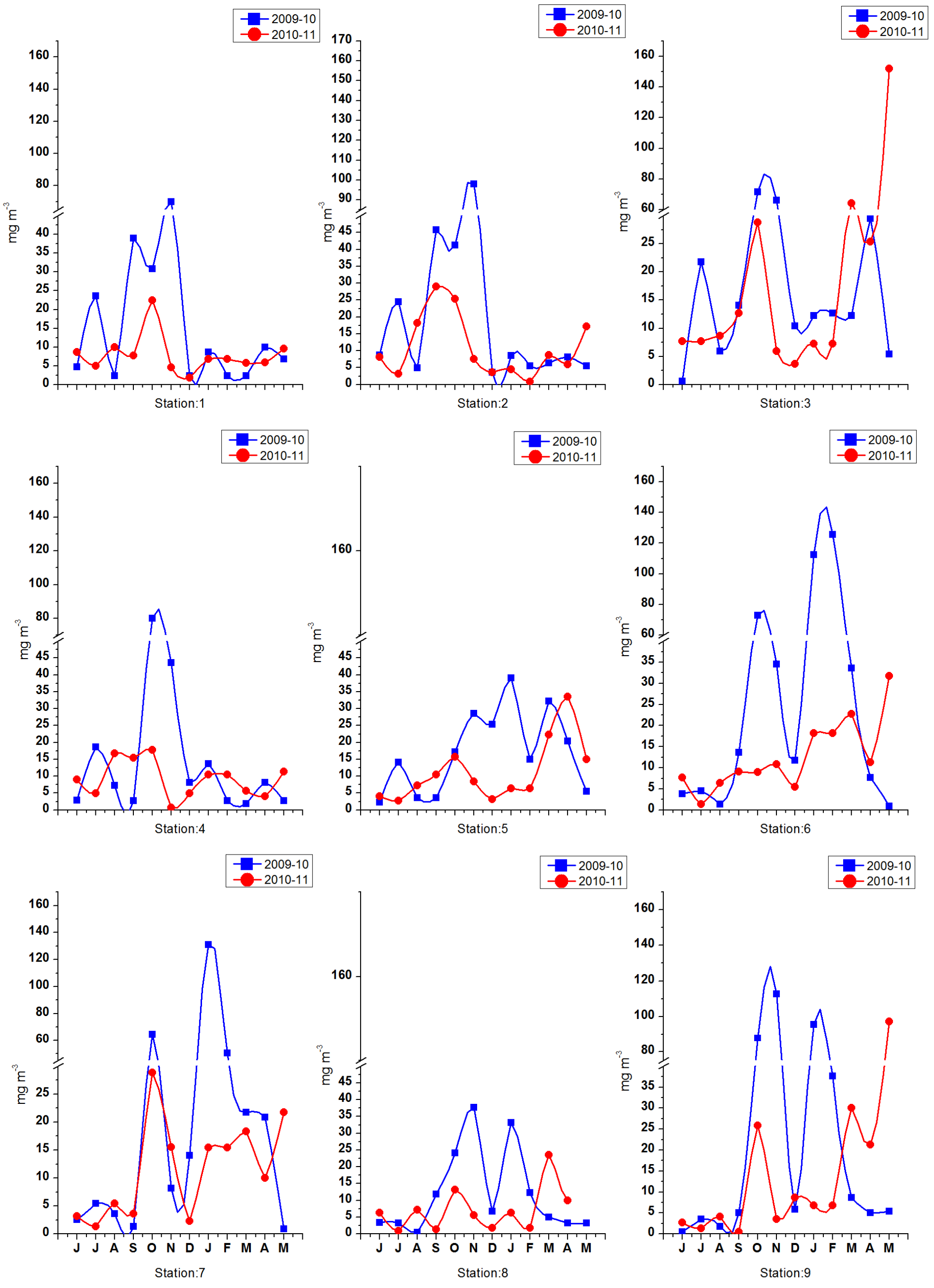


Fig. 4.8. Mean monthly variation of phaeophytin in selected stations of Cochin estuary during 2009-11 period

4.4.9 Active Chlorophyll

The average value of active chlorophyll in the Cochin estuary was 10.68 ± 9.85 mg m^{-3}. Mean station wise values of active chlorophyll ranged from 7.03 ± 3.32 mg m^{-3} at station 8 to 15.17 ± 3.32 mg m^{-3} at station 3. It was high (12.51 ± 2.49 mg m^{-3}) in the southern zone of the estuary and low (7.91 ± 2.49 mg m^{-3}) in the central zone of the estuary. The active chlorophyll values in the central zone of the estuary ranged from 7.35 mg m^{-3} at station 1 to 8.78 mg m^{-3} at station 5. In the southern zone, station 3 showed higher chlorophyll values (15.17 mg m^{-3}) compared to station 2 (9.85 mg m^{-3}). The minimum value of active chlorophyll was observed at station 8 (7.03 mg m^{-3}) and the maximum was recorded at station 6 (14.03 mg m^{-3}).

Mean monthly variations of active chlorophyll were maximum in May 2011(89.45 mg m^{-3}) at station 3 and minimum in July 2009(0.12 mg m^{-3}) at station 9 (Table 4.9.1 and Fig.4.9). It was higher during the 2009-10 period (12.99mg m^{-3}). During the 2009-10 period, the values ranged from 1.99 mg m^{-3} in June 2009 to 32.63 mg m^{-3} in November 2009. In the 2010-11 period, the maximum value of active chlorophyll (26.85 mg m^{-3}) was observed in May 2011 and the minimum (1.87 mg m^{-3}) was recorded in July 2010.

The active chlorophyll values were maximum during the post-monsoon period (15.96 mg m^{-3}) and minimum during the monsoon period (4.70 mg m^{-3}). During the monsoon period, the highest value of active chlorophyll (26.97 mg m^{-3}) was recorded in September 2009 and lowest (0.12 mg m^{-3}) in July 2009. The post-monsoon period values ranged from

1.07 mg m^{-3} in December 2010 to 77.16 mg m^{-3} in January 2010. In the pre-monsoon period, the values lie within the range of 0.53 mg m^{-3} in May 2010 to 89.45 mg m^{-3} in May 2011.

The variations were significant at 1% level between seasons ($p \leq 0.001$) and significant at 5% level between stations ($p \leq 0.05$) and between seasons and stations ($p \leq 0.05$) (Table 4.9.4).

Table 4.9.1 Mean monthly variation of active chlorophyll in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**
J'09	2.76	5.16	0.36	1.69	1.34	2.23	1.51	1.96	0.94	1.99
J	13.88	14.42	12.82	10.95	8.28	2.67	3.20	1.87	0.12	7.58
A	1.34	2.94	3.47	4.27	2.14	0.80	2.14	0.27	1.07	2.05
S	22.96	26.97	8.28	1.60	2.14	8.01	0.80	6.94	2.94	8.96
O	18.16	24.30	42.19	46.99	10.15	42.99	37.91	14.15	51.53	32.04
N	41.12	57.67	38.98	25.63	16.82	20.29	4.81	22.16	66.22	32.63
D'09	1.34	2.14	6.14	4.81	14.95	6.94	8.28	4.01	3.47	5.79
J'10	5.07	5.07	7.21	8.01	22.96	66.22	77.16	19.49	56.07	29.70
F	1.34	3.20	7.48	1.60	8.81	73.96	29.64	7.21	22.16	17.27
M	1.34	3.74	7.21	1.07	18.96	19.76	12.82	2.94	5.07	8.10
A	5.87	4.81	17.36	4.81	12.02	4.54	12.28	1.87	2.94	7.39
M	4.01	3.20	3.20	1.60	3.20	0.53	0.53	1.87	3.20	2.37
J	5.07	4.81	4.54	5.34	2.40	4.54	1.87	3.74	1.60	3.77
J	2.94	1.87	4.54	2.94	1.60	0.80	0.80	0.53	0.80	1.87
A	5.87	10.68	5.07	9.88	4.27	3.74	3.20	4.27	2.40	5.49
S	4.54	17.09	7.48	9.08	6.14	5.34	2.14	0.80	0.27	5.87
O	16.39	16.49	24.34	16.58	11.05	2.25	13.22	10.22	24.24	14.98
N	3.77	4.96	5.98	2.50	5.55	3.88	7.88	4.12	5.05	4.85
D'10	1.07	2.14	2.14	2.94	1.87	3.20	1.34	1.07	5.07	2.31
J'11	4.01	2.67	4.27	6.14	3.74	10.68	9.08	3.74	4.01	5.37
F	3.40	5.12	37.74	3.29	13.11	13.35	10.79	13.88	22.81	13.72
M	1.13	3.34	8.81	1.34	10.75	14.69	13.68	3.47	6.74	7.11
A	3.47	3.47	14.95	2.40	19.76	6.68	5.87	5.87	12.55	8.34
M'11	5.61	10.15	89.45	6.68	8.81	18.69	12.82	32.31	57.14	26.85

Table 4.9.2 Mean season wise variation of active chlorophyll in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	10.24±10.17	4.61±1.24	16.42±17.98	6.31±6.85	3.14±2.22	3.4±1.83
2	12.37±10.93	8.61±6.73	22.29±25.55	6.57±6.73	3.74±0.76	5.52±3.19
3	6.23±5.47	5.41±1.4	23.63±19.63	9.18±10.23	8.81±6.02	37.74±36.65
4	4.63±4.39	6.81±3.25	21.36±19.39	7.04±6.56	2.27±1.71	3.43±2.31
5	3.47±3.23	3.60±2.03	16.22±5.30	5.55±3.96	10.75±6.57	13.11±4.77
6	3.43±3.16	3.60±1.98	34.11±26.07	5.00±3.84	24.7±33.87	13.35±5.00
7	1.91±1.02	2.00±0.99	32.04±33.55	7.88±4.92	13.82±11.97	10.79±3.50
8	2.76±2.89	2.34±1.94	14.95±8.02	4.79±3.87	3.47±2.54	13.88±13.06
9	1.27±1.19	1.27±0.93	44.32±27.92	9.59±9.78	8.34±9.26	24.81±22.55

Table 4.9.3 Mean station wise variation of active chlorophyll (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	0.53	53.40	0.00	31.51
2	1.07	50.73	0.53	64.61
3	0.36	86.51	0.36	92.38
4	0.53	16.58	1.07	82.24
5	1.07	36.85	0.53	27.77
6	0.00	108.94	0.00	67.82
7	0.00	59.27	0.53	116.41
8	0.00	41.12	0.53	26.70
9	0.12	67.28	0.00	88.64

Table 4.9.4 ANOVA of active chlorophyll in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	600.057	2.624
Season	2	4619.749	20.199**
Station	8	529.307	2.314*
Surface water, Bottom water	1	79.939	0.350
Season * Station	16	464.230	2.030*
Season * Surface water, Bottom water	2	107.375	0.469
Station * Surface water, Bottom water	8	125.721	0.550
Error	394	228.709	
Total	432		
R^2=0.198			

** Variation is significant at 1% level

* Variation is significant at 5% level

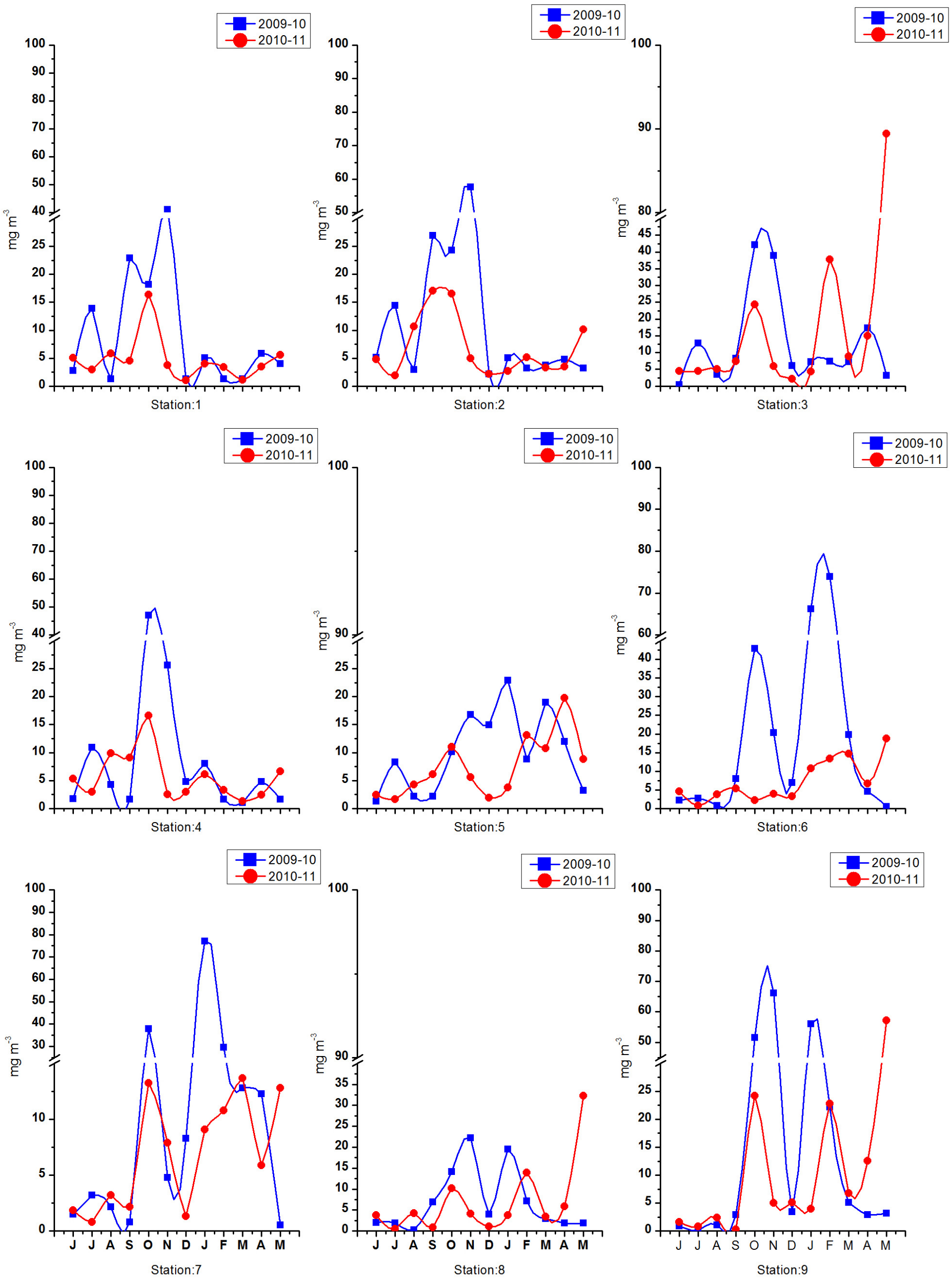


Fig. 4.9. Mean monthly variation of active chlorophyll in selected stations of Cochin estuary during 2009-11 period

4.4.10 Algal biomass

The dry weight of algal biomass of Cochin estuary was 742.05 ± 536.00 ml L^{-1} dry wt. Mean station wise values of algal biomass ranged from 968.55 ± 207.27 ml L^{-1} dry wt at station 6 to 413.96 ± 207.27 ml L^{-1} dry wtat station 1. The dry weight of the algal biomass was found to be high in the northern zone (824.95±88.30 ml L^{-1} dry wt) and low in the central zone (650.59±88.30 ml L^{-1} dry wt) of the estuary.

It was high during the post-monsoon period and low during the monsoon period. During the monsoon period, the dry weight of algal biomass varied between 12.33 ml L^{-1} dry wt in August 2009 and 1967.05 ml L^{-1} dry wtin September 2009. During the post-monsoon period, the highest algal biomass dry weight was observed in January 2010 (5953.29 ml L^{-1} dry wt) and the lowest (110.46 ml L^{-1} dry wt) in December 2010. The range of dry weight of algal biomass during the pre-monsoon period was from 94.77 ml L^{-1} dry wt in May 2010 to 4353.56 ml L^{-1} dry wt in May 2011.

The dry weight of algal biomass was higher during the 2009-10 period (785.89 ml L^{-1} dry wt) compared to the 2010-11 period (698.21ml L^{-1}dry wt). Mean monthly values of algal biomass ranged from 5953.29 ml L^{-1} dry wt in January 2010 at station 7 to 12.33ml L^{-1} dry wt in August 2009 at station 9 (Table 4.10.1).

The ANOVA result of dry algal biomass showed that the variations were significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.01$) and between seasons and stations ($p \leq 0.001$) (Table 4.10.4).

Table 4.10.1 Mean monthly variation of algal biomass (dry weight) in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Mean
J'09	523.83	795.14	477.37	339.75	244.15	83.77	60.66	53.77	362.53	326.77
J	87.82	67.15	139.00	71.92	69.39	136.58	14.79	91.38	874.83	172.54
A	164.72	351.21	479.67	376.23	239.67	101.10	26.04	80.77	12.33	203.53
S	1318.95	1967.05	813.43	571.12	423.41	206.98	168.79	169.98	200.42	648.90
O	1632.92	2349.13	1176.45	2265.99	3280.29	520.54	660.84	656.66	123.38	1407.36
N	322.62	309.94	996.81	1068.08	1121.65	1333.80	807.98	842.38	406.88	801.13
D'09	228.52	271.87	712.06	422.03	1408.88	606.12	684.93	262.74	171.81	529.89
J'10	337.95	415.18	667.47	619.88	1789.58	5102.82	5953.29	1650.03	4767.56	2367.08
F	214.87	361.99	809.35	308.31	813.71	2017.14	1745.77	750.19	1968.75	998.90
M	165.99	689.78	1436.14	315.11	2092.70	2243.90	1714.36	551.58	523.08	1081.40
A	478.64	424.15	1211.90	485.60	991.16	476.47	948.26	232.12	269.70	613.11
M	122.30	379.53	595.04	287.70	453.45	184.14	214.92	188.77	94.77	280.07
J	457.66	510.03	374.61	425.85	148.04	100.25	54.54	132.11	88.76	254.65
J	274.55	366.78	457.76	307.44	136.56	84.13	28.56	45.52	63.96	196.14
A	332.24	401.69	360.51	463.03	362.04	171.92	98.80	58.20	53.41	255.76
S	431.80	1223.04	681.97	870.80	660.43	477.32	94.64	25.01	40.84	500.65
O	630.51	836.53	888.20	1094.00	1900.10	1890.82	2026.76	852.95	1367.41	1276.36
N	351.09	459.24	583.70	672.90	977.40	1116.45	1191.71	575.10	770.93	744.28
D'10	155.69	213.73	206.93	280.95	264.04	218.47	150.21	110.46	220.98	202.39
J'11	267.08	327.45	655.98	643.76	768.06	1240.06	1398.16	761.87	724.40	754.09
F	358.85	620.01	1330.08	479.79	1238.28	1233.12	1133.63	1199.10	1844.21	1048.56
M	245.45	463.86	1013.11	349.18	1087.76	1230.41	1155.83	430.67	714.08	743.37
A	395.70	450.25	1116.18	618.40	1678.21	915.34	738.98	686.60	464.99	784.96
M'11	435.40	945.91	1860.95	471.79	948.87	1553.62	1506.09	2480.03	4353.56	1617.35

Table 4.10.2 Mean season wise variation of algal biomass (dry weight) in selected stations of Cochin estuary during 2009-11 period

Stations	**Monsoon period (Mean±SD)**		**Post-monsoon period (Mean±SD)**		**Pre-monsoon period (Mean±SD)**	
	2009-10	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**
1	523.83±563.11	374.06±85.59	630.51±670.03	351.09±202.74	245.45±159.99	358.85±81.81
2	795.14±836.74	625.38±403.08	836.53±1010.22	459.24±270.8	463.86±152.87	620.01±230.51
3	477.37±275.34	468.71±148.51	888.2±241.27	583.7±282.78	1013.11±380.69	1330.08±377.73
4	339.75±205.42	516.78±245.16	1094±826.75	672.9±332.56	349.18±91.69	479.79±110.05
5	244.15±144.56	326.77±245.42	1900.1±959.93	977.4±684.12	1087.76±706.33	1238.28±316.2
6	132.11±54.54	208.4±183.29	1890.82±2172.2	1116.45±688.31	1230.41±1050.27	1233.12±260.58
7	67.57±70.24	69.13±33.61	2026.76±2618.48	1191.71±779.88	1155.83±727.64	1133.63±313.56
8	98.98±49.91	65.21±46.65	852.95±583.76	575.1±330.64	430.67±267.49	1199.1±911.76
9	362.53±370.3	61.74±20.34	1367.41±2270.15	770.93±469.18	714.08±854.73	1844.21±1777.29

Table 4.10.3 Mean station wise variation of algal biomass (dry weight) (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	**Surface**		**Bottom**	
	Min	**Max**	**Min**	**Max**
1	125.08	960.24	44.01	2305.60
2	43.90	3516.80	90.40	2737.73
3	190.48	2116.97	87.52	3066.99
4	92.89	2519.29	50.95	2012.69
5	35.28	3223.44	103.50	3337.14
6	56.68	5075.80	77.33	5129.84
7	1.96	4828.14	16.09	7078.44
8	2.28	2994.93	29.59	2269.46
9	6.51	5045.65	18.16	7974.70

Table 4.10.4 ANOVA of algal biomass (dry weight) in selected stations of Cochin estuary during 2009-11 period

Source	**df**	**Mean Square**	**F**
Model	37	240.538	3.615
Season	2	1972.076	29.635**
Station	8	206.199	3.099**
Surface water, Bottom water	1	48.419	0.728
Season * Station	16	188.271	2.829**
Season * Surface water, Bottom water	2	1.207	0.018
Station * Surface water, Bottom water	8	30.374	0.456
Error	394	66.546	
Total	432		
R^2=0.253			

** Variation is significant at 1% level

* Variation is significant at 5% level

The wet weight of algal biomass was found to be low (3.20 g m^{-3}) during monsoon period and high (10.10 g m^{-3}) during the post-monsoon period. During the monsoon period, the highest wet weight of algal biomass (19.67 g m^{-3}) was recorded in September 2009 and lowest (0.12 g m^{-3}) in August 2009. The range of wet weight of algal biomass during the post-monsoon period was from 1.10 g m^{-3} in December 2010 to 59.53 g m^{-3} in January 2010. In the pre-monsoon period, the maximum wet weight of algal biomass was recorded in May 2011(43.54 g m^{-3}) and the minimum in May 2010 (0.95 g m^{-3}).

The algal biomass values were high at station 6 (9.69 ± 2.07 g m^{-3}) and low at station 1 (4.14 ± 2.07g m^{-3}). The northern zone of the estuary had the highest biomass value (8.25 ± 0.88 g m^{-3}) while lowest value was recorded in the central zone (6.51 ± 0.88 g m^{-3}). The maximum value of wet weight of algal biomass in the central zone was observed at station 1 (9.62 g m^{-3}) and minimum at station 5 (4.14 g m^{-3}). In the southern zone, the wet weight of algal biomass was higher at station 3 (7.94 g m^{-3}) compared to station 2 (6.33 g m^{-3}). The highest value of algal biomass in the northern zone was recorded at station 6 (9.69 g m^{-3}) and the lowest at station 8 (5.37).

The average algal biomass of the Cochin estuary was 7.42 g m^{-3}. The annual variation of algal biomass was observed to be high during the 2009-10 period (7.86 g m^{-3}). Mean monthly values of algal biomass ranged from 59.53 g m^{-3}in January 2010 at station 7 to 0.12 g m^{-3} in August 2009 at station 9. In the 2009-10 period, the highest wet weight of algal biomass was observed in January 2010 (23.69 g m^{-3}) and the lowest was recorded in July 2009 (1.73 g m^{-3}). In the 2010-11 period, the wet weight of algal biomass ranged from 1.96 g m^{-3} in July 2010 to 16.17 g m^{-3} in May 2011 (Table 4.11.1 and Fig.4.11).

Table 4.11.1 Mean monthly variation of algal biomass (wet weight) in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Mean
J'09	5.24	7.95	4.77	3.40	2.44	0.84	0.61	0.54	3.63	3.27
J	0.88	0.67	1.39	0.72	0.69	1.37	0.15	0.91	8.75	1.73
A	1.65	3.51	4.80	3.76	2.40	1.01	0.26	0.81	0.12	2.04
S	13.19	19.67	8.13	5.71	4.23	2.07	1.69	1.70	2.00	6.49
O	16.33	23.49	11.76	22.66	32.80	5.21	6.61	6.57	1.23	14.07
N	3.23	3.10	9.97	10.68	11.22	13.34	8.08	8.42	4.07	8.01
D'09	2.29	2.72	7.12	4.22	14.09	6.06	6.85	2.63	1.72	5.30
J'10	3.38	4.15	6.67	6.20	17.90	51.03	59.53	16.50	47.68	23.67
F	2.15	3.62	8.09	3.08	8.14	20.17	17.46	7.50	19.69	9.99
M	1.66	6.90	14.36	3.15	20.93	22.44	17.14	5.52	5.23	10.81
A	4.79	4.24	12.12	4.86	9.91	4.76	9.48	2.32	2.70	6.13
M	1.22	3.80	5.95	2.88	4.53	1.84	2.15	1.89	0.95	2.80
J	4.58	5.10	3.75	4.26	1.48	1.00	0.55	1.32	0.89	2.55
J	2.75	3.67	4.58	3.07	1.37	0.84	0.29	0.46	0.64	1.96
A	3.32	4.02	3.61	4.63	3.62	1.72	0.99	0.58	0.53	2.56
S	4.32	12.23	6.82	8.71	6.60	4.77	0.95	0.25	0.41	5.01
O	6.31	8.37	8.88	10.94	19.00	18.91	20.27	8.53	13.67	12.76
N	3.51	4.59	5.84	6.73	9.77	11.16	11.92	5.75	7.71	7.44
D'10	1.56	2.14	2.07	2.81	2.64	2.18	1.50	1.10	2.21	2.02
J'11	2.67	3.27	6.56	6.44	7.68	12.40	13.98	7.62	7.24	7.54
F	3.59	6.20	13.30	4.80	12.38	12.33	11.34	11.99	18.44	10.49
M	2.45	4.64	10.13	3.49	10.88	12.30	11.56	4.31	7.14	7.43
A	3.96	4.50	11.16	6.18	16.78	9.15	7.39	6.87	4.65	7.85
M'11	4.35	9.46	18.61	4.72	9.49	15.54	15.06	24.80	43.54	16.17

Table 4.11.2 Mean season wise variation of algal biomass (wet weight) in selected stations of Cochin estuary during 2009-11 period

Stations	**Monsoon period**		**Post-monsoon period**		**Pre-monsoon period**	
	(Mean±SD)		**(Mean±SD)**		**(Mean±SD)**	
	2009-10	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**
1	5.24±5.63	3.74±0.86	6.31±6.7	3.51±2.03	2.45±1.6	3.59±0.82
2	7.95±8.37	6.25±4.03	8.37±10.1	4.59±2.71	4.64±1.53	6.2±2.31
3	4.77±2.75	4.69±1.49	8.88±2.41	5.84±2.83	10.13±3.81	13.3±3.78
4	3.4±2.05	5.17±2.45	10.94±8.27	6.73±3.33	3.49±0.92	4.8±1.1
5	2.44±1.45	3.27±2.45	19±9.6	9.77±6.84	10.88±7.06	12.38±3.16
6	1.32±0.55	2.08±1.83	18.91±21.72	11.16±6.88	12.3±10.5	12.33±2.61
7	0.68±0.7	0.69±0.34	20.27±26.18	11.92±7.8	11.56±7.28	11.34±3.14
8	0.99±0.5	0.65±0.47	8.53±5.84	5.75±3.31	4.31±2.67	11.99±9.12
9	3.63±3.7	0.62±0.2	13.67±22.7	7.71±4.69	7.14±8.55	18.44±17.77

Table 4.11.3 Mean station wise variation of wet weight of algal biomass (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	**Surface**		**Bottom**	
	Min	**Max**	**Min**	**Max**
1	1.25	9.60	0.44	23.06
2	0.44	35.17	0.90	27.38
3	1.90	21.17	0.88	30.67
4	0.93	25.19	0.51	20.13
5	0.35	32.23	1.04	33.37
6	0.57	50.76	0.77	51.30
7	0.02	48.28	0.16	70.78
8	0.02	29.95	0.30	22.69
9	0.07	50.46	0.18	79.75

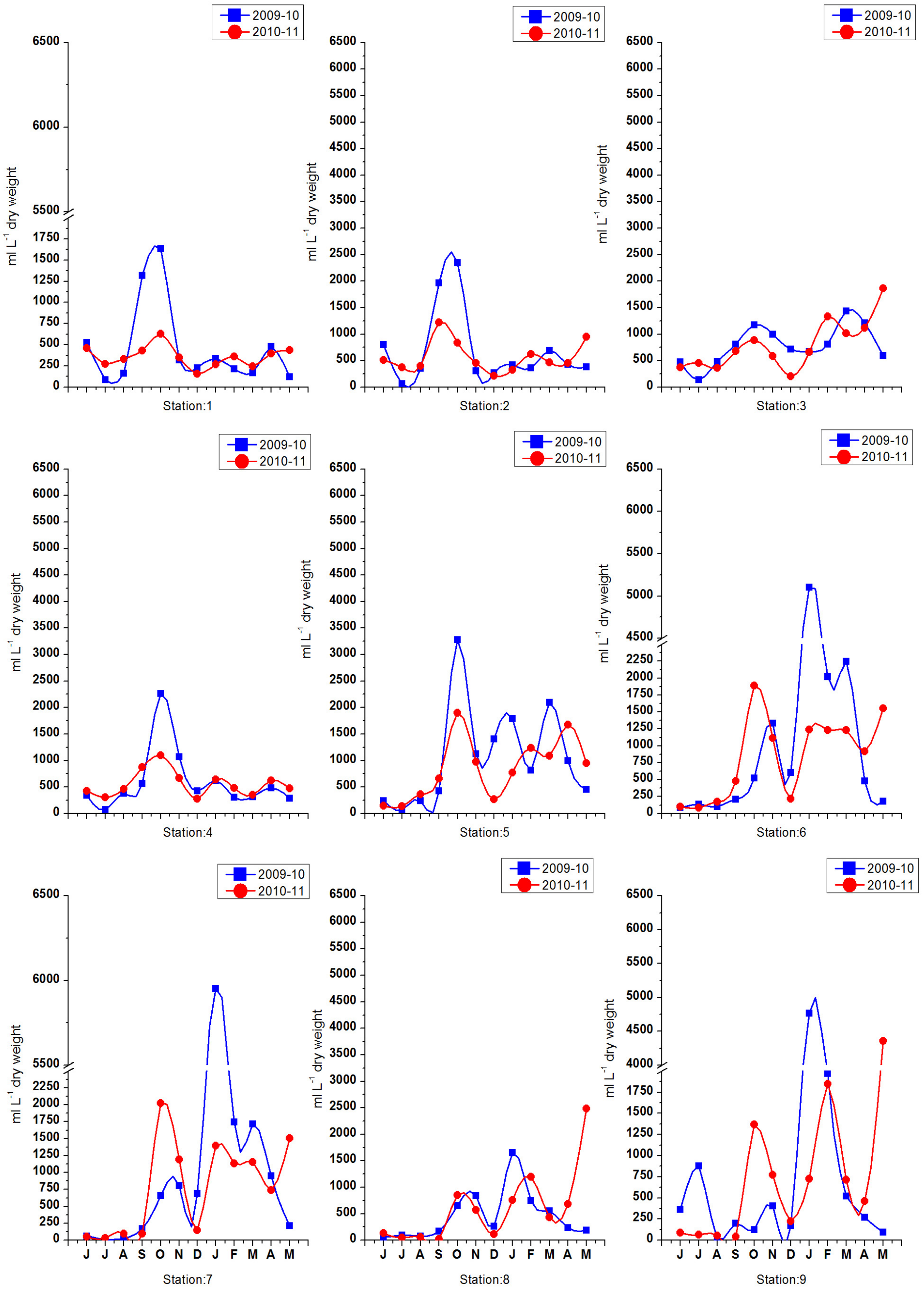


Fig. 4.10. **Mean monthly variation of algal biomass (dry weight) in selected stations of Cochin estuary during 2009-11 period**

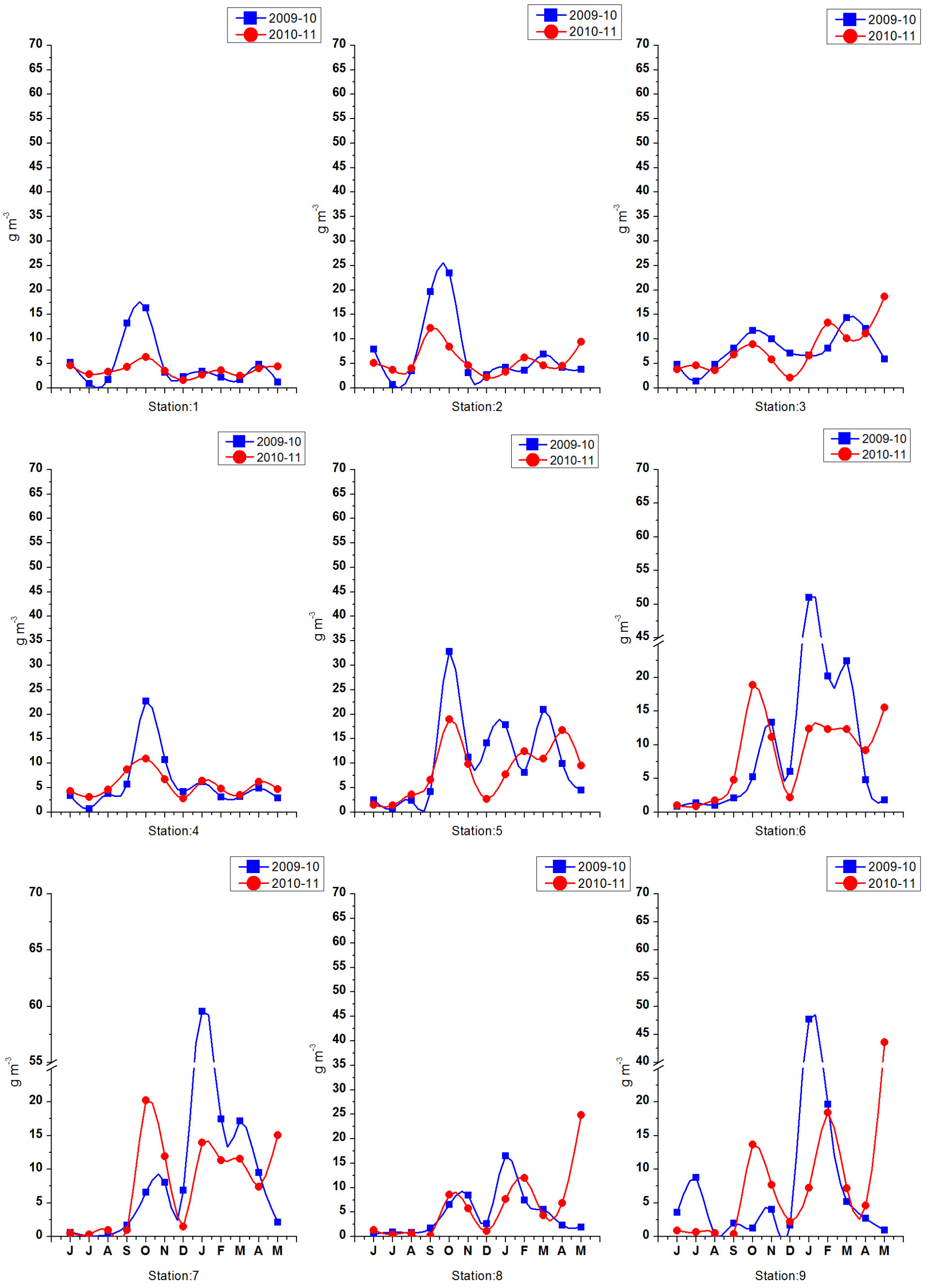


Fig. 4.11. Mean monthly variation of algal biomass (wet weight) in selected stations of Cochin estuary during 2009-11 period

4.4.11 Phytoplankton carbon

The average phytoplankton carbon in the Cochin estuary was 553.77 ± 400 mgC m^{-3}. The phytoplankton carbon was higher in the surface waters in most of the stations. The highest value of 722.80 mgC m^{-3} was recorded at station 6 and lowest value of 308.93 mgC m^{-3} was recorded at station 1. The northern zone exhibited the highest phytoplankton carbon (615.64 ± 65.90mgC m^{-3}).

The phytoplankton carbon was higher during the post-monsoon period (753.97mgC m^{-3}) and lower during the monsoon period (238.71mgC m^{-3}). In the monsoon period, the maximum and minimum values were 9.21 mgC m^{-3} and 1467.95 mgC m^{-3} respectively. In the post-monsoon period, the values were within the range from 82.44 mgC m^{-3} to 4442.76 mgCm^{-3}. During the post-monsoon period, the highest phytoplankton carbon recorded was 3248.93 mgC m^{-3} in May 2011 and the lowest was 70.73 mgC m^{-3} in May 2010.

The phytoplankton carbon was higher during the 2009-10 period (586.48 mgC m^{-3}) compared to the 2010-11 period (521.05 mgC m^{-3}). Mean monthly values of phytoplankton carbon ranged from 4442.76 mgC m^{-3} in January 2010 at station 7 to 9.20 mgC m^{-3} in August 2009 at station 9 (4.12.1 and Fig.4.12). In the 2009-10 period, the highest and lowest values were 1766.48 mgC m^{-3} and 128.76 mgC m^{-3} respectively. In the 2010-11 period, the values were within the range from146.37 mg C m^{-3} to 1206.98 mgC m^{-3}.

The variations were significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.01$) and between seasons and stations ($p \leq 0.001$) (Table 4.12.4).

Table 4.12.1 Mean monthly variation of phytoplankton carbon in selected stations of Cochin estuary during 2009-11 period

	Stations									
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Mean
J'09	390.92	593.39	356.24	253.55	182.21	62.51	45.27	40.13	270.54	243.86
J	65.54	50.11	103.73	53.67	51.79	101.93	11.04	68.20	652.86	128.76
A	122.93	262.10	357.97	280.77	178.86	75.45	19.44	60.28	9.21	151.89
S	984.29	1467.95	607.04	426.21	315.98	154.46	125.96	126.85	149.57	484.25
O	1218.60	1753.09	877.95	1691.04	2447.98	388.46	493.17	490.05	92.08	1050.27
N	240.76	231.30	743.89	797.08	837.05	995.38	602.97	628.64	303.64	597.86
D'09	170.54	202.89	531.39	314.95	1051.41	452.33	511.15	196.08	128.22	395.44
J'10	252.21	309.84	498.11	462.60	1335.51	3808.08	4442.76	1231.37	3557.88	1766.48
F	160.35	270.14	603.99	230.09	607.25	1505.33	1302.81	559.85	1469.22	745.45
M	123.87	514.76	1071.75	235.16	1561.72	1674.55	1279.38	411.63	390.36	807.02
A	357.20	316.53	904.41	362.39	739.67	355.58	707.66	173.23	201.27	457.55
M	91.27	283.24	444.06	214.71	338.40	137.42	160.39	140.88	70.73	209.01
J	341.54	380.62	279.56	317.80	110.48	74.81	40.71	98.59	66.24	190.04
J	204.89	273.72	341.62	229.44	101.91	62.79	21.31	33.97	47.74	146.37
A	247.94	299.77	269.04	345.55	270.18	128.30	73.73	43.43	39.86	190.86
S	322.24	912.72	508.94	649.85	492.86	356.21	70.63	18.67	30.48	373.62
O	470.53	624.28	662.83	816.42	1417.98	1411.06	1512.51	636.53	1020.45	952.51
N	262.01	342.71	435.60	502.17	729.40	833.17	889.34	429.18	575.32	555.43
D'10	116.19	159.50	154.43	209.67	197.05	163.04	112.10	82.44	164.91	151.03
J'11	199.32	244.37	489.54	480.42	573.18	925.42	1043.41	568.56	540.60	562.76
F	267.80	462.69	992.60	358.05	924.09	920.24	845.99	894.85	1376.27	782.51
M	183.17	346.17	756.05	260.59	811.76	918.22	862.56	321.39	532.89	554.75
A	295.30	336.01	832.97	461.50	1252.40	683.09	551.48	512.39	347.01	585.79
M'11	324.93	705.90	1388.77	352.08	708.11	1159.42	1123.95	1850.77	3248.93	1206.98

Table 4.12.2 Mean season wise variation of phytoplankton carbon in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	390.92±420.23	279.15±63.87	470.53±500.02	262.01±151.30	183.17±119.4	267.8±61.05
2	593.39±624.43	466.71±300.81	624.28±753.90	342.71±202.09	346.17±114.08	462.69±172.03
3	356.24±205.48	349.79±110.83	662.83±180.05	435.6±211.03	756.05±284.1	992.6±281.89
4	253.55±153.3	385.66±182.95	816.42±616.98	502.17±248.18	260.59±68.42	358.05±82.13
5	182.21±107.88	243.86±183.15	1417.98±716.37	729.4±510.54	811.76±527.11	924.09±235.97
6	98.59±40.70	155.53±136.79	1411.06±1621.04	833.17±513.66	918.22±783.78	920.24±194.46
7	50.43±52.42	51.59±25.09	1512.51±1954.09	889.34±582.00	862.56±543.01	845.99±234.00
8	73.86±37.25	48.66±34.81	636.53±435.64	429.18±246.75	321.39±199.62	894.85±680.42
9	270.54±276.34	46.08±15.18	1020.45±1694.14	575.32±350.14	532.89±637.86	1376.27±1326.34

Table 4.12.3 Mean station wise variation of phytoplankton carbon (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Surface		Bottom	
	Min	Max	Min	Max
1	93.34	716.60	32.84	1720.60
2	32.76	2624.48	67.46	2043.08
3	142.15	1579.83	65.31	2288.80
4	69.32	1880.07	38.02	1502.01
5	26.33	2405.55	77.24	2490.40
6	42.30	3787.91	57.71	3828.24
7	1.46	3603.09	12.01	5282.42
8	1.70	2235.02	22.08	1693.63
9	4.86	3765.41	13.55	5951.27

Table 4.12.4 ANOVA of phytoplankton carbon in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	37	1339633.491	3.615
Season	2	10982767.874	29.635**
Station	8	1148439.579	3.099**
Surface water, Bottom water	1	269616.553	0.728
Season * Station	16	1048558.821	2.829**
Season * Surface water, Bottom water	2	6725.664	0.018
Station * Surface water, Bottom water	8	169172.221	0.456
Error	394	370603.998	
Total	432		
R^2=0.253			

** Variation is significant at 1% level

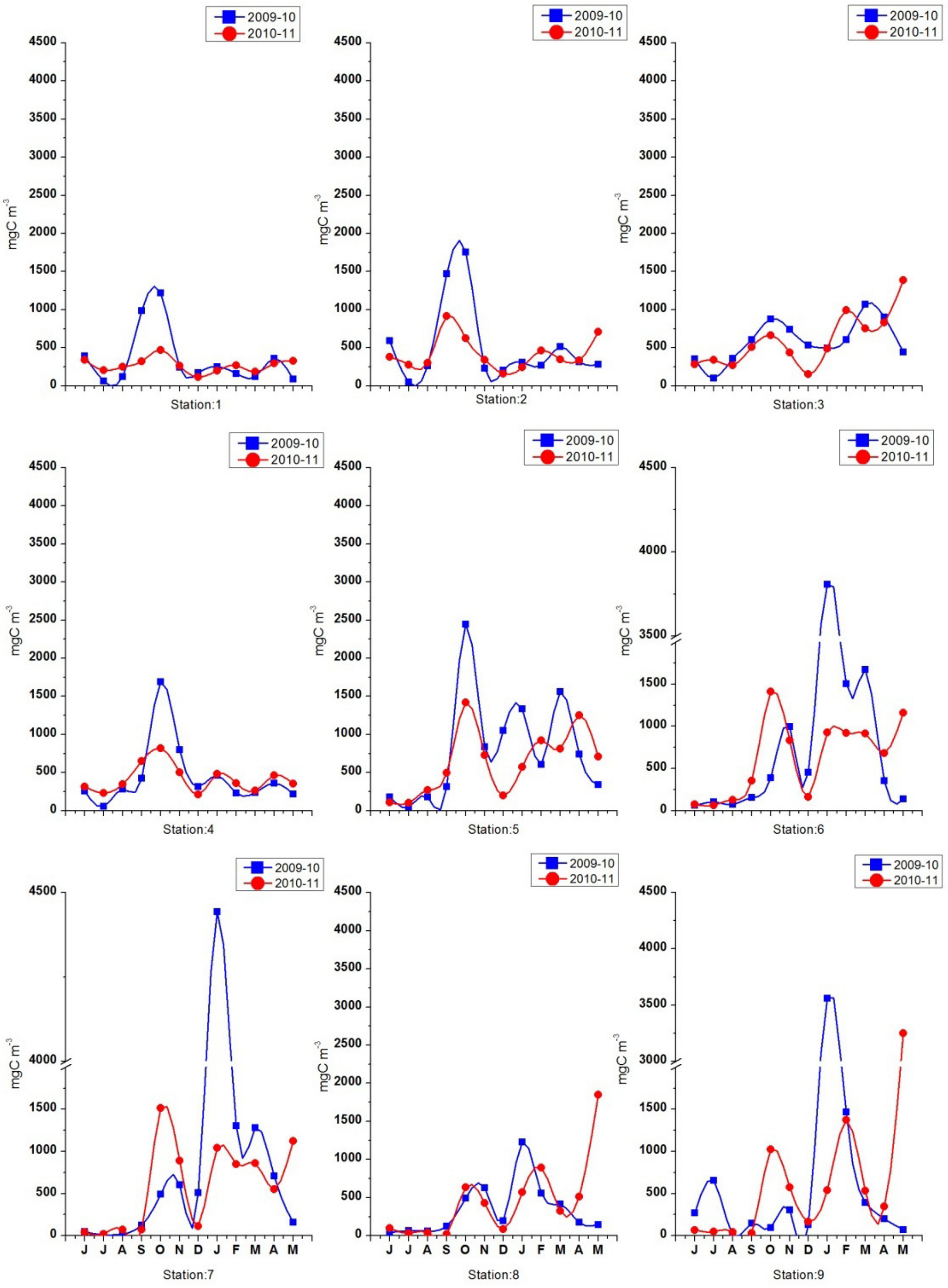


Fig. 4.12. Mean monthly variation of phytoplankton carbon in selected stations of Cochin estuary during 2009-11 period

4.4.13Total cell density of phytoplankton

Total cell density of phytoplankton during the study period was 541.39 × 10^4 cells L^{-1}. The mean season wise analysis of total cell density showed similar values during the monsoon period and pre-monsoon period. The seasonal variation of total density showed maximum values during the pre-monsoon period (23.74 × 10^4 cells L^{-1}) followed by the monsoon period (23.04 × 10^4 cells L^{-1}) and post-monsoon period (20.89 × 10^4 cells L^{-1}) periods. The mean total cell density was higher during the post monsoon period (1.92 × 10^4 cells L^{-1}) and lower during the monsoon period (1.67 × 10^4 cells L^{-1}) and pre-monsoon period (1.67 × 10^4 cells L^{-1}). During the 2009-10 period, the highest total density of phytoplankton was recorded in April 2010 (75.45 × 10^4 cells L^{-1}) and the lowest in August 2009 (2.72 × 10^4 cells L^{-1}). During the 2010-11 period, the maximum value was reported in August 2010 (94.99 × 10^4 cells L^{-1}) and minimum in April 2011 (5.72 × 10^4cells L^{-1}).The zone-wise variation of total phytoplankton cell density was maximum in southern zone (35.29 × 10^4cellsL^{-1}) and minimum in the northern zone(13.29 × 10^4 cellsL^{-1}). The mean station -wise phytoplankton cell density was higher at station 3(57.04 × 10^4 cells L^{-1}) and lower at station 8 (8.09 × 10^4 cells L^{-1}).

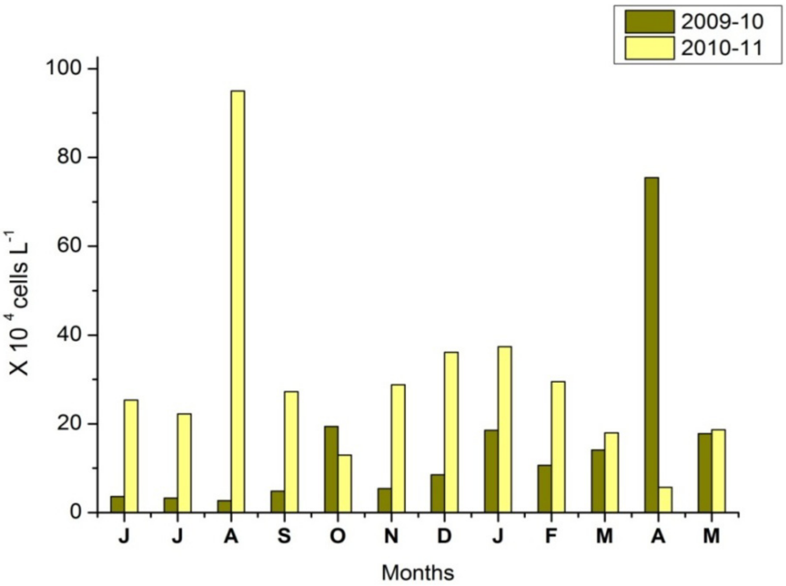


Fig. 4.13. Mean monthly wise variation of total density of microphytoplankton in selected stations of Cochin estuary during 2009-11 period

4.4.13 Composition of microphytoplankton

Composition, distribution and mean cell density of microphytoplankton in Cochin estuary during 2009-11 period is given in Table 4.13.3. In the present investigation, 93 genera of microphytoplankton (excluding nanoplankton) were identified. The microphytoplankton mainly comprised of the representatives from Bacillariophyceae, Pyrrophyceae, Chlorophyceae, Cyanophyceae, Charophyceae, Eustigmatophyceae, Zygnemophyceae and Coccolithophoraceae classes. Diatoms dominated the community at all stations and all months throughout the study period. The total cell density of the Bacillariophyceae contributed about 80.21% followed by Cyanophyceae (9.92%), Chlorophyceae (4.7%), Charophyceae (3.24%), Pyrrophyceae (1.75%), Zygnemophyceae (0.14%), Eustigmatophyceae (0.03%) and Coccolithophoraceae (0.02%).

Among the Bacillariophyceae, 49 genera of diatoms contributed to the numerical abundance of phytoplankton. About 17 genera of chlorophycean members were identified from Cochin estuary during the entire study period. Cyanophceans comprised of 11 genera. Pyrrophycean groups were represented about 9 genera of dinoflagellates and charophyceans by 4 genera. All the other classes were represented by a single genus. Seven groups of microphytoplankton members were present at stations 1, 2, 3 and 4 whereas stations 5, 6, 7, 8 and 9 contributed five groups to the total phytoplankton composition. Eustigmatophyceae, Coccolithophoraceae and Zygnemophyceae were absent at stations 5, 6, 7 and 8. Zygnemophyceans were observed only once in the sample at station 9 in January 2011.

Bacillariophyceae formed 91.21% of the microphytoplankton composition at station 1, where Cyanophceae contributed 6.08% and Pyrrophyceae 1.78%. Representatives of other groups were also present in this station (Chlorophyceae, Charophyceae, Eustigmatophyceae, Coccolithophoraceae), which contributed less than 0.65%. At station 2, seven groups of phytoplankton were identified. Bacillariophyceae formed 90.36% of the total; Chlorophyceae contributed 3.81%, Pyrrophyceae 3.60%, Cyanophceae 2.08%, Eustigmatophyceae 0.12%, Charophyceae 0.02% and Coccolithophoraceae 0.01%. At station 3, Bacillariophyceae formed 80.07% of the total, Charophyceae 8.43%, Cyanophceae 5.11%, Chlorophyceae 4.75%, Pyrrophyceae 1.59%, Coccolithophoraceae 0.03% and Eustigmatophyceae 0.02%. At station 4, Bacillariophyceae formed 79.64% of the total, Cyanophceae 10.16%, Pyrrophyceae 4.82%, Chlorophyceae 4.52%, Charophyceae 0.70%, Coccolithophoraceae 0.09% and Eustigmatophyceae 0.08%. At station 5, Bacillariophyceae formed 82.10% of the total, while the remaining composition was: Cyanophceae 15.08%, Chlorophyceae 1.21%, Pyrrophyceae 1.01%, and Charophyceae 0.59%. At station 6, the composition was: Bacillariophyceae 88.97%, Cyanophceae 5.92%, Chlorophyceae 3.61%, Charophyceae 1.40% and Pyrrophyceae 0.10%. At station 7, Bacillariophyceae formed 61.10% of the total composition, Cyanophceae 27.77%, Chlorophyceae 6.34%, Pyrrophyceae 3.06% and Charophyceae 1.74%. At station 8, Bacillariophyceae formed 61.34% of the total, Chlorophyceae 18.58%, Charophyceae 15.88%, Cyanophceae 3.81% and Pyrrophyceae 0.39%. At station 9, Bacillariophyceae formed 73.71% of the total, Chlorophyceae 10.29%, Cyanophceae 8.20%, Charophyceae 6.22% and Zygnemophyceae 1.57%.

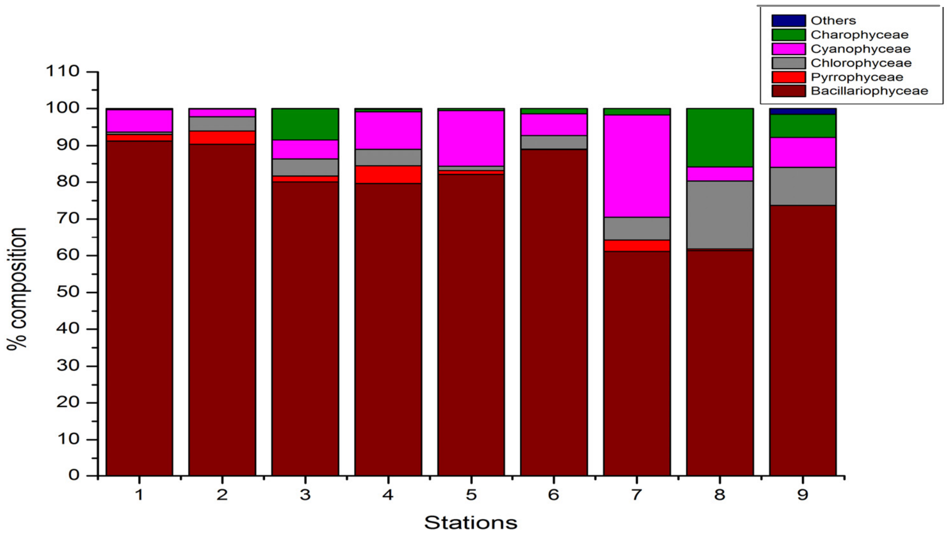


Fig. 4.14. Station wise distribution of percentage composition of microphytoplankton groups in Cochin estuary during 2009-11 period.

Table 4.13.1 Mean seasonal variation of percentage composition of microphytoplankton in selected stations of Cochin estuary during the study period.

Monsoon period

Microphytoplankton	Stations								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Bacillariophyceae	97.44	93.49	83.48	86.59	81.81	78.01	79.25	73.33	62.69
Pyrrophyceae	0.39	0.85	0.55	1.05	0.86	0.00	1.94	1.11	-
Chlorophyceae	0.10	2.35	3.30	0.70	3.44	4.81	2.59	7.78	7.46
Cyanophyceae	1.91	3.18	4.98	10.15	13.17	13.06	14.59	3.33	19.40
Charophyceae	0.07	0.02	7.64	1.38	0.72	4.12	1.62	14.44	10.45
Eustigmatophyceae	0.07	0.11	0.02	0.05	-	-	-	-	-
Zygnemophyceae	-	-	-	-	-	-	-	-	-
Coccolithophoraceae	0.01	-	0.02	0.08	-	-	-	-	-

Post-monsoon period

Microphytoplankton	Stations								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Bacillariophyceae	89.78	82.76	79.04	88.11	79.43	96.53	94.67	78.77	73.33
Pyrrophyceae	8.67	10.65	2.09	5.83	0.78	0.17	2.84	0.47	-
Chlorophyceae	0.50	4.80	0.22	1.49	2.33	1.24	1.07	15.57	12.84
Cyanophyceae	0.34	1.66	4.67	4.42	16.30	2.07	1.42	3.30	11.36
Charophyceae	0.45	-	13.93	-	1.16	-	-	1.89	1.48
Eustigmatophyceae	0.13	0.12	0.03	0.09	-	-	-	-	-
Zygnemophyceae	-	-	-	-	-	-	-	-	0.99
Coccolithophoraceae	0.13	0.02	0.03	0.06	-	-	-	-	-

Pre-monsoon period

Microphytoplankton	Stations								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Bacillariophyceae	84.13	96.00	84.19	9.00	99.72	93.15	81.31	65.90	83.94
Pyrrophyceae	5.82	0.67	0.31	1.08	-	-	-	-	-
Chlorophyceae	4.76	0.67	6.20	3.78	0.14	2.62	10.38	26.59	6.83
Cyanophyceae	4.76	2.67	8.99	5.14	0.14	3.23	6.23	4.62	8.84
Charophyceae	0.53	-	0.31	-	-	1.01	2.08	2.89	0.40
Eustigmatophyceae	-	-	-	-	-	-	-	-	-
Zygnemophyceae	-	-	-		-	-	-	-	-
Coccolithophoraceae	-	-	-	-	-	-	-	-	-

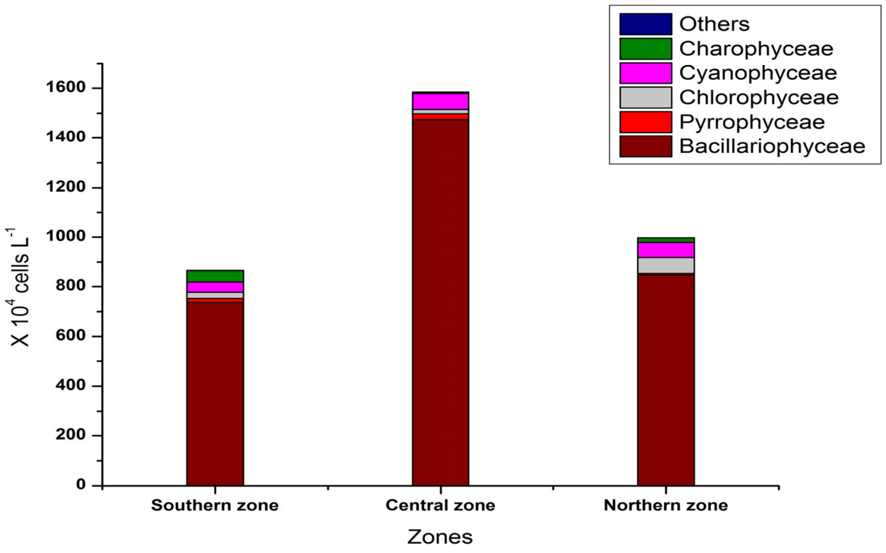
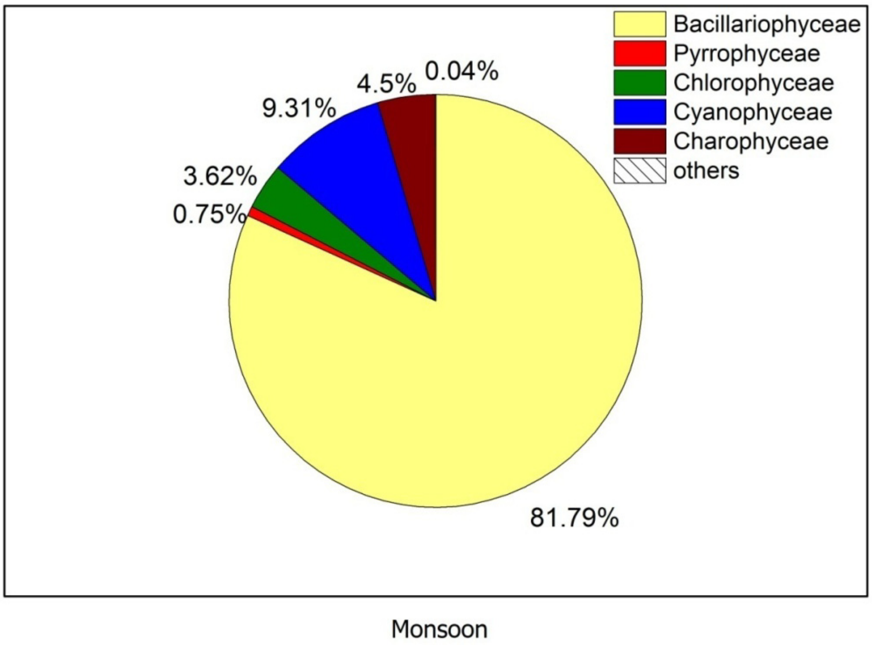
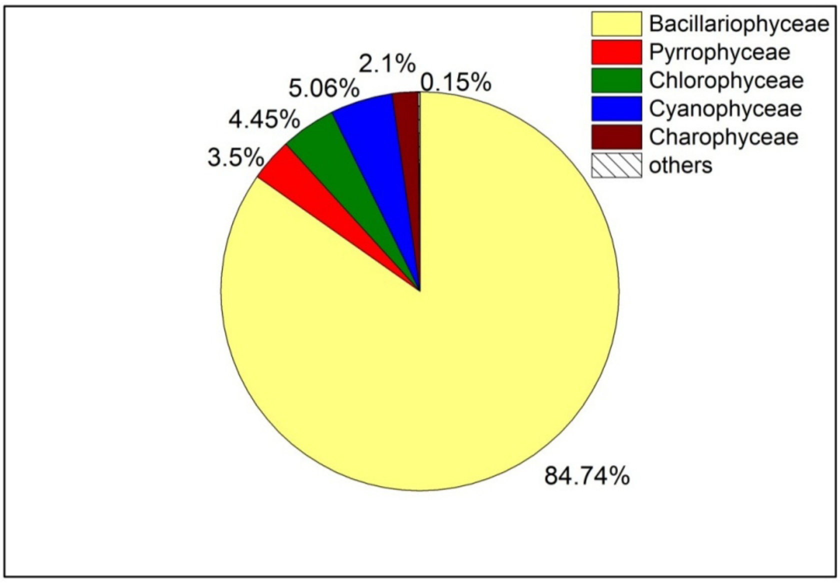
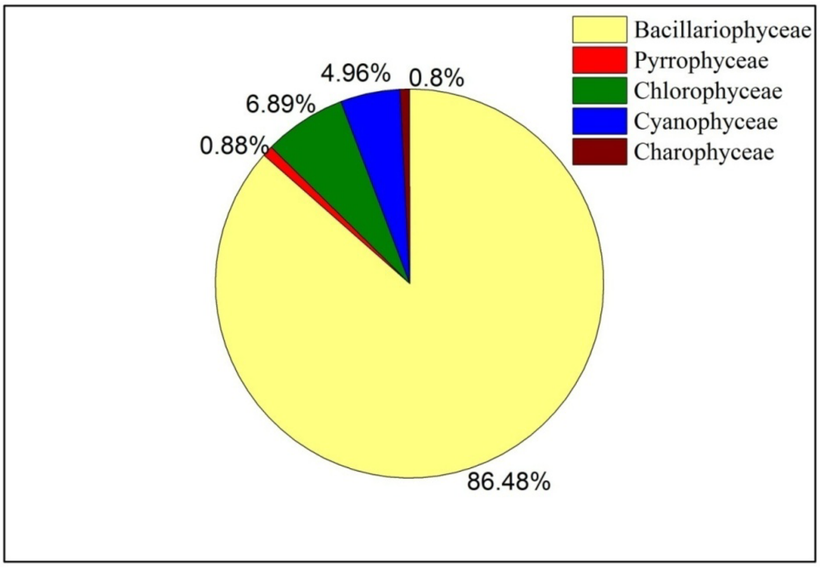


Fig. 4.15. **Zone wise distribution of cell density of microphytoplankton groups in Cochin estuary during 2009-11 period**





Post monsoon



Pre monsoon

Fig. 4.16. Mean seasonal variation of percentage composition of microphytoplankton in the Cochin estuary during the study period

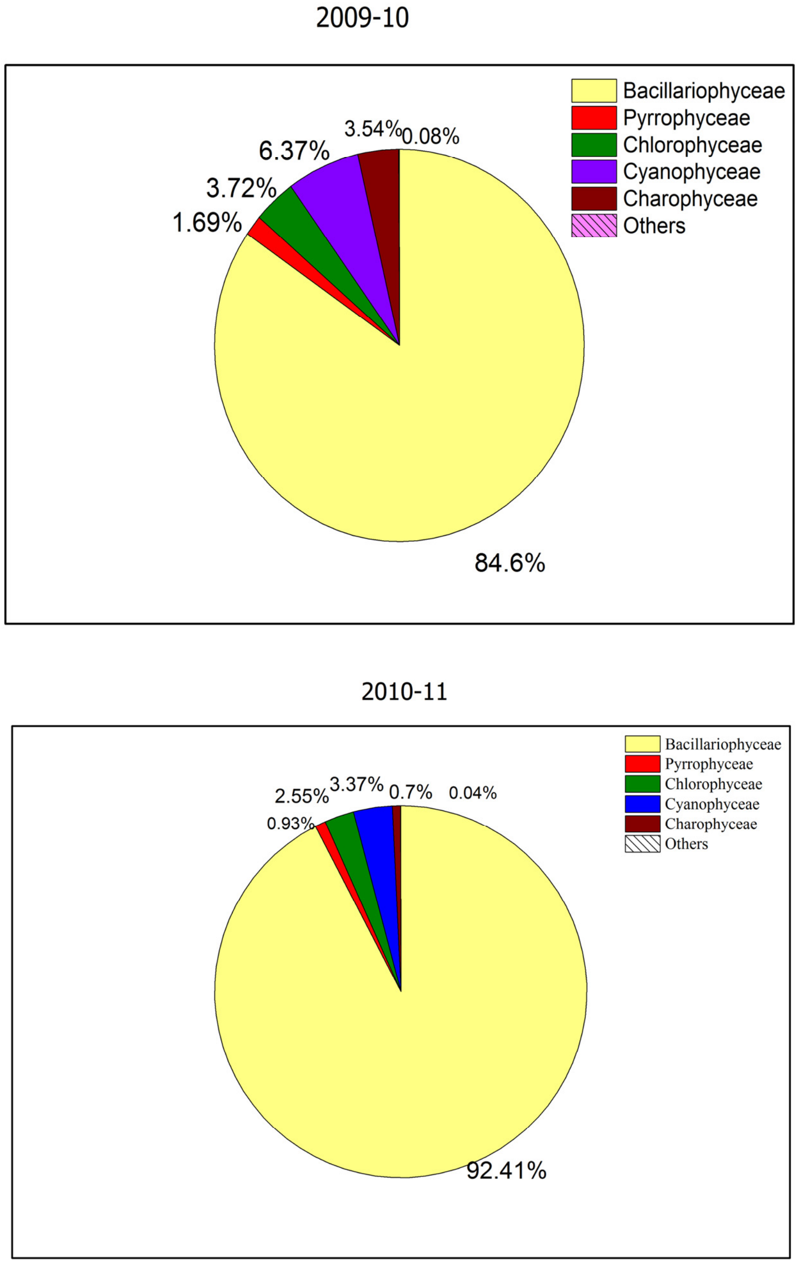


Fig. 4.17. Mean percentage composition of microphytoplankton in Cochin estuary during 2009-11period

4.4.13.1 Bacillariophyceae

In Bacillariophyceae, Pennales (8 families, 27 genera) contributed significantly to the diatom composition than Centrales (14 families, 22 genera). Thalassiosiraceae (4 genus) in centric diatoms and Naviculaceae (8 genus) in pennate diatoms contributed to the total diatom composition.

Diatoms showed the maximum cell density in July 2010 (76×10^4 cells L^{-1}) and the minimum in August 2009 (1.49×10^4 cells L^{-1}). The mean cell density of diatoms was maximum in the central zone (25.88×10^4 cells L^{-1}) and minimum in northern zone (11.16×10^4 cells L^{-1}). The mean seasonal variation of cell density was higher during the post-monsoon period (19.06×10^4 cells L^{-1}) compared to the pre-monsoon period (16.44×10^4 cells L^{-1}) and post-monsoon period (169844 cells L^{-1}). Station 5 showed the maximum numerical abundance (32.53×10^4 cells L^{-1}) while the minimum values were observed in station 8 (5.84×10^4 cells L^{-1}). The annual mean cell density of diatom was higher (12.80×10^4 cells L^{-1}) during the 2009-10 period than the 2010-11 period (23.58×10^4 cells L^{-1}).

In the monsoon period, the maximum percentage composition was recorded at station 1 (97.44%) and the minimum at station 9 (62.69%). In the post-monsoon period, the mean percentage composition of diatoms was the highest at station 6 (96.53%) and lowestat station 9 (73.33%). In the pre-monsoon period, the highest value was at station 5 (99.72%) and the lowest at station 8 (65.90%).

Succession of species occurred when the environmental conditions became exceptionally favourable for certain organisms to appear in high aggregations. *Nitzschia, Melosira, Coscinodiscus, Pleurosigma, Navicula* were found to be very common during most part of the year which indicated that these diatom groups have wide range of tolerance. *Melosira* was found to be dominant during monsoon period (68.18%) as compared to other period (pre-monsoon period- 3.73% and post-monsoon period- 3.51%). *Coscinodiscus* emerged as the most dominant diatom genera during the post-monsoon period (42.41%) in comparison with other periods (pre-monsoon period- 21.64% and post-monsoon period- 18.64 %). *Nitzschia*was the dominant group during the post monsoon period (61.35%) in comparison with other periods (pre- monsoon- 11.58% and monsoon- 4.73%). *Pleurosigmaand Navicula*alsothrive well during the different seasons of the estuary.

ANOVA analysis of diatoms cell density showed that it was significant at 5% level between seasons and stations ($p \leq 0.05$).

Table 4.13.2 ANOVA of abundance of Bacillariophyceae in Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	26	20225651.908	1.998
Season	2	19287046.267	1.905
Station	8	18461794.967	1.824
Season * Station	16	19136289.358	1.890*
Error	144	10123848.443	
Total	171		
R^2=0.265			

* Variation is significant at 5% level

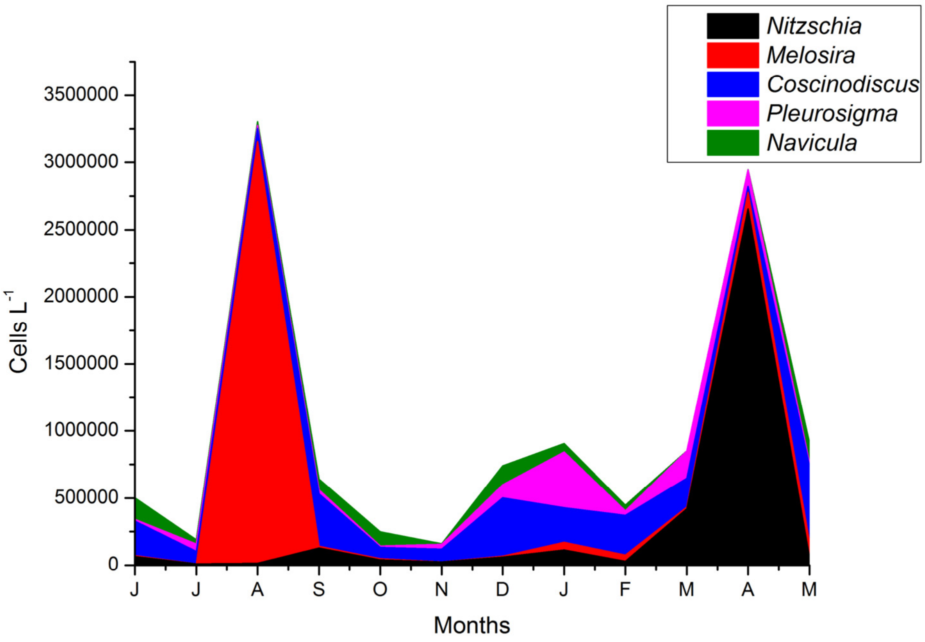


Fig.4.18. Mean monthly abundance variation of the five dominant diatom genera in the Cochin estuary during 2009-11 period

4.4.13.2 Chlorophyceae

In chlorophyceae, 10 families and 17 genera were identified from the study stations. The mean monthly variation of the cell density of green algae was the maximum in April 2010 (1.32×10^4 cells L^{-1}) and minimum in November 2009 (0.07×10^4 cells L^{-1}). The cell density was highest at station 8 (1.44×10^4 cells L^{-1}) and lowest at station 1 (0.19×10^4 cells L^{-1}). The northern zone (0.85×10^4 cells L^{-1}) showed the highest cell density, followed by the southern (0.65×10^4 cells L^{-1}) and the central (0.30×10^4 cells L^{-1}) zones. Mean seasonal variation of cell density was the highest during the pre-monsoon period (0.83×10^4 cells L^{-1}) and the lowest during the monsoon period (0.41×10^4 cells L^{-1}). A comparatively higher abundance was observed in the 2010-11 period (0.74 × 10^4 cells L^{-1}) than the 2009-10 period (0.57 × 10^4 cells L^{-1}).

The seasonal variation of the numerical abundance of Chlorophyceans was highest at station 8 (7.78%) in all the seasons. Lowest mean percentage abundance was recorded at station 1 (0.10%) in the monsoon period, station 3 in the post-monsoon period (0.22%) and station 5 in the pre-monsoon period (0.14%).

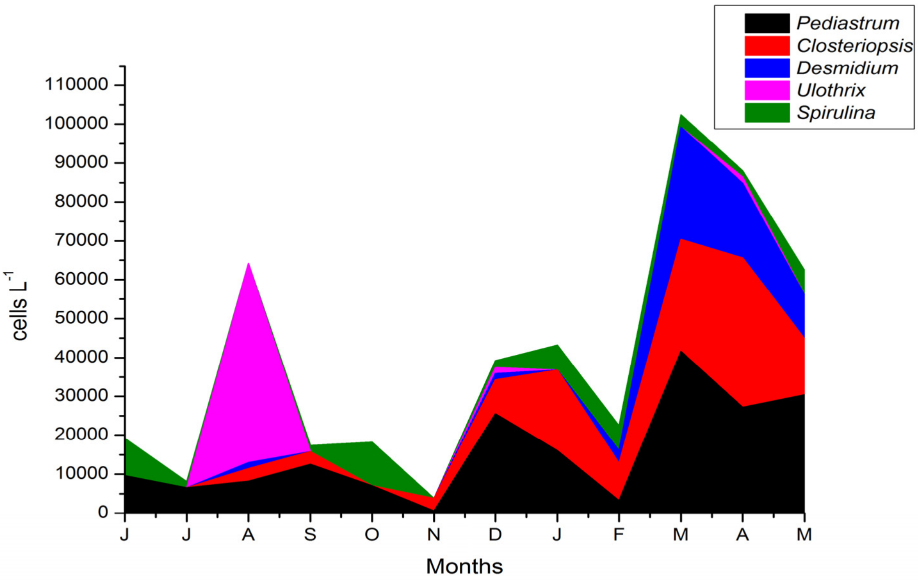


Fig. 4.19. Mean monthly abundance variation of the five dominant green algae genera in the Cochin estuary during 2009-11 period

Among the Chlorophyceans, *Pediastrum* dominated during the pre-monsoon period and post-monsoon period. In the monsoon period, *Ulothrix* (0.90%) was the dominant group followed by *Pediastrum* (0.55%) and *Staurastrum* (0.25%). *Ulothrix* (0.47%) and *Closteriopsis* (0.35%) were the major groups during the post-monsoon period.

Closteriopsis (0.67%) and *Desmidium* (0.40%) percentage was high during the pre-monsoon period. The dominant Charophycean members were *Spondylosium* and *Micrasterias* during the monsoon period and the post-monsoon period. *Spondylosium*, followed by *Gonantozygon* contributed a major share during the pre-monsoon period.

4.4.13.3 Cyanophyceae

In cyanophyceae, 7 families and 11 genera were identified. When the average cell density of cyanophyceae was compared between stations and maximum cell density was observed at station 3 (1.73×10^4 cells L^{-1}) while the minimum was observed at station 8 (0.30×10^4 cells L^{-1}). Cyanophyceans showed the maximum cell density in June 2010 (4.94×10^4 cells L^{-1}) and minimum in November 2009 (0.01×10^4 cells L^{-1}). The central zone showed the highest biomass of 1.12×10^4 cells L^{-1} and the minimum 0.80×10^4 cells L^{-1} in the northern zone of the estuary. The cell density was higher during the 2010-11 period (1.42×10^4 cells L^{-1}). Mean seasonal variation of cell density of cyanophyceans was higher during the monsoon period (1.15×10^4 cells L^{-1}) compared to the pre-monsoon period (0.76×10^4 cells L^{-1}) and post-monsoon period (8622 cells L^{-1}).

Seasonal variations of the percentage composition of the blue green algae were maximum at station 9 (19.40%) and minimum at station 1 (1.91%) during the monsoon period season. In the post-monsoon period, the maximum abundance was observed at station 5 (16.30%) and minimum at station 1 (0.34%). The blue green algae were the highest in count at station 5 (8.99%) and lowest at station 3 (0.14%).

Cyanophyceans were the second dominant group. *Anabena, Oscillatoria* and *Spirogyra* were the abundant groups in the monsoon period and the post-monsoon period. *Oscillatoria* (1.84%), *Spirogyra* (0.08%) and *Nostoc* (0.09%) contributed a significant share in the blue green algae community of phytoplankton.

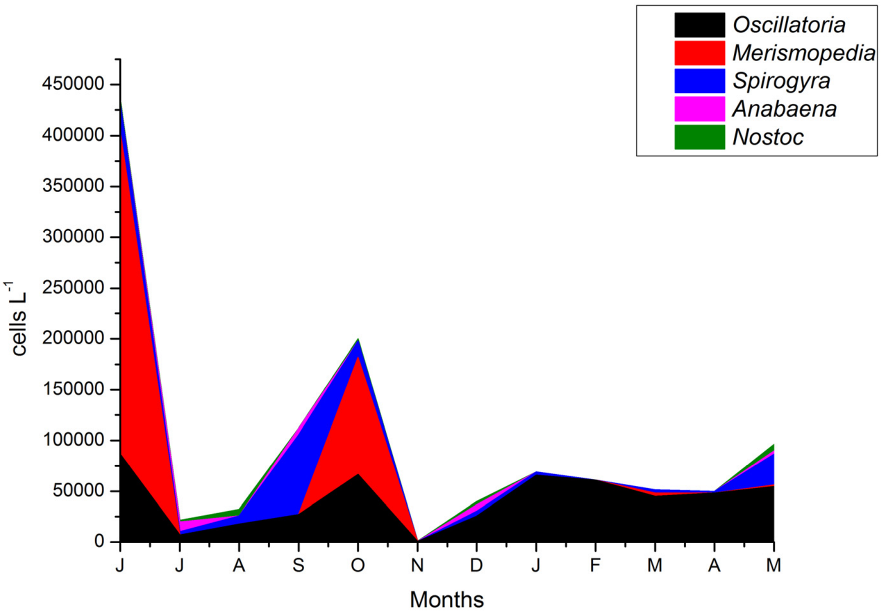


Fig. 4.20. Mean monthly abundance variation of the five dominant blue green algae genera in the Cochin estuary during 2009-11 period

4.4.13.4 Pyrrophyceae

In Pyrrophyceae, 9 genera from 7 families were identified from the Cochin estuary during the study period. Mean station wise distribution of cell density of dinoflagellate was high at station 1 (0.60×10^4 cells L^{-1}) and was zero at station 9. Dinoflagellates were present in only some of the months. The maximum cell density was observed in December 2010 (1.03×10^4 cells L^{-1}) and the lowest value was zero in March and May

2010. The zone-wise distribution of pyrrophyceans was maximum in southern zone (0.42 × 10^4 cells L^{-1}) and minimum in the northern zone (0.07 × 10^4 cells L^{-1}). The post-monsoon period showed the maximum cell density (0.57 × 10^4 cells L^{-1}), compared to the pre-monsoon period (0.12 × 10^4 cells L^{-1}) and monsoon period (0.15 × 10^4 cells L^{-1}) periods. The dinoflagellate abundance was high during the 2009-10 period (0.27 × 10^4 cells L^{-1}).

The dinoflagellates were absent in some of the stations across all seasons. The seasonal variation of pyrrophyceans were maximum at station 7 (1.94%) in the monsoon period. The maximum was 10.65% at station 2 in the post-monsoon period and 26.59% at station 8 in the pre-monsoon period.

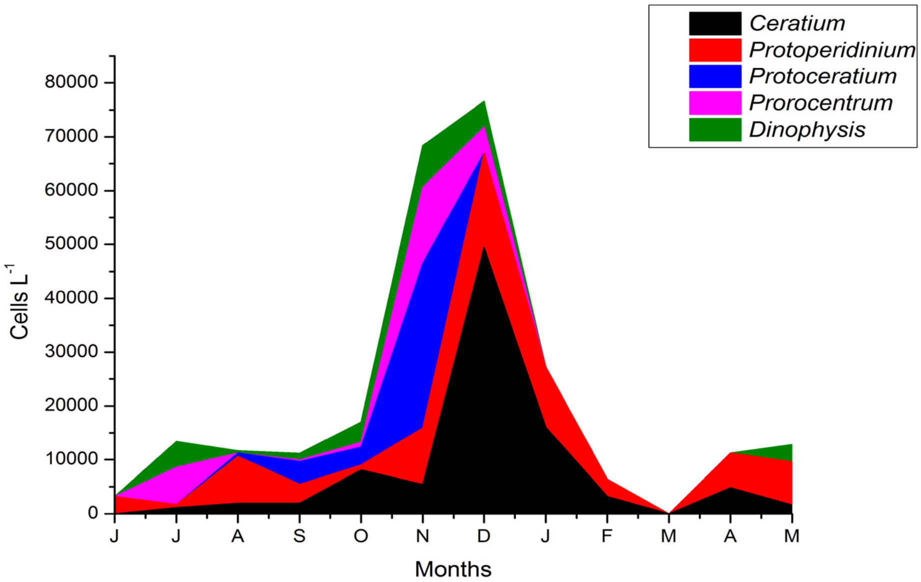


Fig. 4.21. Mean monthly abundance variation of the five dominant dinoflagellates genera in the Cochin estuary during 2009-11 period

The seasonal succession of dinoflagellates was evident during the study period. The major groups among them during the monsoon period were *Protoperidinium*(0.24%), *Dinophysis* (0.13%) and *Prorocentrum* (0.11%). In the post-monsoon period, *Ceratium*(0.69%) was the major group followed by *Protoperidinium* (0.48%). *Ceratium* (0.23%), *Protoperidinium* (0.19%) and *Dinophysis* (0.07%) dominated in the pre-monsoon period.

4.4.13.5 Charophyceans and Others

The four genera of charophyceans come under three families during the study period. The maximum cell density of Charophyceans was present in June 2010 (2.90 $\times 10^4$ cells L^{-1}) and the minimum was zero in November 2009. Station 3 showed the maximum abundance (2.54 $\times$ 10^4 cells L^{-1}) while the minimum was at station 2 (0.0016 $\times$ 10^4 cells L^{-1}). The southern zone showed the maximum abundance (1.27 $\times$ 10^4 cells L^{-1}) and the minimum count was observed in central zone (0.08 $\times$ 10^4 cells L^{-1}). The cell density was high during the monsoon period (0.51 $\times$ 10^4 cells L^{-1}) and low during the pre-monsoon period (0.10 $\times$ 10^4 cells L^{-1}). The mean annual variation was the maximum in the 2010-11 period (0.51 $\times 10^4$ cells L^{-1}). In the monsoon period, the charophyceans were maximum at station 8 (14.44%) and minimum at station 2 (0.02%). In the post-monsoon period, station 3 showed the maximum (13.43%) and the minimum count was zero at stations 2, 4, 6 and 7. In the pre-monsoon period, the highest percentage composition was observed from station 8 and the Charophyceans were absent at stations 2, 4 and 5. The members of Eustigmatophyceae, Zygnemophyceae and Coccolithophoraceae were absent in most of the months. These three groups together contribute 0.18% the total cell density of microphytoplankton community. In the post-monsoon period, these groups contributed 1.59 % of the total composition of the community. The maximum composition was at station 9 (0.99%) and the minimum was zero at stations 5, 6, 7 and 8. The members of the groups were entirely absent in the pre-monsoon period at all the stations. In the monsoon period, they contributed 0.35% to the total community. The highest composition was at station 4 (0.13%) and it was absent at station 5,6,7,8 and 9.

Table 4.13.3 Composition, distribution and mean cell density (X10^4 cells L^{-1}) of microphytoplankton in Cochin estuary during 2009-11 period

	Months											
Bacillariophyceae	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**
Achananthes	-	-	-	-	2.24	-	0.32	-	-	-	-	-
Aulacoseira	19.20	3.20	4.08	0.32	11.52		4.48	-	0.32	-	-	3.52
Amphiprora	-	-	0.16	0.03	0.18	0.18	0.32	-	-	0.32	-	-
Amphora	0.32	0.48	0.60	0.27	0.61	0.12	1.09	2.56	-	-	-	-
Asteromphalus	-	0.72	-	0.02	0.06	0.03	-	-	-	-	-	-
Asterionella	-	0.67	0.49	0.15	0.37	0.06	0.72	1.44	-	-	-	0.16
Bacillaria	-	0.09	-	-	-	-	2.72	0.64	-	1.92	-	-
Bacteriastrum	-	-	-	0.05	0.69	0.99	0.16	-	-	-	-	-
Caloneis	-	0.69	-	-	-	-	-	-	-	-	-	0.16
Campylodiscus	-	-	0.16	0.05	0.09	0.78	1.04	5.76	-	12.16	5.12	-
Chaetoceros	-	1.56	0.15	0.18	0.12	0.09	2.36	0.80	-	-	1.12	0.16
Climacosphenia	0.32	0.46	-	0.02	0.18	0.06	0.88	-	-	-	-	-
Cocconeis	-	0.24	-	0.06	4.78	0.18	0.50	0.80	-	-	3.84	0.16
Coscinodiscus	25.60	9.40	9.70	38.84	8.42	9.50	43.45	25.76	29.28	21.44	4.48	56.32
cyclotella	-	10.50	2.72	16.96	0.32	-	11.84	1.76	-	-	-	4.80
Cylindrotheca	0.32	0.48	1.12	-	-	-	0.96	1.12	0.32	-	-	1.92

Cymbella	-	0.48	-	-	0.03	0.03	0.96	-	-	-	-	-
Ditylum	-	0.32	-	0.03	0.09	0.03	0.02	-	-	-	-	-
Diploneis	0.32	0.83	0.32	0.09	0.35	0.03	0.32	0.32	-	-	-	0.96
Eucampia	-	0.41	0.06	0.30	3.23	0.06	0.13	-	-	-	-	-
Fragilariopsis	3.52	1.24	0.98	2.46	0.24	1.11	1.68	0.48	22.40	-	-	-
Grammatophora	-	0.67	-	-	-	-	-	-	-	-	-	-
Guinardia	1.28	-	-	0.02	3.00	0.12	-	-	-	-	-	-
Gyrosigma	4.80	1.03	0.64	5.04	3.93	0.18	2.29	3.04	1.60	-	8.00	2.24
Hantzhia	1.28	0.11	-	-	0.64	-	-	-	-	-	-	-
Isthmia	-	0.16	-	-	3.20	-	-	-	-	-	-	-
Leptocylindricus	7.36	6.40	-	-	2.88	-	2.56	4.16	-	-	-	2.56
Licmophora	4.80	0.16	-	-	4.16	-	0.16	0.64	-	-	-	-
Melosira	0.64	-	314.08	1.30	0.96	-	0.64	5.60	4.80	1.28	12.16	11.52
Navicula	16.00	3.12	2.75	7.92	10.56	0.36	14.18	6.48	4.16	-	0.16	14.88
Nitzschia	6.57	1.00	1.47	12.89	3.96	2.45	6.02	11.36	2.88	41.92	265.60	5.76
Odontella	2.24	8.23	1.15	1.76	2.11	2.65	12.02	9.76	2.88	5.44	6.56	4.80
Pinnularia	1.92	0.66	-	0.16	-	-	1.20	0.80	0.64	0.32	1.12	0.64
Planktoniella	-	1.28	-	0.84	0.32	2.12	3.20	1.44	1.60	-	1.44	0.64
Pleurosigma	1.28	5.49	2.36	3.09	1.04	3.64	9.60	41.44	3.52	20.48	12.16	2.56
Pseudonitzschia	-	1.68	0.14	0.21	0.30	0.22	1.33	1.12	-	-	-	-
Rhizosolenia	-	0.85	1.05	1.18	0.61	0.24	1.10	1.60	-	-	-	0.32
Skeletonema	2.88	4.96	0.21	3.57	0.06	10.47	3.13	0.96	-	-	-	0.16
Stephanopyxis	-	0.59	-	-	-	-	-	0.32	-	-	-	0.96
Striatella	-	-	-	-	-	-	-	-	-	-	-	-
Surirella	0.32	0.64	0.48	0.48	1.31	0.03	0.88	2.72	0.32	-	0.64	0.16
Synedra	0.64	1.28	0.79	0.11	0.80	0.09	2.16	1.60	0.96	-	-	0.64
Tabellaria	-	0.26	0.06	0.09	0.03	0.12	0.16	-	-	-	-	-
Thalassionema	1.28	3.46	1.60	0.15	1.17	0.06	3.39	0.80	0.64	-	0.16	-
Thalassiosira	-	1.49	0.66	1.95	0.15	0.32	5.01	65.60	1.92	-	0.16	0.48
Thalassiothrix	-	0.15	0.26	0.19	0.42	0.07	0.03	0.80	-	-	-	-
Trachyneis	-	0.11	-	-	0.06	0.06	-	0.16	-	-	-	-
Triceratium	0.96	1.12	0.16	0.32	1.40	1.37	3.94	2.40	-	3.52	3.04	2.08
Tropidoneis	-	-	-	0.03	0.03	0.03	-	-	-	-	-	-
Pyrrophyceae												

Ceratium	-	0.11	0.20	0.20	0.81	0.54	4.94	1.60	0.32	-	0.48	0.16
Dinophysis	-	0.48	0.05	0.12	0.38	0.78	0.48	-	-	-	-	0.32
Gonyaulax	-	0.22	0.12	-	0.06	-	-	-	-	-	-	-
Gymnodinium	-	0.08	-	-	-	-	0.16	-	-	-	-	-
Peridinium	-	-	-	0.02	-	-	-	-	-	-	-	-
Phalacroma	-	0.11	0.15	0.04	-	-	0.05	-	-	-	-	-
Prorocentrum	-	0.69	-	0.03	0.09	1.41	0.48	-	-	-	-	-
Protoceratium	-	-	0.06	0.42	0.33	3.06	-	-	-	-	-	-
Protoperidinium	0.32	0.06	0.87	0.35	0.09	1.05	1.76	1.12	0.32	-	0.64	0.80
Chlorophyceae												
Actinastrum	-	-	-	0.16	-	-	-	-	0.64	-	-	-
Chlorella	-	0.16	-	-	-	-	-	0.48	-	-	-	-
Closteriopsis	-	-	0.32	0.32	-	0.32	0.88	2.08	0.96	2.88	3.84	1.44
Coleastrum	-	0.48	-	-	-	-	-	-	-	-	-	0.32
Cosmarium	-	-	-	-	-	-	0.24	1.28	-	-	-	0.16
Desmidium	-	-	0.16	-	-	-	0.16	-	0.32	2.88	1.92	1.12
Gymnozyga	0.96	-	-	-	0.96	-	-	-	-	-	-	-
Hyalotheca	-	-	-	-	-	-	-	-	0.64	-	-	-
Hydrodictyon	-	-	-	0.05	0.15	-	-	-	-	-	-	-
Pediastrum	0.96	0.65	0.82	1.26	0.71	0.06	2.55	1.60	0.32	4.16	2.72	3.04
Scenedesmus	1.28	0.25	0.32	1.78	2.24	-	-	0.64	-	0.32	0.16	0.80
Selenastrum	0.32	0.33	-	-	-	0.21	-	0.32	-	0.64	0.32	-
Staurastrum	-	0.24	0.16	1.28	-	-	1.12	0.64	-	-	0.32	0.16
Tetraselmis	-	-	-	-	-	-	0.16	-	-	-	-	-
Ulothrix	-	-	5.12	-	-	-	0.16	-	-	-	0.16	-
Uronema	-	-	-	0.16	-	-	-	-	-	0.32	0.48	0.16
volvox	-	0.16	-	-	-	-	0.96	0.16	-	-	-	-
Cyanophyceae												
Anabaena	-	0.96	-	0.64	-	-	0.64	-	-	-	-	0.32
Gleocapsa	-	-	0.16	-	-	-	0.16	-	-	0.32	-	-
Lyngbya	0.96	-	-	-	0.96	-	-	-	-	-	-	-
Merismopedia	31.68	-	-	-	11.52	-	-	-	-	0.32	-	0.16
Nostoc	0.32	0.16	0.64	0.02	0.21	0.03	0.32	-	-	-	-	0.64
Oscillatoria	8.64	0.69	1.75	2.70	6.65	0.06	2.53	6.56	6.08	4.48	4.80	5.44

Phormidium	-	0.76	-	-	-	-	0.16	0.16	-	-	-	-
Spirogyra	2.88	0.32	0.80	7.84	1.60	-	0.48	0.32	-	0.32	0.16	3.04
Spirulina	0.96	0.16	-	0.16	1.12	-	0.18	0.64	0.64	0.32	0.16	0.64
Synechococcus	-	0.64	-	-	-	-	-	-	-	-	-	-
Trichodesmium	-	0.02	-	-	-	-	-	-	-	-	-	-
Charophyceae												
Closterium	1.76	0.16	0.32	0.16	0.64	-	0.80	0.48	-	0.96	0.32	0.64
Gonatozygon	24.00	-	0.18	-	24.00	-	-	-	-	-	0.32	0.64
Micrasterias	0.32	-	0.96	-	-	-	0.16	0.16	0.64	0.32	-	0.16
Spondylosium	-	0.02	-	3.36	-	-	-	-	-	-	-	-
Eustigmatophyceae												
Nannochloropsis	-	0.14	0.09	0.05	0.11	0.11	0.03	-	-	-	-	-
Zygnemophyceae												
Penium	-	-	-	-	-	-	-	0.32	-	-	-	-
Coccolithophoraceae	-											
Coccolithophores	-	0.03	-	0.06	-	0.09	0.04	-	-	-	-	-

4.5 Data analysis

4.5.1 Multivariate analysis of primary production and chlorophyll (a,b,c)

4.5.2 Cluster and MDS analysis

The station wise MDS ordination of primary production (Fig.4.22.) in the estuary showed a stress value below 0.05 is an excellent similarity. The bottom waters of station 5 and 6 showed very high similarity. The surface and bottom strata of the stations 1, 3, 6 and 8 showed a close similarity in the primary production. The surface water of station 4 was dissimilar with all the other stations. The surface waters of station 5 showed a very distant similarity with other stations.

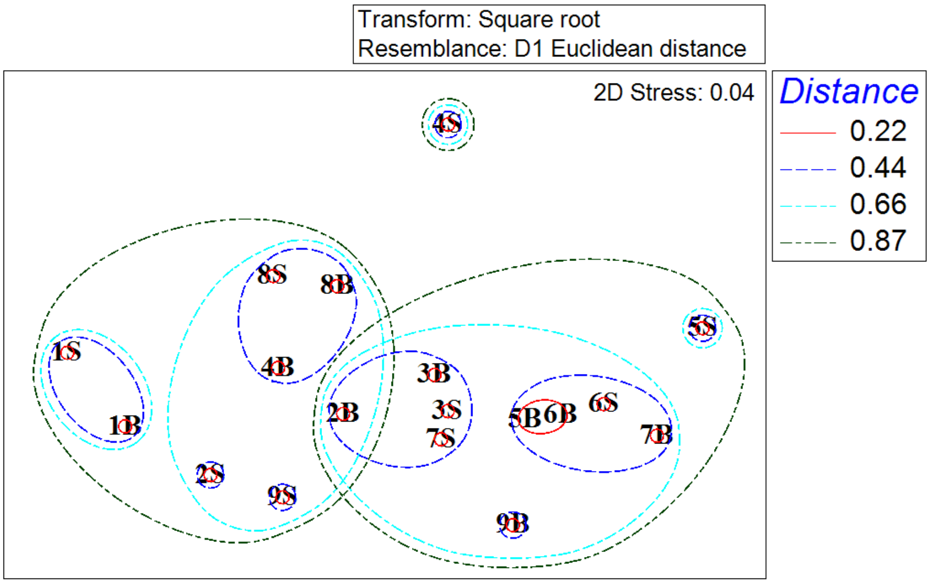


Fig.4.22. MDS showing similarity clusters formed by mean station wise surface and bottom values of primary production (GPP, NPP) and chlorophyll (a,b,c) in Cochin estuary during 2009-11period

The dendrogram of the similarity showed six clusters (Fig.4.23). June and November 2009 formed the first and fifth clusters. The second cluster is formed by months from June 2010, July 2010, August 2009 and 2010, May 2010 and December 2010. The third cluster is formed by the months February to April 2009, June 2009, September 2009 and December 2010. The fourth cluster formed by January and May. October 2009 and 2010 formed the sixth cluster. The dendrogram of the primary production of the estuary showed that the southwest and northeast monsoon period significantly influence the spatio-temporal variations of production.

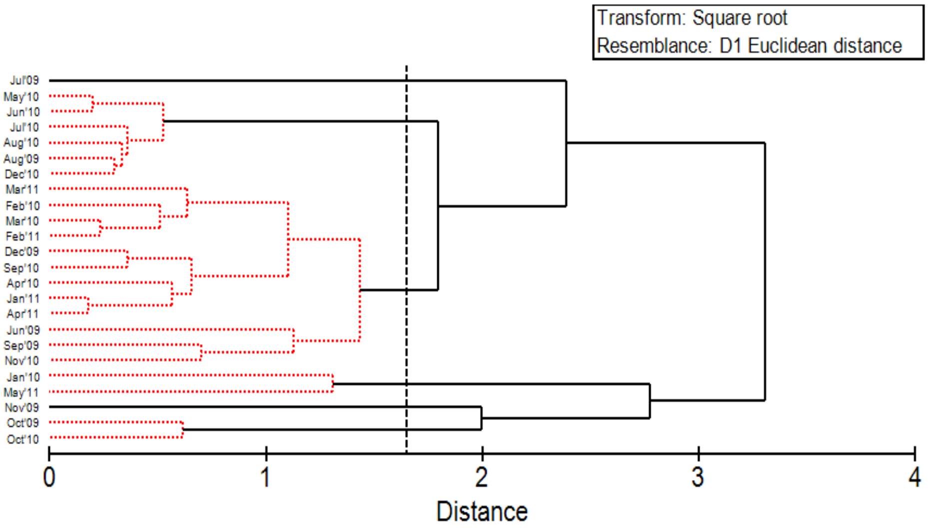


Fig. 4.23. Dendrogram showing similarity clusters formed by mean monthly values of primary production (GPP, NPP) and chlorophyll (a,b,c) in Cochin estuary during 2009-11period

4.5.3 Univariate analysis of microphytoplankton community structure

The richness based on phytoplankton groups among the different stations were compared (Fig.4.24). The Shannon diversity index (H' log (2)) and evenness index (J') were maximum at station 8 (4.97 and 0.88) and minimum at station 1 (2.54 and 0.44). Majority of the stations in the central zone and northern zone showed high diversity. The spatial variation of diversity may be due to the influence of salinity. The Richness index (d) was high at station 3 (7.77) and low at station 5 (5.33). The evenness was high at station 8 and low at station 1.

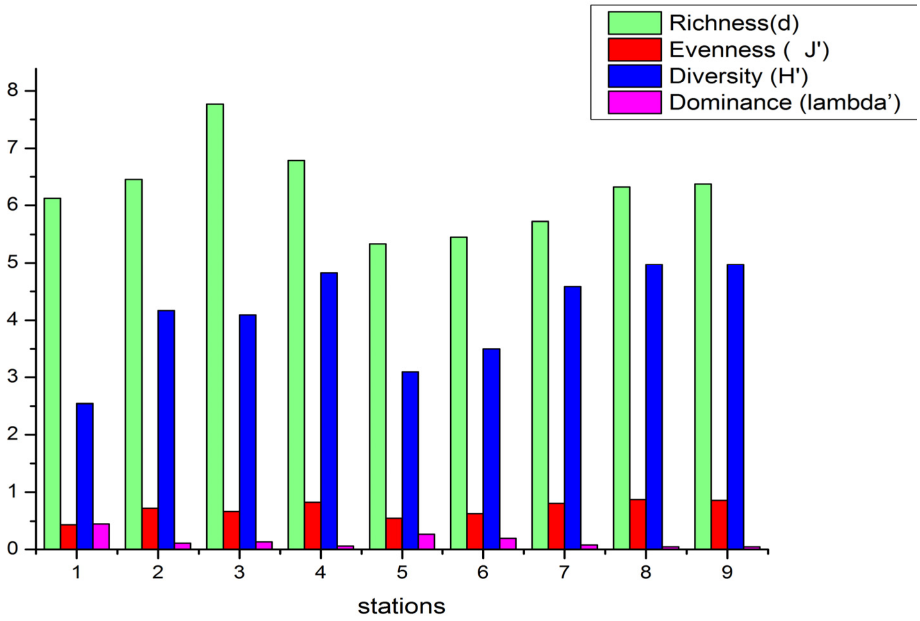


Fig. 4.24. Mean station wise variation of diversity indices of microphytoplankton in selected stations of Cochin estuary during 2009-11 period

The mean monthly variation of richness of microphytoplankton community in the Cochin estuary was compared (Fig.4.25). The maximum richness was observed in July (4.91) and the minimum in March (1.57). Evenness was high in July (0.79) and low in August (0.20). Shannon Weiner diversity was the highest in July (4.84) and lowest in August (1.15). Dominance of microphytoplankton groups ranged from 0.94 in July 2010 to 0.24 in August.

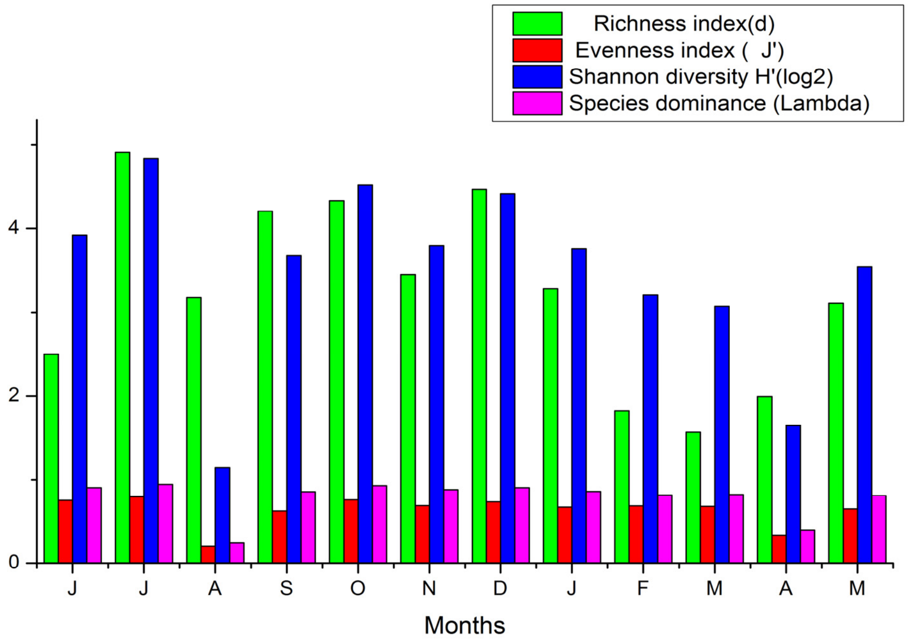


Fig. 4.25. **Mean monthly variation of diversity indices of microphytoplankton in the Cochin estuary during the study period**

When the richness of microphytoplankton in different seasons were compared (Fig.4.26), richness (d) has the same values in the post-monsoon period and pre-monsoon periods (0.51) and was low in the monsoon period. Evenness index ranged from J' =0.91 in post-monsoon period to J'= 0.78 in monsoon period. The maximum diversity was in the post-monsoon period (H'= 2.89), followed by the pre-monsoon period (H'=2.75) and monsoon period (H'=2.47) periods. The minimum dominance index (0.17) was observed in the post-monsoon period and maximum in the monsoon period (0.24).

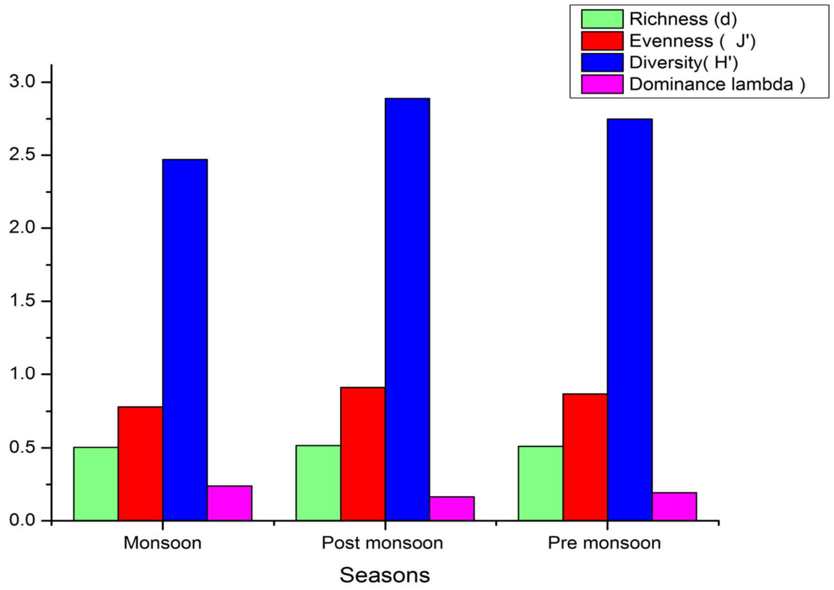


Fig. 4.26. Mean seasonal variation of diversity indices of microphytoplankton in the Cochin estuary during the study period

4.5.4 MDS analysis of microphytoplankton community structure

The MDS analysis of mean numerical abundance of micophytoplankton indicated the similarity of stations based on salinity. For the two-dimensional plots a stress value less than 0.05 is an excellent representation and a stress less than 0.1 corresponds to good ordination, with no real risk of drawing false inferences. In the monsoon period season, the southern and central zone of the estuary along with station 7, forms an MDS subset while the stations of the northern zone forms another set with 80% similarity. In the post-monsoon period, three subsets arise, also influenced by fresh water inflow. In the pre-monsoon period, a single subset is formed which includes all the stations except stations 5 and 2. The similar stations have either a few species in common or the same species.

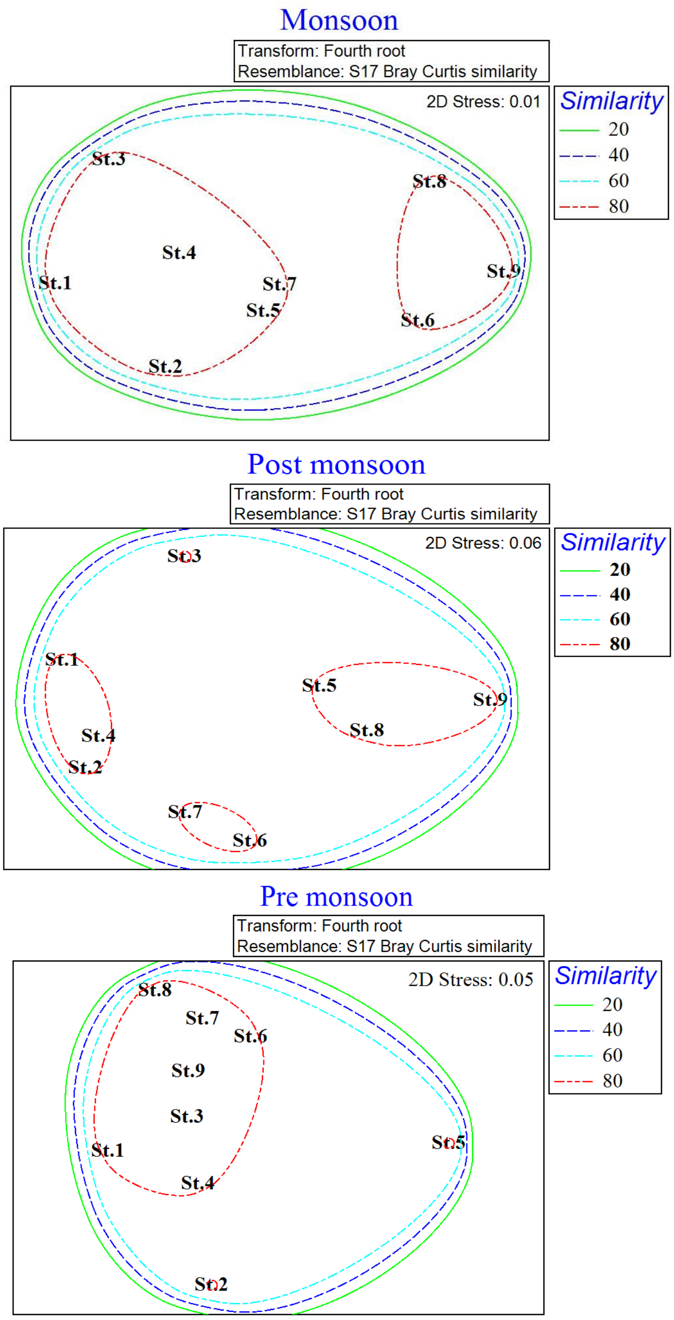


Fig. 4.27. MDS plot of mean season-wise numerical abundance of microphytoplankton in Cochin estuary during 2009-11 period

4.5.5 BEST Analysis

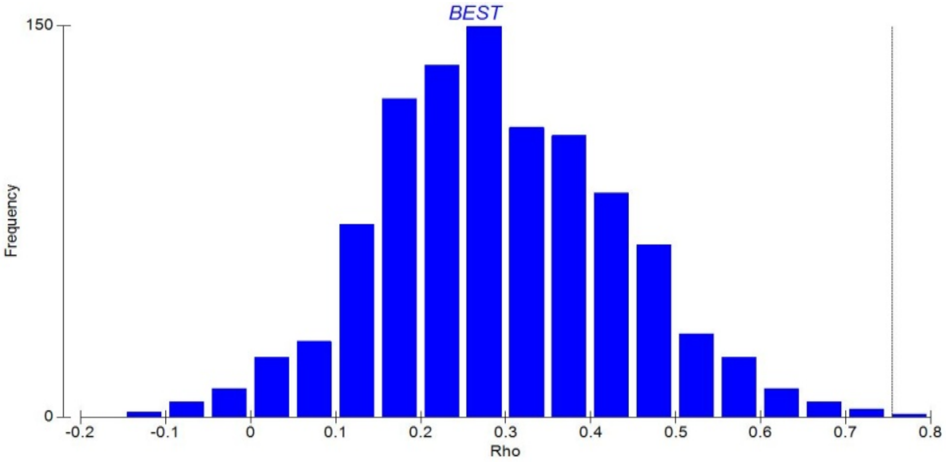
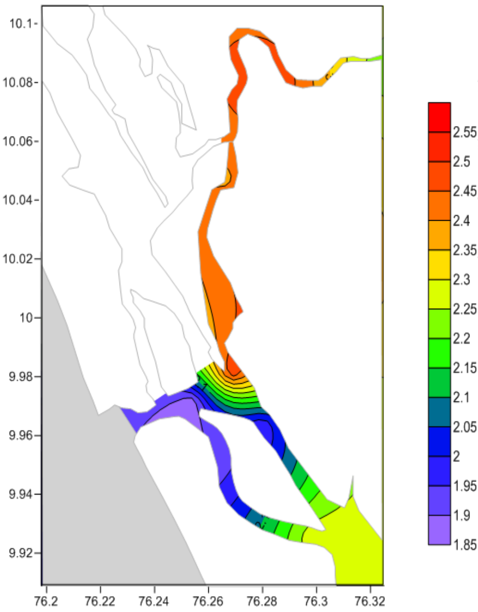


Fig. 4.28. BEST analysis of microphytoplankton with the water quality parameters in the Cochin estuary during 2009-11 period

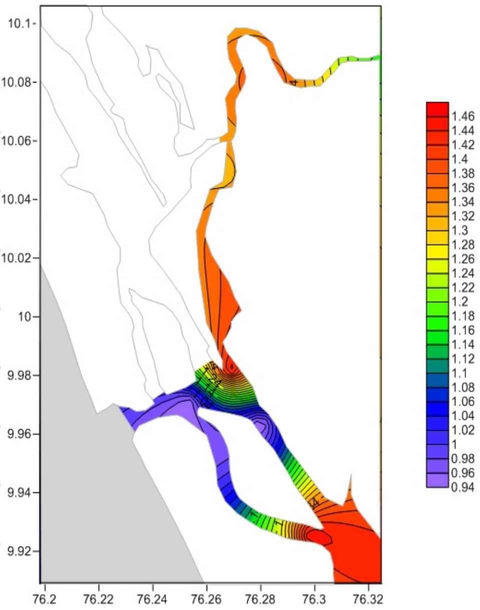
Table 4.13.4 BEST analysis of microphytoplankton with the water quality parameters in the Cochin estuary during 2009-11 period

	Variables	Variables selected	Best correlation values (Rho)
1	Water temperature	2,3,4,5,6	0.755
2	Dissolved Oxygen	3,6	0.746
3	Salinity	3	0.743
4	Turbidity	3,4,6	0.738
5	Chlorophyll 'a'	2,3,4,6	0.732
6	GPP	2,3,5,6	0.714
7	Phosphate	3,4,5,6,	0.711
8	Nitrate	2,3,4,5	0.710
9	Silicate	2,3,6	0.709
10	Ammonia	3,4,5	0.701

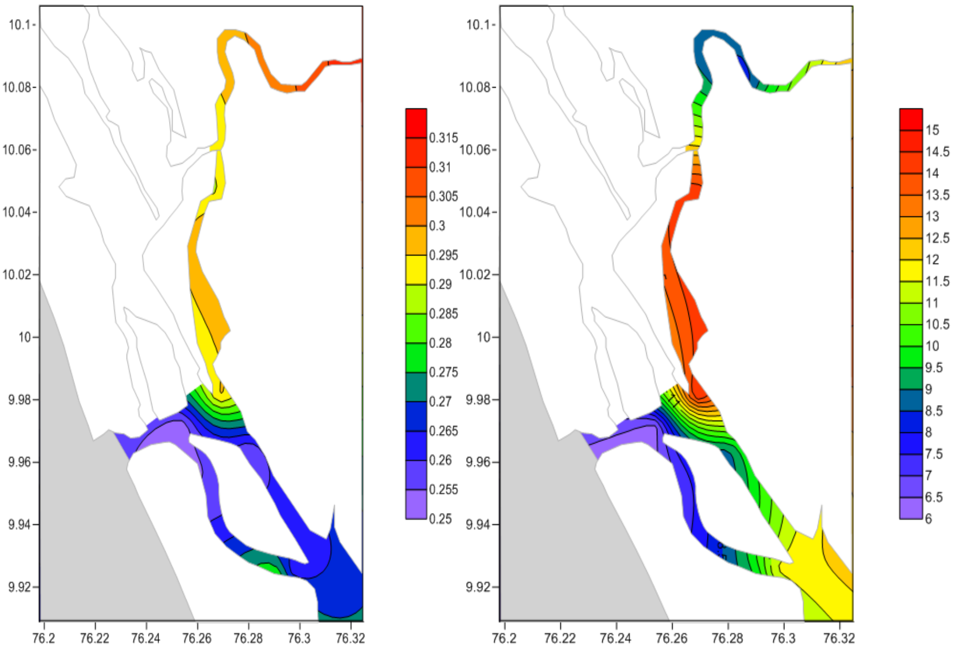
The BEST analysis of microphytoplankton abundance with various environmental parameters such as water temperature, dissolved oxygen, salinity, turbidity, chlorophyll ‘a’, gross and primary production, phosphate, nitrate, silicate and ammonia was done. The results showed that dissolved oxygen, salinity, turbidity, chlorophyll ‘a’ and gross primary production had a strong influence on phytoplankton abundance, with a correlation value of 0.755. Factors such as salinity and gross primary production control the phytoplankton abundance with a correlation of 0.746. The third correlation value was 0.743, indicating the interaction with the salinity only. The analysis was found to be significant at 0.2% with a rho value of 0.755 (Table 4.13.4).



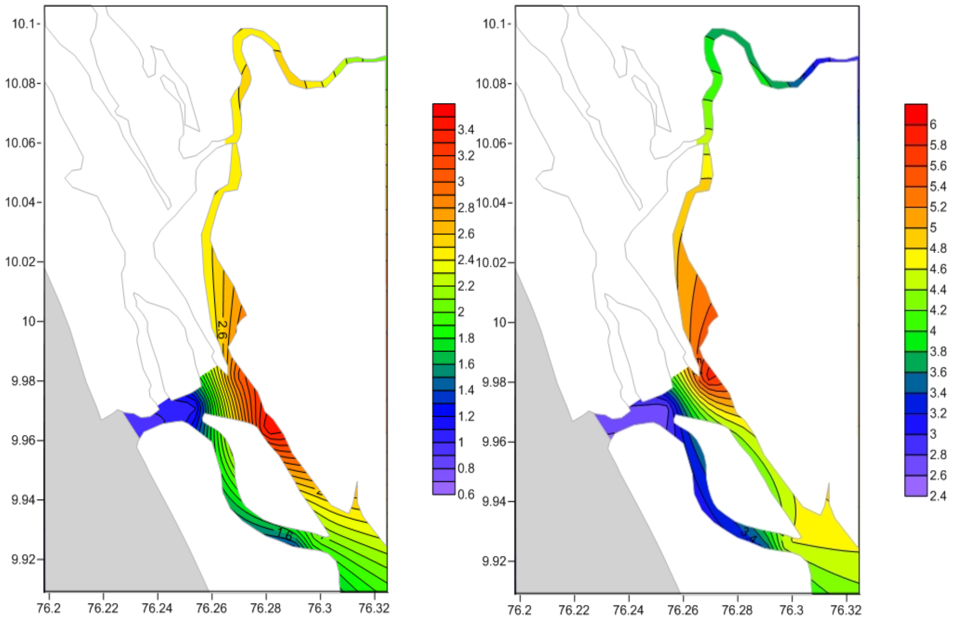
Gross primary production



Net primary productivity



Respiration **Chlorophyll a**



Chlorophyll b **Chlorophyll c**

Fig. 4.29. Distribution of GPP, NPP, Respiration, chlorophyll, a, b and c in the Cochin estuary during 2009-11 period

4.6 Discussion

Aquatic metabolism, represented by gross primary productivity (GPP), ecosystem respiration (ER), and net ecosystem production (NEP) of the water column, provides a useful composite indicator of ecosystem function in an aquatic ecosystem. GPP represents the total autotrophic conversion of inorganic carbon to organic forms. ER represents the total oxidation of organic carbon to inorganic carbon by both heterotrophic and autotrophic organisms. NEP represents the balance between system level production and respiration. NEP also serves as a metric for the trophic state of ecosystem and can transcend the range of spatial and temporal scales that are relevant for assessing ecological changes (Cole et al., 2000; Young et al., 2011).

Table 4.13.5 Primary production in different estuaries

Area		Primary productivity	Reference
Cochin estuary	GPP	300 g C m^{-2} d^{-1}	Qasim et al., 1969
Mandovi estuary	GPP	135-550 mgC m^{-3}d^{-1}	Dehadrai and Bhargava, 1972.
Zuari estuary	GPP	150-580 mgC m^{-3}d^{-1}	
Vembanad lake	GPP	150- 650 gC m^{-2} d^{-1}	Nair et al., 1975
Cochin estuary	GPP	125 mgCm^{-3} hr^{-1}	Pillai et al., 1975
Kadinamkulam	GPP	152.33 mgCm^{-3} hr^{-1}	Nair et al., 1983
Backwater	NPP	84.28 mgC m^{-3} hr^{-1}	
Ashtamudi estuary	GPP	88.68 to 1596.3 mgC m^{-3}d^{-1}	Nair et al., 1984
	NPP	22.41 and 1330.25 mgCm^{-3}d^{-1}	
Cochin estuary	GPP	0.753 gC m^{-3} d^{-1}	Selvaraj et al., 2003
	NPP	0.603 gC m^{-3} d^{-1}	
	GPP	52.08-183.33 mgCm^{-3} hr^{-1}	Renjith et al., 2004
	NPP	26.04-111.46 mgCm^{-3} hr^{-1}	
Valanthakad backwater	NPP	0.12-1.80 gC m^{-3} d^{-1}	Meera and Bijoy Nandan, 2010
Kodungallur	GPP	1580 mgCm^{-3}d^{-1}	Bijoy Nandan et al., 2014
Azhikode estuary	NPP	790 mgCm^{-3}d^{-1}	
Cochin estuary	GPP	2.27 gC m^{-3} d^{-1}	**Present study**
	NPP	1.26 gC m^{-3} d^{-1}	

In tropical areas, primary production continues on a uniform rate throughout the year with slight seasonal variations (Menzel and Ryther, 1961). The primary production was more or less uniform throughout the study period. In the present study, the primary production (GPP and NPP) was highest during the post-monsoon period in the Cochin estuary. The nitrate and silicate concentrations were found to be high during the monsoon period. But, ammonia, phosphate and nitrite were high during the pre-monsoon period. This indicated that high concentration of nutrients brought by monsoon period runoff and ample supply of sunlight helped to increase the phytoplankton production. Similar findings was observed by Qasim et al.(1972), Pillai et al. (1975), Selvaraj et al.(2003), Renjith et al. (2004), Meera and BijoyNandan(2010). Subsequently, during the pre-monsoon period, the gross primary production in the Cochin estuary was decreased. It may be due to high salinity, low amount of nutrients and decrease in runoff. The net primary production in the Cochin estuary recorded the lowest during monsoon period. Our result support the findings of Qasim(1979), that the light penetration in the water column is considerably reduced due to high turbidity in the monsoon months, resulting in low primary production in the Cochin estuary. In contrast to this, Nair et al.(1975) and Gopinathan et al.(1984) reported peaks of production during monsoon period and early post-monsoon period in the Cochin estuary. The Light: Nutrient Hypothesis, developed in the context of ecological stoichiometry theory (Sterner and Elser, 2002), states that an increase in nutrients will increase both primary production and nutrient content of primary producers, especially when light is the limiting factor. According to our results, the nutrient concentration was high during the monsoon and pre monsoon period but the primary production was high during the post monsoon period. It may be due to the fact that light penetration in the water column acts as a limiting factor for the primary production. The net and gross primary production were strongly correlated, significant at 1% level (r^2=0.743) and showed a weak negative correlation significant at 5% level with attenuation coefficient (r^2=-0.521). In the present study, the correlation analysis of primary production did not show any correlation with the water temperature, salinity and pH. The same observation was reported by Pillai et al., 1975, Jacob et al., 1984, Nair et al., 1984, Renjith et al., 2004.

The calculated net primary production accounts about 55% of the gross primary production which means that about 45% would be utilized for respiration. But practically the community respiration comes to about 12% of gross primary production. The difference in percentage of respiration with GPP may be due to the large export potential of organic matter by the ecosystem as reported by Cermeno et al., 2006 from Ria de vigo, a coastal ecosystem in Spain. Renjith, 2006 reported that net primary production is 70% of gross production and 30% for respiration in the Cochin estuary.

Community respiration showed a strong positive correlation with gross and net production (r^2=0.867, r^2=0.603) in the estuary. The same results were observed by Abril et al., 2003 from the Lore estuary on the French Atlantic coast. Caffrey et al., 2014 observed a strong coupling between respiration and primary production (r>0.8) in the northeast Gulf of Mexico estuaries. The relationship between primary production and respiration is an important factor in shaping the functioning of ecosystems. It determines the cycling of carbon, oxygen and energy in ecosystems. The closeness of the ratio of primary production to respiration have been identified as indicators of ecosystem maturity and system proximity to a well developed, climactic status (Odum 1969; 1983; Palmeri et al., 2014).

In the present study, the average gross primary production of the estuary was eight-fold higher than the respiration. Qasim et al., 1969 reported that the gross primary production (767±304 mgC m^{-2} d^{-1}) in the Cochin estuary was three times higher than the respiration (261±154 mgC m^{-2} d^{-1}). They also reported high GPP/R ratios during monsoon period and low during the pre-monsoon period, indicating the system was net autotrophic. Olsen et al., 1999 also reported that the plankton community respiration exceeds primary production except during spring season in the Gulf of Riga is a relatively autonomous subsystem of the Baltic Sea. Buford et al., 2008 found that the productivity to respiration ratio was high during high tide in the Darwin harbour, Australia.

Gupta et al., 2009 reported that GPP, NPP and community respiration was high during pre-monsoon period. The mean monthly values of NPP: GPP ratio of the estuary ranged from 0.40 to 0.79. About half of the values lie below 0.5, indicating the unhealthy status of the Cochin estuary. Ketchum et al., 1958 have pointed out that the ratio of NPP: GPP photosynthesis in a healthy population should approach unity if respiration is 5-10% of the total photosynthesis. It also indicates the physiological state physiological state of phytoplankton organisms arising due to nutrient deficiency. In such cases the ratio would be nearer to zero.

The increased respiration in the Cochin estuary indicates that heterotrophic organisms dominated during the study period. So the Cochin estuarine system consumes more organic carbon than they produce. The decadal changes suggest that increased human interference transformed the autotrophic system to a highly heterotrophic system. Our present findings were supported by the works of Azevedo et al.(2006); and Shoji et al. (2008); Gupta et al. (2009) in the Cochin estuary.

The heterotrophy of the Cochin estuary in the present study may be due to the input of large allochthonous organic matter to the system particularly from adjacent marshes and mangroves (Kemp et al. 1997; Caffrey, 2004).The total inorganic carbon of Cochin estuary was high, by which it acts as a source of carbon rather than a sink (Department of Environment and Climate change- Report, 2014). Heterotrophy is common in turbid estuaries, because heterotrophy or autotrophy in the ecosystems is controlled by factors such as light that limit primary production (Little, 2000).

Chlorophyll 'a', which constitutes the chief photosynthetic pigment of phytoplankton, is an index that would provide the primary production potential upon which the biodiversity, biomass, and carrying capacity of that system depends.

Table 4.13.6 Chlorophyll 'a'in different estuaries and coastal areas

Area	Chlorophyll 'a'	Reference
Cochin estuary	5.7-7.3 mg m^{-3}	Qasim et al., 1969
Vemband lake	2-21 mg m^{-3}	Nair et al., 1975
Estuarine system of Goa	3.05-4.42 mg m^{-3}	Bhargava and Dwivedi, 1976
Neuse river estuary	13.5 mg m^{-3}	Mallin and Paeral, 1994
Perdido Bay	5.2-16.1 mg m^{-3}	Maculey et al., 1995
Gurupur estuary	1.69-10.59 mg m^{-3}	Gowda et al., 2002
Pensacola Bay	1-26 mg m^{-3}	Murrel and Lorres, 2004
Douro estuary, Portugal	0.3-14.9 mg m^{-3}	Azevedo et al., 2006
Cochin estuary	1-34.6 mg m^{-3}	Renjith, 2006
Foz de Almargem	0-14 mg m^{-3}	Coelho et al., 2007
Coastal embayments of Korea	0.29-127.42 mg m^{-3}	Kim et al., 2007
Cochin estuary	5.2-16.1 mg m^{-3}	Gupta et al., 2009
Curonian estuary and	91.8 mg m^{-3}	Naumenko, 2009
Vistula estuaries	41.7 mg m^{-3}	
Brazilian estuary	0.54-37.7 mg m^{-3}	Alves et al., 2013
Kodungallur- Azhikode estuary	6.42 mg m^{-3}	BijoyNandan et al., 2014
Vembanad estuary	6.81-17.52 mg m^{-3}	Cleetus et al., 2015
Cochin estuary	11.17 mg m^{-3}	Present study

Chlorophyll 'a' concentration was higher in the northern zone. This suggests that the upper estuary is more productive than the lower estuary, as a result of the higher nitrogen concentrations from riverine origins (Mallin et al., 1993; Mallin, 1994; Malej et al., 1995; Duggan et al., 2008; Vidjak et al., 2009). In our study, the chlorophyll 'a' values were higher during post-monsoon period and lower in monsoon period. Jyothibabuet al. (2006) reported that chlorophyll 'a' values were high during the peak summer monsoon period in the Cochin estuary. Vineetha et al., (2015a,b) reported that the seasonal scenario in the chlorophyll 'a' distribution in the

Cochin estuary during the study period revealed relatively higher values during the pre-monsoon period (5.6–31.2 mg m^{-3}, av.10.9 ± 8.4 mg m^{-3}) compared to the monsoon period (4.8–17.6 mg m^{-3}, av.8.7 ± 4.1 mg m^{-3}) and post-monsoon periods (2.7–16.8 mg m^{-3}, av. 6.9 ± 4.5 mg m^{-3}).

The present findings from the Cochin estuary showed a three-fold increase of Chlorophyll ‘a’ in pre-monsoon period and post-monsoon periodcompared to the monsoon period. According to Nair et al., 1975, chlorophyll ‘a’ values during the pre-monsoon period would be 2-3 times higher than that obtained in the monsoon period. The total amount of chlorophyll ‘a’ during the post-monsoon period season was found to be intermediate, higher than the amount observed during the pre-monsoon period and lower than the value reported during the monsoon period season in Cochin estuary(Akram, 2003). In contrast to this, chlorophyll‘ a’ concentration in the pre-monsoon period was found to be intermediate in the present study. The abundance of zooplankton in the study region was higher during pre-monsoon period as observed in the successive chapter, which may have resulted in a decrease in Chlorophyll ‘a’ concentration and production at that time. The low values of chlorophyll during the monsoon period may be due to the increased flushing of phytoplankton biomass in the estuary. Qasim et al., 1969 observed the highest organic production during the monsoon period in the Cochin estuary. Gupta et al., 2009 reported that the chlorophyll ‘a’ was three-fold higher in early monsoon period. Gopinathan et al., 1984, Devassy and Goes, 1989 and Nair, 1990 and Gowda et al., 2002 have observed the peaks during pre and post-monsoon period in different estuaries of India.

In the present study the seasonal cycles of gross primary production and chlorophyll 'a' were synchronous, but Qasim and Reddy, 1967 observed that the seasonal cycles of primary production and chlorophyll and stated that the two were not synchronous. This may be due to the presence of dead and inactive chlorophyll from detritus and stirred up sediment.

Chlorophyll ' a' showed a weak negative correlation significant at 5% level with rainfall (r^2= -0.457), river discharge (r^2= -0.461), attenuation coefficient (r^2= -0.452) and nitrate-nitrogen (r^2=-0.437). A positive correlation significant at 5% level was observed with salinity (r^2= 0.511) and net primary production (r^2=0.504). The increased rainfall caused the sediment to be suspended in the water column. This caused the attenuation coefficient to be high during the monsoon period. However, chlorophyll ' a' values were low during the monsoon period. The inverse correlation of chlorophyll ' a' with nitrate indicates nutrient uptake during phytoplankton growth (Pennock and Sharp, 1994; Eyre, 2000; Livingston, 2003) and illustrates the central role that phytoplankton plays in trapping nutrients (Fisher et al., 1988). Thomas et al., 2005 observed the inverse relation of chlorophyll 'a' with DIN in the eutrophic estuary of South Africa. There were instances of chlorophyll ' a' and primary productivity being positively correlated (Bhattathiri et al., 1980). The negative correlation of chlorophyll 'a' with nitrate significant at 1% level and phosphate significant at 5% level was reported by Gopinathan, 1972, Nair et al., 1984, and Meera. S. and Bijoy Nandan, 2010. The negative relationship of nitrite and nitrate with the productivity parameters could be indicative of a rapid uptake of these salts leading to depletion or lowering of concentration at the peak production period (Vijayakumaran et al., 1996). The relationship of chlorophyll with phosphorus compounds was not observed in the present study, as in the case of Adriatic Sea by Zoppini et al., 1995 and Shivaprasad et al., 2013 from the Cochin estuary. Zoppini et al., 1995 observed that the chlorophyll measurements in the study missed the contribution of the picoplankton and this may have weakened the correlation with the nutrients. However a significant relationship with the riverine inputs was observed in the Adriatic Sea. The present findings support the above results.

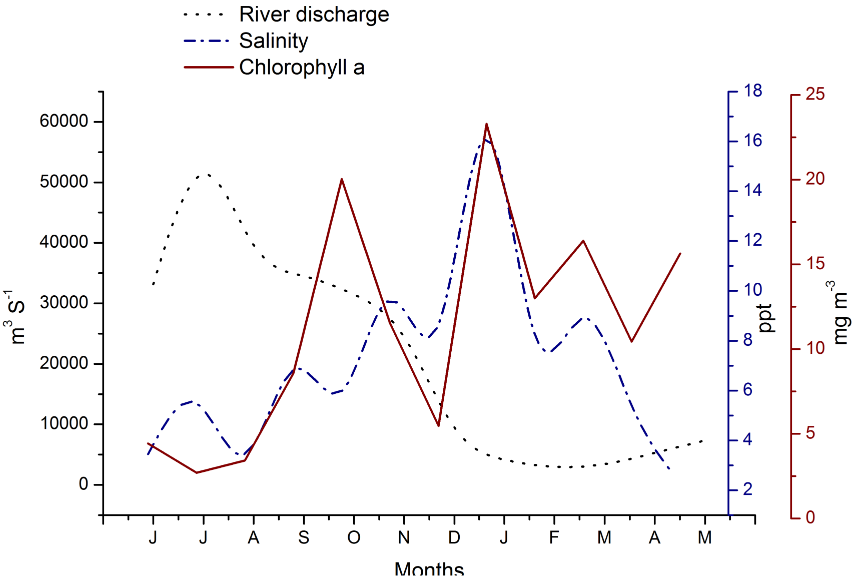


Fig. 4.30. Relationship showing mean monthly river discharge, salinity and Chlorophyll 'a' in the Cochin estuary during the study period

The relationship among river discharge, salinity and chlorophyll 'a' did not show a definite trend (Fig.4.30). The maximum chlorophyll concentrations were observed during the months of least river runoff, when the surface salinity was high in the Cochin estuary (Shivaprasad et al., 2013; Janardanan et al., 2015). In the present study, the above relationship was worked out only in some months. The correlation analysis of chlorophyll 'a' showed a weak negative correlation with river discharge and weak positive correlation with salinity. It may be due to the high tolerance of phytoplankton to withstand salinity changes irrespective of seasons. A similar observation was made by Jyothibabu et al., 2006 from the same region.

Gowda et al., 2002 reported that the phytoplankton pigments and primary production is largely determined by the species composition. Qasim et al, 1972 stated that the temperature of water is of little direct importance to production in tropical seas, whereas salinity has a marked influence on photosynthesis and growth of phytoplankton. Jyothibabu et al., 2006 reported that primary production was increased in Cochin estuary due to the higher concentration of nutrients. However, chlorophyll 'a' was not positively correlated with the major nutrients (nitrate, phosphate and silicate), probably due to the exceedingly high concentration of these nutrients present at many stations.

Chlorophyll 'a' is the most predominant pigment of the phytoplankton organisms (Strickland, 1960). The other chlorophyll and associated pigments were always lesser than the chlorophyll 'a'. The chlorophyll 'b' in the Cochin estuary was higher during post- monsoon period and lower during pre-monsoon period, the monsoon period values were intermediate between these two seasons. The seasonal peaks in chlorophyll 'b' in the Cochin estuary was supported by the observations of Bhargava and Dwivedi, 1976 in the estuarine systems of Goa where the chlorophyll 'b' concentration was maximum in post-monsoon period, ranging from 0 to 10 mg m^{-3}. According to Qasim and Reddy, 1967 the chlorophyll 'b' in the Cochin backwaters ranged from 0 to 27.4 mg m^{-3} during monsoon period, while in the Vellar estuary a concentration of 13.4 mg m^{-3} was recorded in July by Krishnamurthy and Sundararaj, 1973. In the present study, chlorophyll 'b' values ranged from 0.05 to 26.46 mg m^{-3}.

Qasim et al., 1967 reported that the Chlorophyll 'a' values were generally less than chlorophyll 'c' in the Cochin estuary during monsoon period months. The biannual mean of chlorophyll 'c' in the Cochin estuary was 4.18 mg m^{-3}, where as in the estuarine system of Goa, the annual mean values of chlorophyll 'c' was 2.67 mg m^{-3}. Chlorophyll 'c' showed a positive correlation significant at 1% level with chlorophyll 'b' (r^2=0.917) and 5% level of significance with silicate-silicon (r^2=0.446).

The present chlorophyll b/a ratio and c/a ratios were always lower than one in most of the region. The ratio indicates the physiological state of phytoplankton population and for a healthy crop it is less than unity (Bhargava and Dwivedi, 1976). The ratios were greater than one in the monsoon period months indicating the unhealthy phytoplankton to primary production. It may be due to the abundance of suspended sediments including dead Chlorophyll 'a' and degraded products having more chlorophyll c than chlorophyll 'a' in the water column during monsoon period (Humphrey, 1962). Qasim and Reddy (1967) have also mentioned that c/a ratios are generally higher than one and nearer to two and often three in the Cochin backwater during monsoon period.

The mean monthly values of total pigments (Chlorophyll 'a' +'b'+'c') ranged from 4.14 to 47.44 mg m^{-3}. The total chlorophyll in the Mandovi-Zuari estuary ranged from 6.01 to 8.12 mg m^{-3}.The mean monthly values of total pigments of the inshore waters off Visakhapatanam remained 6 mg m^{-3} in most of the months (Vijayakumaran, 2005).

In the present study, carotenoid values ranged from 0.07 mg m^{-3} to 51.53 mg m^{-3}. According to Qasim and Reddy (1967), carotenoid pigments in Cochin backwaters ranged from 8.25 mg m^{-3} to 14.60 mg m^{-3}. Seventy percent of the samples exhibited a ratio less than one. The higher ratio of carotenoids to chlorophyll 'a' indicates an unhealthy and chlorotic phytoplankton population (Ketchum et al., 1958). The high ratio may be due to the stirred up sediments and degradation products of chlorophyll 'a', which increases the carotenoid values as suggested by Qasim and Reddy, 1967. It was less than one in port Novo backwaters and Goan waters (Krishnamurthy and Sundararaj, 1973, Bhargava and Dwivedi, 1976). The carotenoid pigment showed a strong positive correlation with chlorophyll 'a' 'b' and 'c' (r^2= 0.718, r^2= 0.809, r^2=0.840); 5% level of significance with net primary production (r^2=0.488) and a weak negative correlation with attenuation coefficient significant at 5% level (r^2= -0.434). Roy et al., 2006 observed a significant linear relation with chlorophyll 'a' and photosynthetic carotenoids in the south-western Indian coasts.

The phaeophytin values indicated the dominance of dead photosynthetic pigments. The ratio of chlorophyll b/a ratio ranged from 0.003 to 4.14 while the ratio of phaeopigments to chlorophyll ‘a’ was higher, ranging from 0.08 to 47.57. The ratios of phaeophytin to chlorophyll ‘a’ were greater than one, suggesting the abundance of detritus and predominance of degraded chlorophyll in the water column. About 65% of the mean monthly ratios were greater than one. These ratios of different components of chlorophyll give an insight into the photo-adaptability as well as physiological and degradation state of the communities (Gopinathan et al., 1994). The health states of the phytoplankton assemblage of the estuaries were assessed by analysing the ratio of total phytoplankton chlorophyll a: total phytoplankton chlorophyll a+ phaeopigments concentration (Bidigare et al., 1986). In the present study, about 62.5% of the mean monthly values were less than 0.5, indicating the unhealthy status of the phytoplankton community. Thomas et al., 2005 used this ratio to study the phytoplankton community structure of two South African estuaries and showed that most of the values greater than 0.5 suggested the actively growing and physiologically healthy status of the phytoplankton community structure. The high concentration of phaeopigments compared to chlorophyll ‘a’ was observed in the most of the stations. This suggests the mass mortality of phytoplankton due to osmotic stress and grazing by zooplankton (Boyle and Silke, 2010). The phaeophytin pigments showed a positive correlation significant at 1% level with net primary production (r^2=0.523), chlorophyll ‘a’ ‘b’ and ‘c’ (r^2=0.761, r^2=0.0664, r^2=0.701) and carotenoids (r^2=0.871).

Present study showed an increasing trend in algal biomass along with chlorophyll 'a'. Algal biomass (dry and wet weight) showed a negative correlation significant at 5% level with rainfall (r^2=-0.444), run off (r^2=o.448), attenuation coefficient (r^2= -0.447) and Nitrate-nitrogen (r^2=-0.428).A positive correlation significant at 1% level was observed between algal biomass and salinity (r^2=0.518), chlorophyll 'a' (r^2=0.997), carotenoids (r^2=0.722) and phaeopigmets (r^2=0.756).A positive relation significant at 5% level was estimated with net primary production (r^2= 0.490).The wet weight of the algal biomass showed a positive correlation significant at 1% level between active chlorophyll (r^2=0.793) and a negative correlation significant at 5% level with attenuation coefficient (r^2= -0.447).

A positive correlation significant at 1% level between active Chlorophyll 'a' and Chlorophyll 'a' 'b' and 'c' (r^2=0.785, r^2=0.669, r^2=0.712), carotenoids (r^2=0.906), phaeophytin (r^2=0.973) and dry weight of algal biomass (r^2=0.793). A positive correlation significant at 5% level between active Chlorophyll 'a' and net primary production (r^2=0.490).

Phytoplankton carbon showed a negative correlation significant at 5% level with rainfall (r^2=-0.444), run off (r^2=0.448), attenuation coefficient (r^2= -0.447) and Nitrate-nitrogen (r^2=-0.428). A positive correlation significant at 1% level was observed between phytoplankton carbon and salinity (r^2=0.518), chlorophyll 'a' (r^2=0.997), carotenoids (r^2=0.722) and phaeopigmets (r^2=0.756), algal biomass dry weight (r^2=1.00), active chlorophyll (r^2=0.793).A positive relation significant at 5% level was estimated with net primary production (r^2= 0.490).

In the previous studies, the euphotic depth of the estuary was given as 2.5 m by Josanto, 1971 and as 2m by Renjith et al., 2004. Qasim et al., 1968 reported that the euphotic zone varies from 2 to 6 metres during the year. For the estimation of annual column production, the euphotic zone depth is taken as 2.94 meters and the photoperiod as 12 hours. In the present study, the annual column production of the estuary was 2437.52 gC m^{-2} y^{-1}. The total area of the study region was around 67.85 km^2. The total annual gross production was 165386 tonnes of carbon per year. According to Nair et al., 1975, the total annual gross production was 100,000 tonnes of carbon for the entire Vembanad Lake. Renjith et al., 2004 reported that the total annual production of the Panangad region was 2971 tonnes of carbon. Based on the present observations, it is seen that the annual column production has decreased by one order of magnitude. It can be inferred that this decrease is caused by anthropogenic influences of the ecosystem. In the north western coastal waters of Adriatic Sea, the primary production ranged from 200-260 gC m^{-2} y^{-1}.

The efficiency of energy transformation is known as photosynthetic efficiency and it is equal to the energy fixed by producers during photosynthesis per unit light energy available in the system at any given time and space. It depends on the water quality and phytoplankton population in an ecosystem (Pathak et al., 2004). According to Qasim et al., 1969 the photosynthetic efficiency of the Cochin estuary was 0.2% to 0.7%. Based on this observation, the efficiency of the present day estuary was calculated. It ranged from 0.05% to 0.2% with an average efficiency of 0.1%. It clearly depicts that the stress on the ecosystem has decreased the efficiency of production. Zoppini et al., 1995 calculated the photosynthetic efficiency of the western coastal waters of the Adriatic Sea using the data of normalised photosynthetic rate and irradiance, where the results ranged from 0.3 to 7.6 mgC^{-1} E^{-1} m^{2}.

The total cell count of microphytoplankton showed seasonal variation corresponding to the primary production and chlorophylls (Fig.4.31). The total phytoplankton cell density, chlorophyll ‘a’ and gross primary production showed a peak during the post-monsoon period and fell during the monsoon period and pre-monsoon period. This observation agrees with the earlier works by Devassy and Goes, 1989 and Gopinathan et al., 1974.

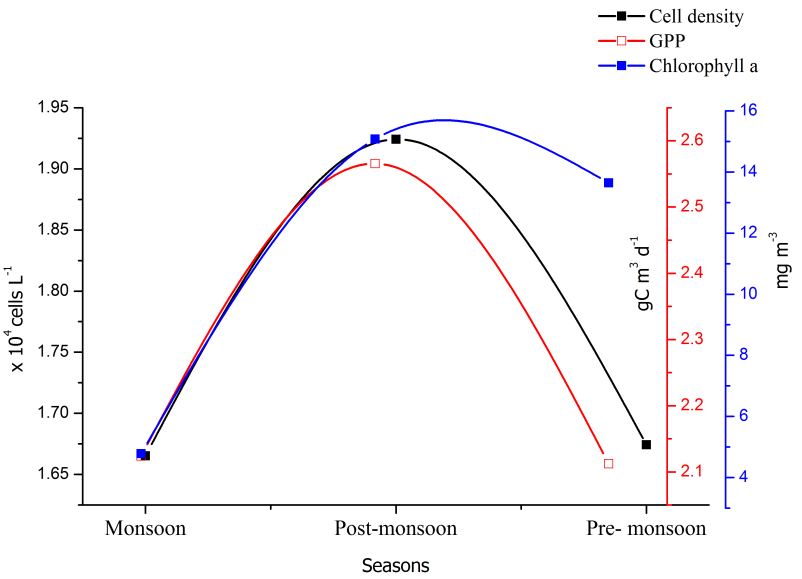


Fig. 4.31 Relationship showing the mean seasonal variation of total cell density, Chlorophyll ‘a’ and GPP in Cochin estuary during 2009-2011

With the onset of monsoon period, the salinity of the estuary decreased, which helps the renewed growth of phytoplankton in the water column. The salinity controls the species composition and succession of phytoplankton. The peak salinity that occurred during the monsoon period was reported in several works (Tiwari and Nair, 1998; Kumaran and Rao, 1975; Devassy and Bhattathiri, 1974; Qasimet al., 1972). In contrast to the earlier studies in Cochin backwaters, phytoplankton density showed a peak during the post-monsoon period. Gopinathan, 1972, observed two peaks of phytoplankton abundance in Cochin estuary: one during the monsoon period and other in the post-monsoon period months. Nair et al., (1983) reported that Kadinamkulam backwater had been most productive during monsoon period and least productive during pre-monsoon period.

The abundance of phytoplankton in the post-monsoon period season may be due to the stability of the water column, which was observed by Rajesh et al., 2002 and Naik et al., 2009. The microphytoplankton was abundant during the 2010-11 period, which may be due to the heavy amount of rainfall that influenced the salinity distribution in the estuary. During the rainy season, cloudy weather and low transparency of the water column might be the reason for the decline in phytoplankton number (Shruthi and Rajasekhar, 2013). A higher phytoplankton population during the post-monsoon period was not attributed to the availability of nutrients in the present study. The instantaneous concentration of nutrients does not seem to have a direct relation with phytoplankton production, because the nutrients do not become a limiting factor due to the regeneration and considerable exchange from the bottom water interface (Ketchum, 1974).

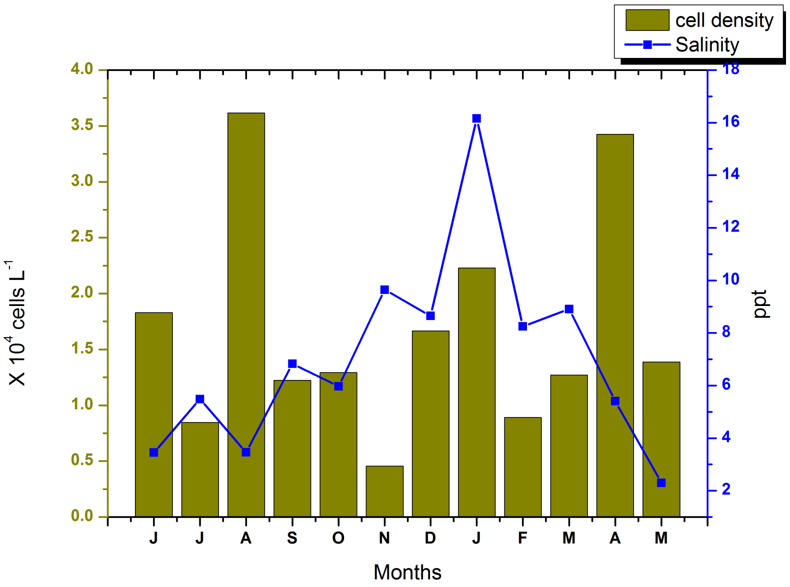


Fig: 4.32. Relationship showing the mean monthly variation of total cell density and salinity in Cochin estuary during 2009-11 period

According to Madhu et al., 2010b the microphytoplankton had higher photosynthetic efficiency in the estuary than the coastal waters. Diatoms were the most abundant group in the backwaters in all the seasons. Diatoms are considered as a euryhaline and eurythermal phytoplankton group, which grow quickly under estuarine conditions (Naik et al., 2009). A similar trend was also observed by Kaladharan et al., 2011 as well as Shruthi and Rajasekhar, 2013. Devassy and Bhattathiri, 1974 reported that the diatoms showed the maximum concentration in the post-monsoon period months. In the present study, while the diatoms contributed a major share of the microphytoplankton community, their temporal variations were less significant. The percentage composition of dinoflagellates was very low during elevated river flow and reduced water residence time in the Cochin estuary. Weaver et al., 2006 observed the same in the upper North Palmico stuarine complex. The phytoplankton cell density suddenly declined during monsoon period due to high turbidity in the study area.

The successions of dinoflagellates in the Cochin estuary have been noticed from the coastal waters of Kalpakkam (Sahu et al., 2012). Their percentage contribution was less as compared to the diatoms. They are more mobile and buoyant than diatoms due to the presence of flagella. They are the dominant producers in the calm and downwelling waters (Ciotti et al., 1995). The dynamic nature of coastal ecosystem makes it unfavourable to dominate as major producers compared to the oceanic waters.

Wasmund et al. (1990) proposed a scheme for the trophic classification of estuarine and coastal marine ecosystems, based on the phytoplankton production. The primary production in the estuaries was less than 100 gCm^{-2}year (Oligotrophic); 100-200 gCm^{-2}year (Mesotrophic) and 200-400 gCm^{-2}year (Eutrophic). Based on annual gross production, the Cochin estuary is under severe eutrophication.

The trophic index (TRIX) in the Cochin estuary showed an annual average of 5.58 (TRIX) unit. Seasonal highest was observed during the pre-monsoon period (6.22) followed by the post-monsoon period (5.34) and monsoon period (5.18). In the spatial scale TRIX observed the maximum in Station 3 (6.40) and comparatively low values in the Station 9 (5.03).

According to Pennaet al.(2004) who studied the Italian coastal waters on the Adriatic Sea, higher values are observed for the TRIX during dry season. Alveset al.(2013) used TRIX to measure the water quality of tropical Brazilian waters and TRIX quantified the Massangana river estuary at a level of medium eutrophication. Jayachandran et al.

(2010) and Bijoy Nandan et al.(2014) reported that the Kodungallur-Azhikode estuary was experiencing high productivity by the influence of the eutrophication. Deteriorated trophic status as determined by the TRIX index was observed only in the surface layer (average TRIX: 5.67) in the coastal areas of the Adriatic Sea (Mozetic et al., 2008).Level of eutrophication in the Obidos lagoon was between ‘‘Medium/High’’ and a state of water quality between ‘‘Good/Bad” was observed (Malhadaset al., 2014). The spatio-temporal variation of the TRIX index in the present study was noticed bad water quality with high level of eutrophication.

The TRIX index with efficiency coefficient is used to assess the estuarine eutrophication. The efficiency coefficient values ranged from -2.79 at station 5 to -3.43 at station 3. The annual average of the efficiency coefficient of the Cochin estuary was -3.14.The seasonal average was high during the post-monsoon period (-2.91) and low during the monsoon period (-3.46). The high amounts of nutrient inputs (eutrophication) stimulate phytoplankton growth. So a large amount of carbon is fixed by phytoplankton, which in turn is recycled by the primary consumers. Bloom may trigger a large amount of carbon deposition on the sediment surface. Microbial degradation of this may trigger hypoxia or anoxia, which in turn smoothens the progress of sediment nutrient leaching. Leaching of this sediment nutrient may promote algal blooms and eutrophication. The continued addition of these allochthonus nutrients, lessened removal of autochthonus nutrients and increased residence time enhances eutrophication (James et al., 2001). The changes may significantly affect the phytoplankton community composition, with subsequent cascading impacts on the higher trophic levels of the food web (McClelland and Valiela, 1998).

Table 4.13.7 The Pearson correlation analysis of primary productivity parameters in Cochin estuary during 2009-11 period.

	Rain fall	Run off	Wat. temperature	Salinity	Nitrite	Nitrate	Phospha	Silicate	Ammo	GPP	NPP	Respi	Chl.a	Chl. b	Chl.c	Caroteno	Phaeo	Algal bio dry	Active chl	Phyto**C**	Algal bio wet	Attenuation coeffecient
Rain fall	1																					
Run off	**0.899****	1																				
Water temperature	-0.399	**-0.57****	1																			
Salinity	-0.382	-0.303	-0.188	1																		
Nitrite-N	-0.091	-0.184	0.277	0.058	1																	
Nitrate-N	**0.597****	**0.660****	**-0.500****	-0.206	0.054	1																
Phosphate-P	-0.374	-0.294	0.243	0.178	0.11	-0.184	1															
Silicate-Si	0.252	0.286	-0.033	-0.234	0.125	**0.550****	0	1														
Ammonia-N	-0.098	-0.178	0.266	0.041	0.355	-0.109	-0.287	-0.062	1													
GPP	-0.096	-0.031	-0.017	0.246	-0.218	-0.066	**-0.408***	-0.313	0.388	1												
NPP	-0.391	-0.253	0.236	0.141	-0.26	-0.201	0.01	-0.165	0.178	**0.743****	1											
Respiration	-0.002	0.092	-0.149	-0.004	-0.244	0.137	**-0.441***	-0.19	0.226	**0.867****	**0.603****	1										
Chlorophyll a	**-0.457***	**-0.461***	0.307	**0.511***	-0.009	**-0.437***	0.177	-0.263	-0.052	0.356	**0.504***	0.221	1									
Chlorophyll b	0.12	0.068	0.206	-0.014	-0.224	0.256	-0.085	0.374	0.03	0.239	0.251	0.323	0.237	1								
Chlorophyll c	0.118	0.096	0.164	0.143	-0.093	0.359	0.02	**0.446***	0.037	0.196	0.272	0.219	0.3	**0.917***	1							
Carotenoids	-0.195	-0.226	0.346	0.296	-0.086	-0.03	**0.074**	0.114	0.001	0.362	**0.488***	0.333	**0.718****	**0.809****	**0.840****	1						
Phaeophytin	-0.302	-0.289	0.285	0.204	-0.152	-0.087	0.104	0.072	-0.052	0.318	**0.523****	0.36	**0.761****	**0.664****	**0.701****	**0.871****	1					
Algal biomass dry	**-0.445***	**-0.448***	0.295	**0.518****	-0.018	**-0.428***	0.181	-0.257	-0.067	0.335	**0.490***	0.202	**0.997****	0.239	0.304	**0.722****	**0.756****	1				
Active chlorophyll	-0.291	-0.288	0.3	0.226	-0.158	-0.096	0.148	0.077	-0.089	0.266	**0.494***	0.286	**0.785****	**0.669****	**0.712****	**0.906****	**0.973****	**0.793****	1			
Phytoplankton **C**	**-0.444***	**-0.448***	0.295	**0.518****	-0.018	**-0.428***	0.181	-0.257	-0.067	0.335	**0.490***	0.202	**0.997****	0.239	0.304	**0.722****	**0.756****	**1.000****	**0.793****	1		
Algal biomass wet	**-0.444***	**-0.448***	0.295	**0.518****	-0.018	**-0.428***	0.181	-0.257	-0.067	0.335	**0.490***	0.202	**0.997****	0.239	0.304	**0.722****	**0.756****	**1.000****	**0.793****	**1.000***	1	
Attenuation co effecient	**0.573****	**0.589****	-0.377	**-0.406***	-0.006	0.460*	-0.175	-0.142	-0.203	**-0.296**	-0.521**	**-0.123**	-0.452*	-0.246	**-0.244**	**-0.434***	**0.351**	**-0.447***	**-0.369**	-0.447*	-0.447*	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

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Chapter 5

ZOOPLANKTON AND SECONDARY PRODUCTION

Contents

5.1 Introduction

Zooplankton plays a key role in the marine food chain by controlling phytoplankton production. Additionally, their critical role as food for larval and juvenile fishes shapes the structure and function of the pelagic ecosystems. They are the key drivers of the biological pump in the ocean system. Zooplankton feed in the surface waters and produce sinking faecal pellets. They actively transport dissolved and particulate matter to deeper waters via vertical migration. Zooplankton grazing and metabolism transforms particulate organic matter into dissolved forms, affecting primary producer populations, microbial remineralisation, and particle export to the ocean's interior. They have key role as nutrient recyclers, ocean energy flow and carbon cycling, population dynamics and trophodynamics.

Classification of plankton based on their size was proposed by Sieburth et al., 1978 and modified and described by Harris et al., 2000 is given below.

Femto-plankton	0.02-0.2µm
Pico-plankton	0.2-2µm
Nano-plankton	2.0-20µm
Micro-plankton	20-200µm
Meso-plankton	0.2-20mm
Macro-plankton	2-20cm
Mega-plankton	20-200cm

Zooplankton ranges over five size classes from nanoplankton to megaplankton. Pico and nanoplankton pass through the finest plankton nets, we were long unaware their abundance and ecological importance. They play an equal role with visible forms in productivity and energy flow. The term 'netplankton'refers to plankton retained by a finest mesh size of 20µm. The predominant microzooplankton is ciliates, eggs and early developmental stages of crustacean larvaeand meroplanktonic larvae. Mesozooplankton group comprises of copepod, rotifers,small hydromedusae, ctenophores, chaetognaths, appendicularians, doliolids, fish eggs and larvae. Macrozooplankton comprises of larger forms of hydromedusae, ctenophore, siphonophore, scyphomedusae, mysids, amphipods, euphausids, salps and eel larvae. The megaplanktonare the large jelly fishes, ctenophores, pelagic tunicates, pyrosomes and chain forming salps.

As secondary producers, zooplankton occupies the second and to some extent the third level in the food web. Zooplankton adapt to the environmental stresses by changing their body size, food spectrum and feeding patterns. In maintaining the balance between bottom-up control and top-down control on a food web, zooplankton plays a key role. Bottom-up control is resource-driven, where the nutrient supply determines the phytoplankton production, which in turn controls the zooplankton grazing. The microbial loop controls the top-down mechanism, where ciliates are the top predators. The traditional and microbial food chain coexist in all regions, but their significance varies according to region and season.

Apart from predation, zooplankton grazing also largely determines the amount and composition of vertical particle flux. This not only fuels the benthic community but contributes to the removal of surplus anthropogenic carbon dioxide from the atmosphere through sedimentation and burial of organic and inorganic carbon compounds. The trophic role and ecological significance of zooplankton communities mainly depends on the diversity, behaviour and interaction of their species. These communities are often dominated by the so-called key taxa, which play a major role in channeling energy up the food web and exercising top-down control through grazing or predation (Harris et al., 2000).

Major environmental challenges like hypoxia, harmful algal blooms, introduction of alien species and global warming affect the zooplankton assemblages in many regions. Changing temperature affects growth rates, fecundity and survival, especially when the magnitude of change approaches the physiological tolerance limits of the species.

Ocean acidification resulting from increased atmospheric CO_2 concentrations alters the pH, inhibiting the biological uptake of calcium carbonate. Shell forming organisms such as foramniferans are at risk due to the reduction in the calcium carbonate uptake. The alterations of pH in the marine systems affect the larval gastropod and bivalve molluscs, ostracods and other groups. In the grazing food chain, 10% of the assimilated food goes as detritus, 70% is utilized for respiration and movement and the remaining 20% is available for secondary production, i.e. available for the predators (Tait and Dipper, 1998). The purpose of our study was to understand the composition and abundance of zooplankton and its role in secondary production.

5.2 Review of Literature

Antony van Leeuwenhoek, using his newly developed microscope, observed oyster veligers as early as 1722. Martinus Slabber, produced some of the first published illustrations of invertebrate larvae in 1778. The use of nets to collect and concentrate plankton during early nineteenth century pioneered by J.V. Thompson and Johannes Muller in the mid- 1800s, started a new era of discovery. The HMS Challenger expedition (1873-76) led by the Britishmen, Sir Charles Wyville Thompson and Dr. John Murray. They towed nets to depths below 3000m and made astonishing discovery of plankton fauna in the deep sea. Victor Hensen first coined the term “plankton” and was rapidly adopted and extended by Haeckel. Sir Alister Hardy’s invention of the Continuous Plankton Recorder (CPR) proved to be one of the most notable developments in plankton research of the early twentieth century.

William. M. Wheeler (1899) and Charles. B. Wilson (1932) studied the copepod from Woods Hole and Chesapeake Bay.

During the 1960s and 1970s, John. D. Costlow, Jr. C. G. Bookhout and Austin. B. Williams raised many Mid-Atlantic crustacean larvae in the laboratory, providing definitive life history information for the first time. Cronin et al., 1962 studied the quantitative aspects of zooplankton in the Delaware River estuary on the Atlantic Coast of United States. Williams et al., 1968 studied taxonomic composition of zooplankton in the shallow estuaries of Beaufort in South Carolina, United States. Fish's publication in the 1930s followed by Gordon. A.Riley and Georgiana. B. Deevey in the 1940s and 1950s initiated work on planktonic food webs that led to studies on productivity, energy flow and trophic efficiency (Johnson and Allen, 2012).

Roper et al., 1983 exclusively studied the zooplankton in the Avon-Heathcote Estuary in New Zealand. Kamiyama, 1994 studied the impact of grazing by microzooplankton in the northern Hiroshima Bay in Japan. Escaravage and Soetaert, 1995 observed that on an annual basis, approximately 6% of the total carbon fluxes pass through the copepod food web in the Westerschelde estuary in Netherlands. Park and Marshall, 2000 observed that the total biomass of micro and mesozooplankton decreased with increase of eutrophication in the lower Chesapeake Bay and Elizabeth River (United States).

Chanton and Lewis, 2002 reported that alterations in the river hydrology may adversely affect the secondary production in the estuary.

Murrel and Lores, 2004 conducted a seasonal study of phytoplankton and zooplankton to understand the pelagic food web in the subtropical estuary of Florida, United States. Telesh et al., 2004 reviewed the plankton of the Baltic estuaries in Europe. Tackx et al., 2004 investigated the spatio-temporal patterns of zooplankton in the Schelde estuary in Europe. Uriarte and Villate, 2004 compared the impacts of pollution on zooplankton communities in the estuaries of the Bay of Biscay in Europe.

Choi et al., 2005 reported that the invasion of non-native zooplankton from ballast water discharge led to heavy alteration of the San Francisco estuary in the United States. David et al., 2005 investigated zooplankton variability at the maximum turbidity zone of the Gironde estuary in France. Gewant et al., 2005 investigated the spatio-temporal variation of macrozooplankton and micronekton of the lower San Francisco estuary in relation to environmental conditions. Marques et al., 2006 studied the zooplankton and icthyoplankton assemblages in the Mondego estuary. Duggan et al., 2008 studied the zooplankton dynamics of an Australian macrotidal estuary. There was a significant drop in species richness from harbour to river sites.

Qian et al., 2008 studied the relationship between salinity and zooplankton distribution in the Chagjiang estuary. The salinity was positively correlated with abundance and negatively correlated with temperature. Youn and Choi, 2008 studied the zooplankton distribution in Han River estuary with respect to tidal cycles. According to tidal states, relatively higher abundance occurred at high tide without regard to season. Albaina et al., 2009 carried out a comparative study of zooplankton to understand the ecosystem health in the Basque estuaries (Bilbao and Urdaibai -Basque coast, Bay of Biscay). Spatial differentiation of the zooplankton community was higher in the estuary of Bilbao, with the relative abundance of most of the taxa decreasing more pronouncedly towards the upstream estuary than in the Urdaibai related to significantly lower values of dissolved oxygen saturation and Secchi disc depth, reflecting the higher degree of pollution, in the Bilbao estuary in Spain.

Beatrix et al. (2009) found out that seasonal trophic dynamics affect variability in the zooplankton community. Favareto et al. (2009) carried out a study to evaluate the selectivity of plankton nets (64 and 200 µm).Higher richness and diversity were observed in the samples from the 200 µm net, and the evenness suggested uniformity in the assemblages of the two nets in most of the studied months. Maya and Strydon (2009) studied the zooplankton dynamics in the south and west coast estuaries in South Africa. Naumenko et al. (2009) carried out a long term monitoring of zooplankton in closed (Curonian) and open (Vistula) estuaries. The mechanism providing the stability of the zooplankton communities in the open-type estuaries is the energy flow through the omnivorous species and the increase in the number of facultative predators at the terminal links of the trophic chain.

Vidjak et al. (2009) observed the population structure and abundance of zooplankton along the Krka estuary located in the middle part of the eastern Adriatic coast. Wooldridge and Deyzel (2009) observed that temperature and salinity are the abiotic factors that control the zooplankton dynamics in the Great Berg estuary in South Africa. According to

Biancalana et al. (2012), untreated sewage effluent significantly decreased the diversity of mesozooplankton in the Bahia Blanca estuary in the south-western Atlantic Ocean. Gutkowska et al.(2012) studied the qualitative and quantitative method for zooplankton sampling in shallow coastal estuaries. Intxausti et al. (2012) analysed the spatio-temporal variation of zooplankton assemblages in the estuary of Bilbao in Spain, relative to hydro-climatic and water quality factors. Paturej and Kowalska (2012) reported that the Ruttner sampler delivers more reliable results in zooplankton communities marked by greater qualitative variation compared to the Apstein plankton net. Pansera et al. (2014) reported that mesh size selection during the sampling procedure reshapes the community structure of zooplankton. The 80µm net catch contains more abundance with copepods, bivalve and veligers larvae compared with 200µm mesh.

Good deals of data are available on the zooplankton distribution in the estuaries of India. Selvakumar et al. (1980) estimated the secondary production in the estuarine system of Goa. Qasim et al. (1978) studied the biological production of the coastal waters of India from Dabhol to Tuticorin. Zooplankton distribution was extensively studied by Rajagopal (1981) in the estuarine and near-shore regions of Mandovi and Zuari estuary. Gajbhiye and Desai(1981) made a comparative account of zooplankton abundance at Versova, Bombay harbour (less polluted), Mahim and Thana (highly polluted) waters. Group diversity of zooplankton was relatively more in unpolluted waters than in polluted waters. Nair et al. (1981) estimated the mean biomass of zooplankton and its composition in the estuaries of Gujarat. Madhupratap et al. (1981) studied the zooplankton biomass and abundance in the Andaman Sea. Girijavallaban(1983) studied the trends in secondary production in the inshore waters of the seas around India. Desai et al.(1983) made an assessment of the zooplankton biomass and composition in polluted (Kolak, Par and Damanganga) and unpolluted estuaries (Auranga) of Gujarat. Distribution of zooplankton biomass was in accordance with the intensity of pollution. Mean rates of secondary production in these estuaries were 265 mgC $100m^{-3}$ d^{-1} (Kolak), 138 mgC$100m^{-3}$ d^{-1} (Par), 109 mgC $100m^{-3}$ d^{-1} (Damanganga) and 80 mgC $100m^{-3}$ d^{-1} (Auranga).

Nair et al.(1983) observed the short term variability in secondary production and zooplankton composition in the Zuari estuary, Goa. Irregularity in the production rate was found to be a characteristic feature of the estuary and it ranged from 52-1388 mgC $100m^{-3}$ d^{-1}.

Mathew et al.(1989) studied the zooplankton biomass as well as secondary and tertiary production of the exclusive economic zone of India. Devi et al. (1992) studied the zooplankton distribution along the southwest coast of India. Gajbhiye and Abidi (1993) observed that diversity of zooplankton was very low in the polluted environment around Mumbai (previously Bombay). Ramaiah et al. (1996) recorded the species, *Pseudodiaptomusbowmani, P.sewelli, Acartiatropica and A.bowmanii* for the first time from theBurhabalanga estuary in Orissa. Goswami and Padmavati (1996) studied zooplankton production, composition and diversity in the coastal waters of Goa. Goswami and Shrivastava (1996) made an attempt to study the impact of oil spills which occurred during the Gulf war on zooplankton standing stock, community structure and diversity in the Northern Arabian Sea. Mathew et al. (1996) investigated the zooplankton abundance in the continental shelf waters of the northeast coast of India.

Padmavati and Goswami (1996) studied the zooplankton ecology in the Mandovi-Zuari estuarine system in Goa. Misra and Panigrahy 1999 exclusively studied the copepods of Bahuda estuary in Orissa. Ramaiah et al. (1996) studied the annual variation of zooplankton biomass in the Burhabalanga estuary in Orissa. Nair et al. (1999) reported that heavy metal accumulation in the carnivorous zooplankton was higher compared to herbivorous zooplankton in the Thane- Bassein creek, Bombay. Vareethiah (1999) studied the composition and abundance of zooplankton in the Thengapatanam estuary, which is a bar-built estuary in the southwest coast of India. Krishnamoorthy and Subramanian (2003) conducted a study on the seasonal variation and species association of meroplankton from the Palk Bay and Gulf of Mannar.

Santhanam and Perumal (2003) carried out an investigation to study the spatio-temporal variations of zooplankton in the Bay of Bengal and the Vellar estuary. Eswari and Ramanibai (2004) studied the species composition and monthly abundance of copepods in relation to the environmental variables in the Cooum and Adayar estuaries. Prabhu et al. (2005) studied the species composition, density and diversity of microzooplankton along with the hydrographical parameters in the Vellar estuary and the Killai backwaters. White et al. (2006) conducted a comparative study of zooplankton assemblages in a polluted harbour and bar-built estuary near Visakhapatanam.Naik et al. (2008) studied the spatio-temporal distribution of zooplankton in Chilkalake.

Resmi et al. (2011) studied distributional variation of zooplankton in relation with the environmental parameters in the coastal waters of Adubidri, Karnataka at various depths. Anjush et al. (2013) observed the trophic efficiency of plankton food webs in the Gulf of Mannarand Palk Bay. Jagadeesan et al. (2013) reported that ocean currents shape the mesozooplankton in the Gulf of Mannar and Palk Bay. Janakiraman et al., (2013) studied zooplankton diversity and density in the Adayar estuary.

Abundance and diversity of zooplankton can be considered as an index to the health of aquatic environment. The quantitative and qualitative distribution of zooplankton in the estuaries of Kerala especially Cochin estuary is a thrust area of research. George (1958) enumerated the various groups of zooplankton existing in the estuary and attempted to correlate the seasonal fluctuations in the population structure with changes in the salinity of the water. Chandrasekharan Nair (1971) made a quantitative study on the zooplankton biomass of Cochin backwaters, with changes in salinity of the estuary seasonally. A study on the hydromedusae from the Cochin backwaters was done by Santhakumari and Vannucci (1971). Pillai et al. (1973) exclusively studied the copepods of Cochin backwaters. Nair et al. (1975) studied the distribution of chaetognaths in the Cochin estuary and found that their distribution varies with the seasonal salinity pattern. Madhupratap et al. (1975) made a study on the species association of calanoid copepods in Cochin backwaters. Pillai et al. (1975) reported that the salinity, temperature and zooplankton biomass showed a significant correlation. The conversion ratio between phytoplankton (primary level) and zooplankton (secondary level) was not maintained, possibly due to the interference of salinity.

Madhupratap and Haridas(1975) and Raoet al.(1975) studied the spatio-temporal variation of zooplankton from Cochin to Alleppey. Silas and Pillai (1975) studied the composition and the seasonal periodicity of zooplankton in the Cochin backwaters. Mathew et al. (1977) and Madhupratap et al. (1979) made a study on the zooplankton distribution in relation to tidal variation in the Alapuzha mud banks and Cochin backwaters respectively. Menon et al. (1977) made a quantitative study on zooplankton of Kerala coast. They were able to find that the distribution of zooplankton depends on the season. Madhupratap et al. (1977) estimated the secondary production in the Cochin backwaters. The average secondary production in the Cochin backwaters was 31.8 mg m^3 d^{-1}. It was considerably higher during the pre-monsoon period (60.0 mg m^3 d^{-1}). Transfer coefficient, from primary to secondary level for the estuary was 2.7%, a large portion of the primary production being available for alternate pathway in the food chain.Madhupratap(1978) reported that higher zooplankton count in the Cochin backwaters occur during pre- monsoon period and salinity to be a key factor associated with changes in abundance of zooplankton.

Literature on zooplankton community in the Cochin and Ashtamudi estuary were given by Madhupratap et al. (1978) and Nair et al. (1985). Madhupratap(1980) studied the ecology of co-existing copepod species in the Cochin backwaters. Haridas et al. (1980) studied the seasonal variation in composition and distribution of zooplankton from the polluted coastal waters of Trivandrum. The study indicated that the effluent discharge from nearby titanium dioxide factory did not affect the zooplankton abundance. Divakaran et al., 1982 reported that peak abundance of zooplankton was recorded during monsoon and early post-monsoon period in the Ashtamudilake. Haridas et al., 1984 exclusively studied the zooplankton in the Cochin estuary. Rosamma Stephen, 1991 reported that the zooplankton population in the Cochin backwaters was decreased due to the vertical and horizontal shrinking of the estuary and increase in industrial effluent discharge. Relative abundance and diurnal variations of zooplankton from six stations along the Kerala coast were investigated by Santhakumari and Peter, 1993. Bijoy Nandan and Abudul Azis, 1994 reported that zooplankton groups/species were depleted in the retting zones of Kadinamkulam estuary in comparison with the nonretting zones. Rotifers, Copepods and copepod naupliii were the major group present at all stations.

Jyothibabu et al., 2006 investigated the impact of fresh water influx on microzooplankton in Cochin backwaters during the pre-summer monsoon period (April-May) and peak summer monsoon period (July-August). Low abundance of microzooplankton along with the low occurrence of meso zooplankton suggests that there will be general lack of planktonic grazers. Vargheese et al., 2006 gave a systematic account on rotifers of the genus *Brachionus* inhabiting the Cochin backwaters. A total of thirteen species were recorded from the area for the first time. Madhu et al., 2007 reported that the standing stock of zooplankton was high during the pre-monsoon period in Cochin estuary. The ratio of carbon content between phytoplankton and zooplankton was quite high during monsoon and post monsoon seasons, but became low during pre monsoon. Vargheese and Krishnan, 2009 observed the zooplankton dynamics of the Cochin estuary. The major group was rotifers followed by copepods. The results of ANOVA indicated that the variations in zooplankton between stations were highly significant. Radhika, 2013 investigated the influence of hydrology on the trophic structure of Cochin backwaters. Cleetus et al., 2015 examined the species diversity and community assemblage of planktonic rotifers in the Vembanad estuary. Vineetha et al., 2015a studied the tidal influence on the diel vertical migration of zooplankton in Cochin estuary. Vineetha et al., 2015b assessed the population structure of copepods in Cochin estuary. The high sex ratio of females favoured higher reproductive output, resulting in higher abundance during the pre- monsoon period.

5.3 Materials and methods

5.3.1 Quantitative estimation of Zooplankton

The samples for zooplankton were collected by filtering 50 litres of sub-surface water through conical plankton net made of thin finest bolting silk of mesh size 100 µm (Vidjak et al., 2009; Pansera et al., 2014). The samples were preserved in 4% buffered formalin and sodiumtetraborate (borax) is used as the buffer. Magnesium chloride (8%) was used as a narcotizing agent and the samples were kept in high quality polythene bottles (Steedman, 1976; Omori and Ikeda, 1984).

The biomass of zooplankton was determined by the volumetric method (settling volume method) and was expressed in ml m^{-3} (Harris et al., 2000; Goswami, 2004; Varghese et al., 2015). The settled volume is obtained by making the sample to a known volume in the graduated centrifuge tube. The plankton is allowed to settle for at least 24 hours before recording the settled volume.

In the qualitative estimation, the zooplankton groups were sorted, counted and identified to the major zooplankton taxon, and the abundance was expressed as individuals per cubic meter (ind.m^{-3}). The identification was done using standard keys of Newell and Newell (1973); Todd and Laverack (1991) and Johnson and Allen (2012).

5.3.2 Secondary productivity

Secondary production can be quantified as the amount of organic tissue built up at trophic level two per unit area per unit time, measured in terms of carbon, or wet/dry weight. The secondary productivity of the Cochin estuary was calculated in terms zooplankton carbon. The estimation of zooplankton carbon was done as follows. The basic value of zooplankton biomass in ml m^{-3} has to be first converted into organic carbon, so as to find the energy available through zooplankton. The settling volume of zooplankton was converted into dry weight using a factor of 0.075 g dry wt.ml^{-1}. Carbon biomass is calculated as 38% of this value, as per the estimate from the biochemical studies done by Cushing, 1971 and Madhupratap et al., 1981.

The column secondary productivity was calculated from the zooplankton carbon values and the generation time of zooplankton as suggested by Cushing, 1971. The generation time (doubling time) of zooplankton (D) is the average time between two consecutive generations in the lineages of a population. It was calculated from the relationship

$D = 71.72\ t^{-1.22}$, where ‘t′ is the temperature. The euphotic zone depth was considered in the calculation so as to derive the secondary productivity in terms of area.

Assimilation and transfer efficiency is the part of energy incorporated into the living organisms which is potentially available for consumers in the next trophic level. A portion of the assimilated energy is utilized for respiration and growth of the organisms. The transfer efficiency from phytoplankton to zooplankton can be estimated from the ratio between phytoplankton carbon and zooplankton carbon (P:Z).

5.3.3 Data analysis

The standard deviation, two-way ANOVA (Analysis of Variance) was calculated using SPSS 22. By using PRIMER v6, multivariate methods (Cluster analysis with SIMPROF, MDS Plots (Non-metric multi dimension scaling), BEST analysis and univariate methods (Margalef's index, Pielou's index, Shannon-Weiner index, Simpson's index)were used for analysis as described previously.

5.4 Results

5.4.1 Biomass

A significant increase in the zooplankton biomass (10.10±1.23 ml m^{-3}) was noticed during the pre-monsoon period as compared to the monsoon period (9.04±1.23 ml m^{-3}) and post-monsoon period (7.65±1.23 ml m^{-3}). In the monsoon period, minimum biomass was 2.00 ml m^{-3}, which was recorded from station 2 in August 2009 and station 8 in June 2010. In the post-monsoon period, the biomass was maximum (2.00 ml m^{-3}) at station 5 in October 2009 and the minimum at station 7 in October 2009. In the pre-monsoon period, the minimum was recorded (1.00 ml m^{-3}) in February 2010 at station 8 and maximum at station 5 (80.00 ml m^{-3}) in April 2011.

The zooplankton biomass was found to be relatively higher in the southern zone of the estuary. In the central zone of the estuary, station 4 (11.61 ml m^{-3}) and station 5 (11.47 ml m^{-3}) had similar biomass values. Station 3 (11.79 ml m^{-3}) showed the higher biomass compared to station 2 (8.53 ml m^{-3}) in the southern zone. In the northern zone, total biomass of the zooplankton ranged from 4.89 ml m^{-3} at station 8 to 9.83ml m^{-3} at station 9. Station wise mean values were maximum at stations 3 and 5 (11.79±2.52 ml m^{-3}) and minimum at station 8 (4.89±2.52 ml m^{-3}). The station wise variation of zooplankton biomass was presented in Table 5.1.2.

Monthly mean values of zooplankton biomass were higher in April 2011 at station 5 with an average biomass of 80.00 ml m^{-3} (Table 5.1.1 and Fig.5.1). The lowest value of 1.00 ml m^{-3} was recorded in February 2010 at Station 8. The inter-annual variation showed that the biomass was higher in the 2010-11 period (10.04±3.90 ml m^{-3}) compared to the 2009-10 period (7.82±1.74 ml m^{-3}). Mean monthly values of biomass were highest in March 2010 (10.16 ± 1.74 ml m^{-3}) and lowest in June 2009 (4.44 ml m^{-3}) during the 2009-10 period. The zooplankton biomass in the estuary ranged from 5.72 ml m^{-3} in January 2011 to 18.67 ml m^{-3} in April 2011during the 2010-11 period.

ANOVA of biomass were significant at 1% level between stations ($P \leq 0.01$) (Table 5.1.3).

Table 5.1.1 Mean season wise variation of biomass of zooplankton in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	5.00±2.16	8.60±7.96	6.50±2.52	4.50±1.47	7.00±2.00	5.33±1.70
2	6.67±3.77	10.50±3.42	8.50±3.00	7.50±1.08	9.50±1.91	8.50±3.34
3	10.33±4.5	20.00±12.44	7.20±3.08	7.23±0.61	15.50±7.19	10.50±3.54
4	7.80±3.02	13.50±8.7	9.75±4.79	9.92±0.12	14.50±4.43	14.17±0.24
5	7.67±3.09	10.00±5.89	6.50±3.42	6.83±2.46	6.80±0.91	32.93±33.35
6	2.67±0.47	9.00±2.00	8.50±3.79	7.50±1.08	6.50±1.00	12.17±8.37
7	4.80±2.36	8.50±1.91	12.50±9.29	7.17±3.79	8.10±1.47	7.37±0.97
8	5.67±3.09	6.00±3.65	5.00±1.15	5.00±0.82	3.75±2.06	3.92±1.64
9	7.47±0.75	18.50±17.54	10.50±5.51	7.17±3.12	6.50±1.00	8.83±1.65

Table 5.1.2 Mean station wise variation of biomass of zooplankton (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Min	Max
1	2.400	20.000
2	4.000	14.000
3	2.800	38.000
4	3.000	26.000
5	2.000	80.000
6	2.000	24.000
7	2.400	24.000
8	1.000	10.000
9	3.000	44.000

Table 5.1.3 ANOVA of biomass of zooplankton in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	26	100.965	2.102
Season	2	108.648	2.261
Station	8	152.172	3.167**
Season * Station	16	74.402	1.549
Error	189	48.043	
Total	216		
R^2=0.224			

** Variation is significant at 1% level

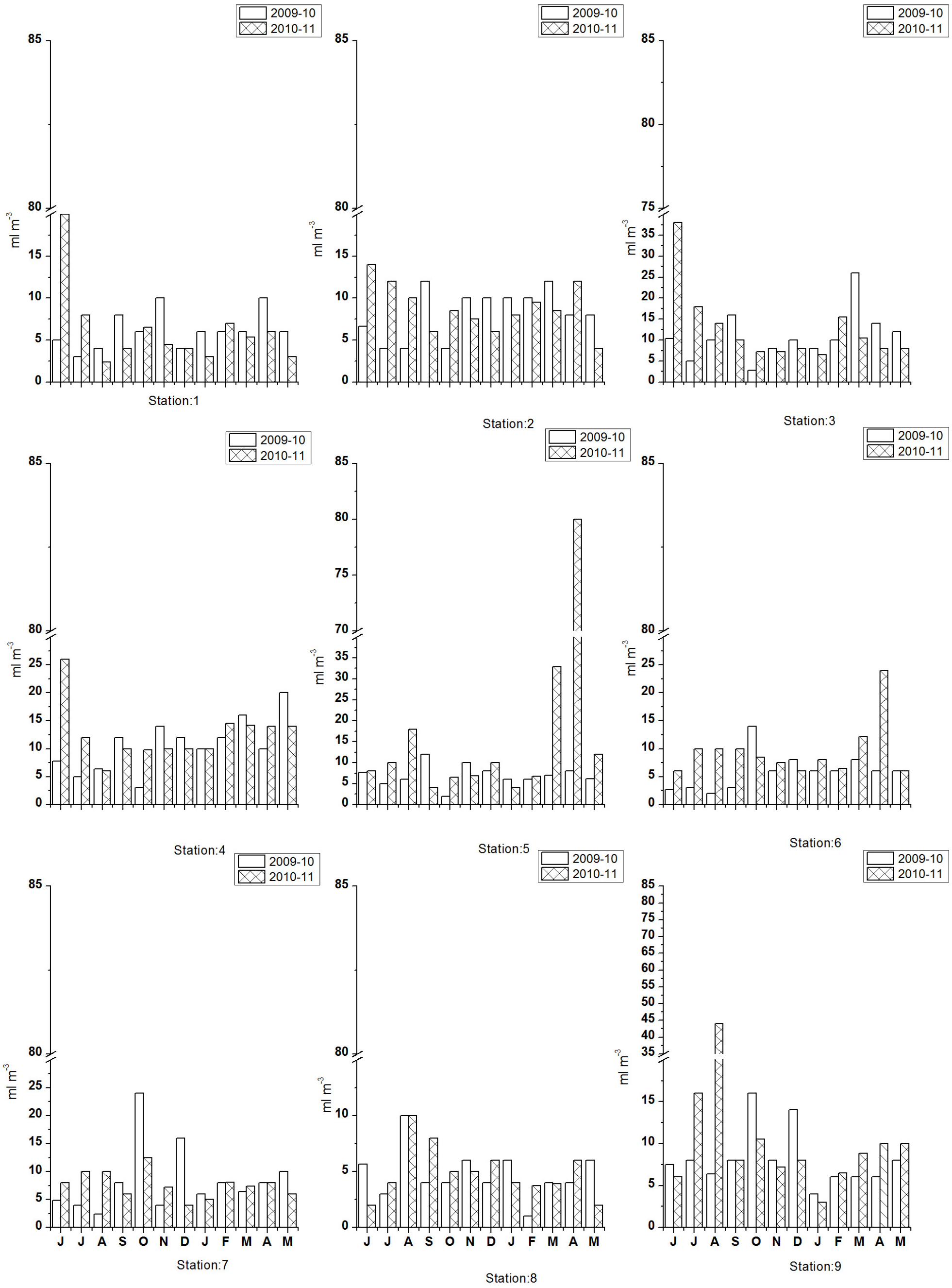


Fig. 5.1. **Mean monthly variation of biomass of zooplankton in selected stations of Cochin estuary during 2009-11 period**

5.4.2 Total numerical abundance

The total numerical abundance of zooplankton during the study period was 403885 ± 12240.19ind m^{-3}.The density was highest during the pre-monsoon period, followed by the post-monsoon period and monsoon period. During the monsoon period, the total numerical abundance of zooplankton ranged between 20 ind m^{-3} to 42880 ind m^{-3}. During the 2009-10 post-monsoon period, it ranged between 300 ind m^{-3} to 62080 ind m^{-3}. During the pre-monsoon period, the abundance varied between 700 ind m^{-3} and 187220ind m^{-3}.

The mean monthly numerical abundance was maximum in March 2010 at station 6 (187200 ind m^{-3}) and minimum in April 2009 at station 3 (20 ind m^{-3}) (Fig.5.2). The annual numerical abundance was higher during the 2009-10period (233070±14533 ind m^{-3}) compared to the 2010-11 period (170815±9347.46 ind m^{-3}). The numerical abundance ranged between 4042 ind m^{-3} in October 2009 and 52007 ind m^{-3} in March 2010 during the 2009-10 period. The zooplankton numerical abundance varied between 1723 ind m^{-3} in June 2010 to 31616 ind m^{-3} February 2011.

The mean numerical abundance was higher in the southern zone (20341±3289.69 ind m^{-3}) and lower in the northern zone (13918±3289.69 ind m^{-3}).In the central zone, zooplankton numerical abundance was higher at station 5 (23899 ind m^{-3}) compared to stations 1(12896 ind m^{-3}) and 4 (18307 ind m^{-3}).The mean station wise numerical abundance of zooplankton ranged from 25093 ± 6538.83ind m^{-3} at station 6 to 7,614±6538.83 ind m^{-3} at station 8. The station wise variation of numerical abundance of zooplankton is presented in Table 5.2.2.

Table 5.2.1 Mean season wise variation of numerical abundance of zooplankton in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period		Post-monsoon period		Pre-monsoon period	
	Mean SD		Mean SD		Mean SD	
	2009-10	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**
1	10953.5±9023.38	13100±16978.15	10770±7785.21	7883.5±2223.52	22855±15419.51	11811.75±8838.22
2	12890±2804.67	10307.5±7557.78	19310±13561.88	17048.75±11239.51	15405±16024.07	20563.75±24727.57
3	7060±5629.66	17515±17586.45	25390±25877.28	16623.33±6481.94	54360±41402.43	27613.33±19120.18
4	9320±6416.04	4565±3009.16	22545±22450.49	12661.67±7933.9	39960±30417.58	20792±14033.65
5	3813.33±4544.34	4750±5990.69	16155±12766.88	14878.33±5947.68	43355±42678.26	60445±20770.61
6	16873.33±10747.41	2195±391.37	16220±13447.84	14206.67±4108.41	56510±87325.81	44550±10822.02
7	6200±5880.48	1660±651.15	25280±9539.36	12106.67±9457.01	13712±9865.4	12340.67±973.46
8	7000±5506.36	1545±912.34	16150±13091.53	6556.67±6794.82	9373.33±5440.11	5057.78±3541
9	13386.67±8822.11	746.67±603.4	11275±7726.6	5211.67±4496.56	18285±11048.17	17598.33±13485.02

ANOVA of total numerical abundance of zooplankton were significant at 1% level between seasons ($p \leq 0.001$), between stations ($p \leq 0.01$) and between seasons and stations ($p \leq 0.01$) (Table 5.2.3).

Table 5.2.2 Mean station wise variation of numerical abundance of zooplankton (minimum- maximum) in selected stations of Cochin estuary during 2009-11 period

Numerical abundance		
Stations	**Min**	**Max**
1	1200	38300
2	960	53280
3	20	109200
4	900	84900
5	300	104960
6	1200	187200
7	880	37120
8	240	32640
9	300	33760

Table 5.2.3 ANOVA of total numerical abundance of zooplankton in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	26	1301232044.488	4.032
Season	2	7010646224.391	21.723**
Station	8	1026149328.577	3.180**
Season * Station	16	725096629.956	2.247**
Error	189	322735510.704	
Total	216		
R^2=0.357			

** Variation is significant at 1% level

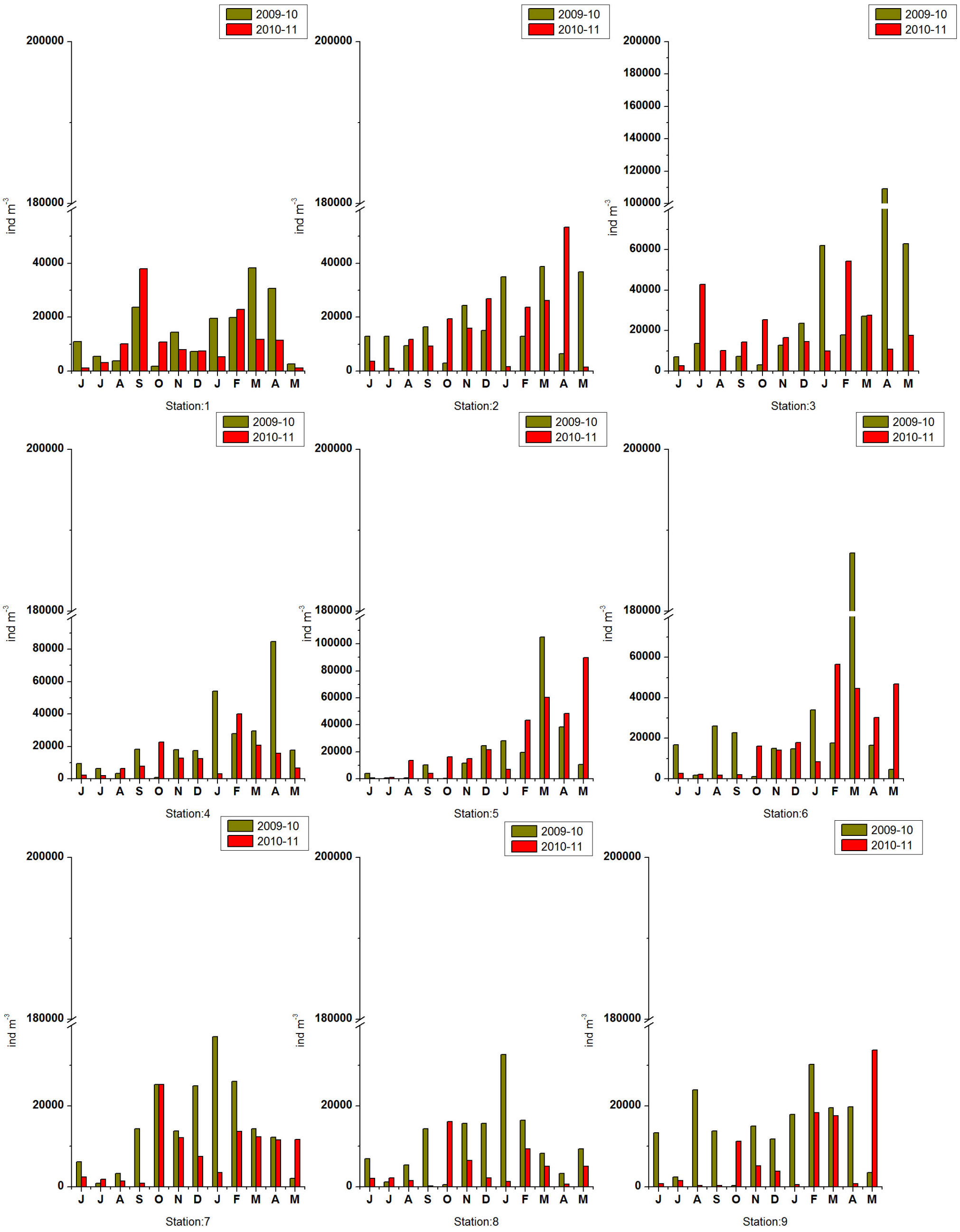


Fig. 5.2. **Mean monthly variation of total numerical abundance of zooplankton in selected stations of Cochin estuary during 2009-11 period**

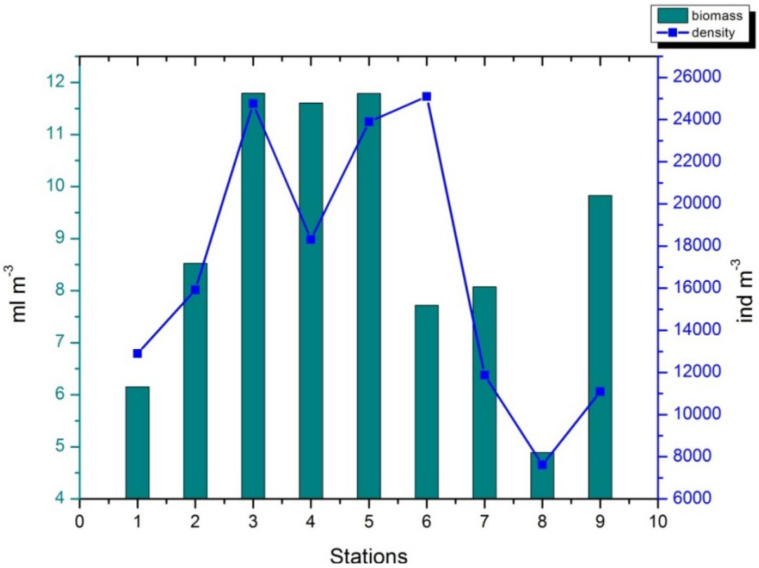


Fig. 5.3. Mean station wise variation of biomass and total density of zooplankton in selected stations of Cochin estuary during 2009-11 period

5.4.3Composition of zooplankton

The composition, distribution and mean cell density of zooplankton groups in Cochin estuary during 2009-11 period is shown in Table 5.7. During the present study, 25 groups of zooplankton were recorded from nine stations across the estuary. They were, foramniferans, tintinnids, rotifers, nematodes, polychaete larvae, cladocera, ostracods, barnacle nauplii, copepods, mysids, cumaceans, isopods, amphipods, insects, crustacean nauplii, zoea, gastropod larvae, mollusc larvae, chaetognatha, tunicates, echinoderm larvae and fish eggs. Out of the 25 groups, 19 were recorded from Station 3.The lowest number of 13 groups was observed from Station 8. The zooplankton community was mainly represented by crustacean nauplii, but other groups such as copepods and rotifers were also present in lesser numbers.

The station wise variation of zooplankton is presented in Fig.5.4. Crustacean nauplii formed 51.11% of the total zooplankton abundance at station 1. The second dominant zooplankton group was copepods (18.70%) followed by rotifers (12.20%). Representatives of other groups were present in this station (polychaete larvae,gastropod veligers,bivalve veligers, foraminifera, tintinnids, ostracods, barnacle nauplii, isopods, amphipods, oikopleura, fish eggs, zoea, nematoda and actinopoda), contributing about 17.99%. At station 2, seventeen groups of zooplankton were identified. Crustacean nauplii formed 48.28% of the total zooplankton composition, copepods contributed 30.33%, rotifers8.39%, tintinnids 5.48%, ostracods 0.29% and others 7.22%.At station 3, the dominant group was crustacean nauplii 37.83%, copepods 33.99%, rotifers 11.60%, tintinnids 4.53%, ostracods 0.76% and the other groups together formed 11.29%. At station 4, crustacean nauplii formed 45.65% of the total zooplankton composition, while the remaining composition was,copepods 32.02%, tintinnids 7.03%, rotifers 6.28%, ostracods 0.41% and others 8.61%. At station 5, crustacean nauplii formed 50.15%, copepods 22.91%, rotifers 11.33%,tintinnids 4.98%, ostracods 0.57% and others 10.06%. At station 6, rotifers formed 44.96% of the total composition, crustacean nauplii 28.28%, copepods 16.39%,tintinnids 3.55%, ostracods 0.54% and others 6.28%.At station 7, crustacean naupliiformed 30.64% of the total, copepods 28.91%, rotifers 24.35%, tintinnids 5.59%, ostracods 0.98% and others 9.43%. At station 8, copepods formed 32.51% of the total composition, crustacean nauplii 31.95%, rotifers 18.29%,tintinnids 10.35%, ostracods 0.16% and others 6.74%. At station 9, crustacean nauplii formed 31.15% of the total, copepods 29.50%, rotifers 24.46%,tintinnids 5.97%, ostracods 1.93% and others 6.99%.

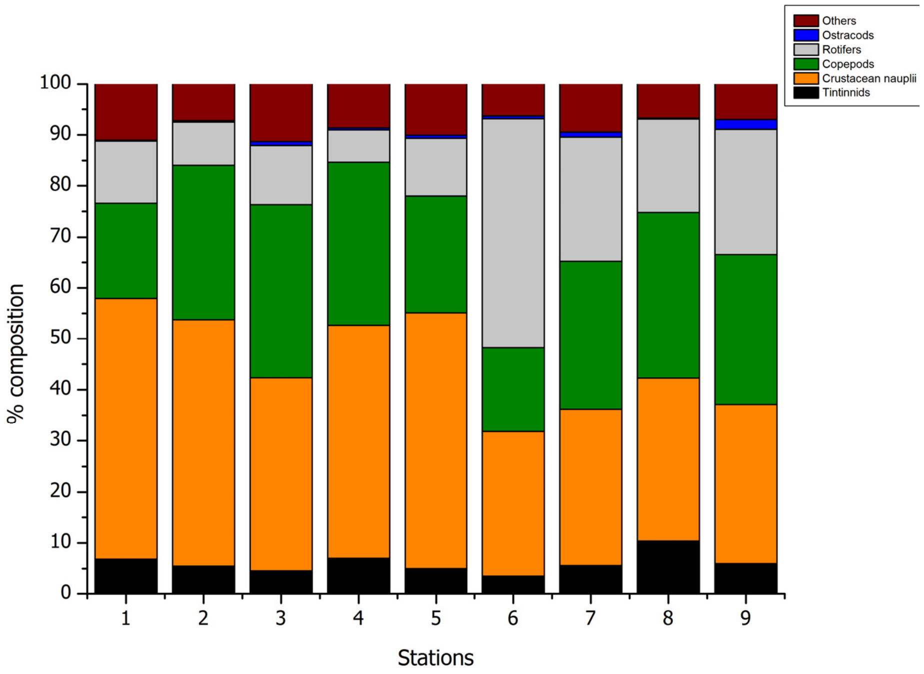
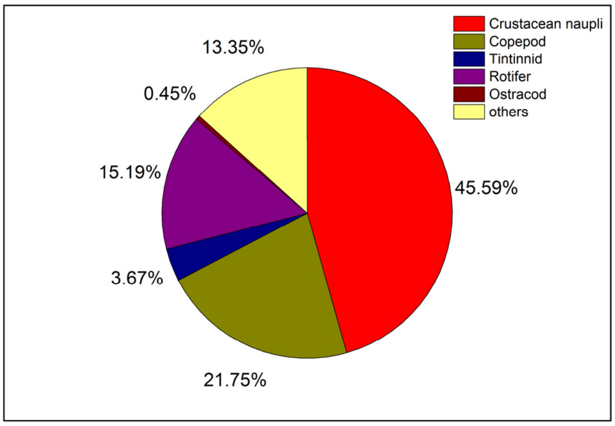


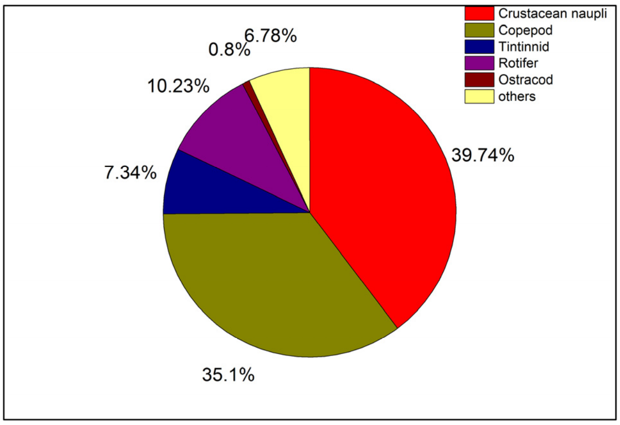
Fig.5.4. Mean station wise variation of percentage composition of zooplankton in Cochin estuary during 2009-11 period

Table 5.3 Mean seasonal percentage composition of zooplankton in Cochin estuary during 2009-11 period

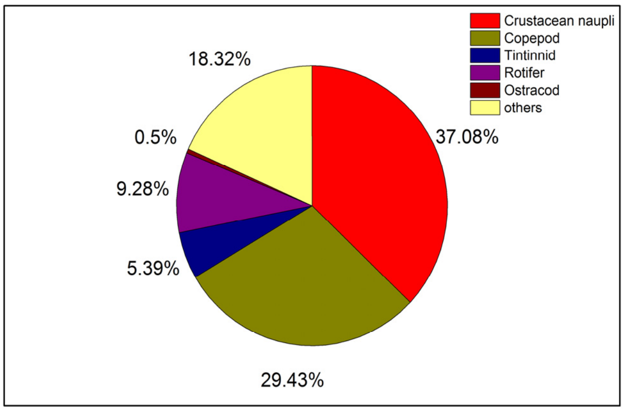
Percentage composition	Monsoon period	Post-monsoon period	Pre-monsoon period
Crustacean nauplii	39.74	37.08	45.59
Copepods	35.10	29.43	21.75
Tintinnids	7.34	5.39	3.67
Rotifers	10.23	9.28	15.19
Ostracods	0.80	0.50	0.45
others	6.78	18.32	13.35



Pre monsoon



Monsoon



Post monsoon

Fig. 5.5. Mean seasonal percentage composition of zooplankton in Cochin estuary during 2009-11 period

5.4.3.1 Crustacean nauplii

Nauplius is the earliest free-living stage in the development of most crustaceans. Crustacean nauplii were the most dominant group in the present study. The numerical abundance of nauplii varied from maximum at station 5 (13681 ind m^{-3}) to minimum at station 8 (2435 ind m^{-3}). It was present throughout the study period. The mean percentage composition was higher at station 1 (51.11%) followed by station 5 (50.15%). At station 6, the mean percentage composition of crustacean nauplii was found to be very low (28.28%). The numerical abundance of crustacean nauplii was higher in the central zone (9435 ind m^{-3}) of the estuary and lower in the northern zone (4337 ind m^{-3}). In the central zone, the abundance ranged between 6596 ind m^{-3} at station 1 to 13681 ind m^{-3} at station 5. The abundance of crustacean nauplii varied between 2435ind m^{-3} at station 8 to 7573ind m^{-3} at station 6.

The mean percentage composition of crustacean nauplii decreased from 45.59% during the pre-monsoon period to 39.74% during the monsoon period and 37.08% during the post-monsoon period. In the monsoon period (2009-10), the numerical abundance of crustacean nauplii ranged between 20 ind m^{-3} in August 2009 at station 6 to 14700 ind m^{-3} in August 2009 at station 3. In the monsoon period (2010-11), the values ranged from 0 to 36000 ind m^{-3}. In the post-monsoon period (2009-10), the numerical abundance of crustacean nauplii was higher at stations 3 and 4 (21760 ind m^{-3}) in January 2010 and lower at station 4 (300 ind m^{-3}) in October 2009. In the post-monsoon 2010-11 period, the numerical abundance ranged from 22720 ind m^{-3} in December 2010 at station 2 to 340 ind m^{-3} in January 2011 at station 9. In the pre-monsoon period, values ranged from 0 at station 2 in March 2010 and station 8 in May 2010 to 57900ind m^{-3} in April 2010 at station 3.

The mean annual abundance was higher during the 2009-10 period (6678 ind m^{-3}) compared to the 2010-11 period (5320 ind m^{-3}). The mean monthly numerical abundance of zooplankton was maximum in January 2010 (11627 ind m^{-3}) and minimum in December 2010 (3056 ind m^{-3}).

ANOVA of numerical abundance of crustacean nauplii was significant at 1% level between seasons ($p \leq 0.001$) (Table 5.4).

Table 5.4 ANOVA of crustacean nauplii in Cochin estuary during 2009-11 period

Source	**df**	**Mean Square**	**F**
Model	26	145621240.553	1.739
Season	2	582352447.685	6.955**
Station	8	148365857.088	1.772
Season * Station	16	89657531.394	1.071
Error	189	83727208.204	
Total	216		
$R^2=0.193$			

** Variation is significant at 1% level

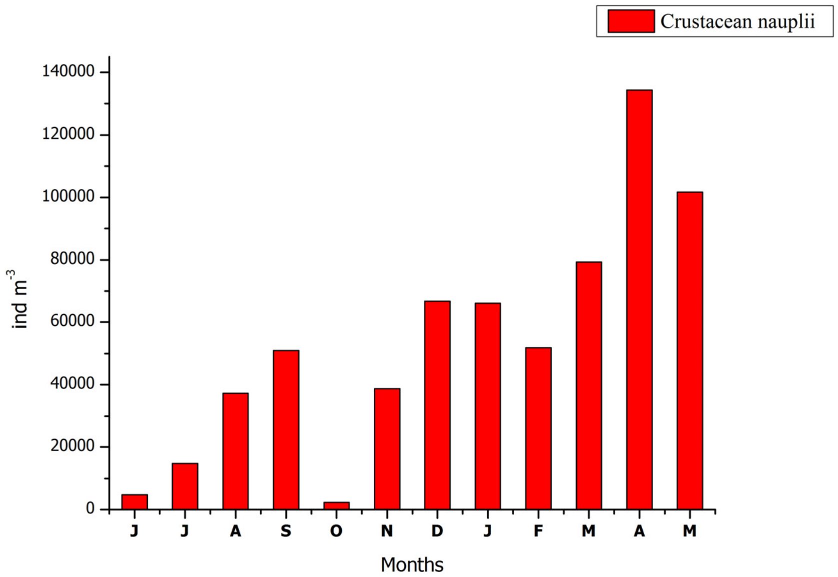


Fig. 5.6. **Mean monthly variation of numerical abundance of crustacean nauplii in Cochin estuary during 2009-11 period**

5.4.3.2 Copepoda

Copepods are the most abundant animals in the mesozooplankton. They are important links in virtually all marine and estuarine food webs. Copepods are both omnivorous particle grazers and opportunistic predators on microzooplankton. Maximum copepod density was recorded at Station 3 (157740 ind m^{-3}). Copepod density was higher during the monsoon period (35.10%), while a sharp decrease was noticed during the post-monsoon period (29.43%) and pre-monsoon period (21.75%) periods. In the monsoon period, the numerical abundance ranged from 0 to 13600 ind m^{-3} in September 2010.The post-monsoon period values varied between 0 to 34240 ind m^{-3}, whereas in the pre-monsoon period it ranged between 0 to 38400 ind m^{-3} in March 2010 at station 5.

Copepods were abundant in the southern zone of the estuary and in lesser numbers in the northern zone. In the southern zone, the mean values of numerical abundance of copepod were 98820 ind m^{-3}at station 2 and 157740 ind m^{-3}at station 3. The minimum abundance in the northern zone was reported from station 8 42120 ind m^{-3} and the maximum was 74620 ind m^{-3} at station 6.

The highest and lowest abundance were recorded in January 2010 (15004 ind m^{-3}) and January 2011 (509 ind m^{-3}) respectively. The annual variation of copepods showed the highest abundance during the 2009-10 period. The annual variation of copepods were the highest, with a value of 38400 ind m^{-3} during the 2009-10 period and 13600 ind m^{-3} during the 2010-11 period.

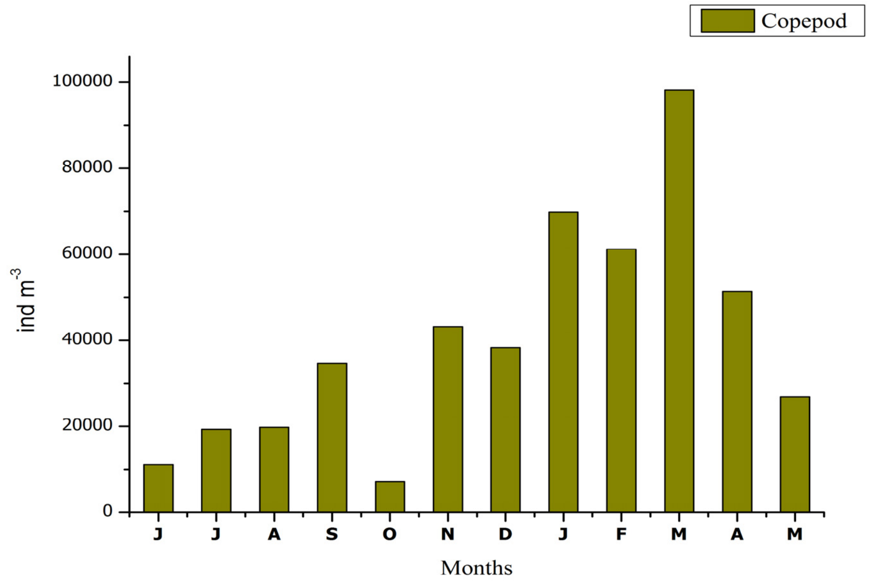


Fig. 5.7. Mean monthly variation of numerical abundance of copepod in Cochin estuary during 2009-11 period

5.4.3.3 Rotifera

Rotifers are among the smallest of the true metazoans. Most rotifer occur in freshwater, a few occur in sea water and some are abundant in brackish waters. They are particularly important as food for many larval fishes at the freshwater and estuarine interface in spring. They form an important link between the microbial loop and higher trophic levels when the rotifers are abundant in spring and other microphagous (small particles) grazers may be virtually absent.

Percentage abundance of rotifers was found to be higher during the pre-monsoon period (15.19%) and decreased during the monsoon period (10.23%) and post-monsoon period (9.28%).

The numerical abundance was compared for each season in both the periods (2009-10 and 2010-11). For the monsoon period, the values ranged from 0 to 16,640ind m^{-3}. In the post-monsoon period, the abundance varied from 0 to 13,760 ind m^{-3}, and in the pre-monsoon period, the values ranged from 0 to 1,60,000 ind m^{-3}.

The mean density of rotifer was highest in station 6 (12040 ind m^{-3}) and lowest in station 4 (1235 ind m^{-3}). Rotifers were abundant in the northern zone of the estuary. The lower values were recorded from the central zone of the estuary (2029 ind m^{-3}). In the central zone, the mean numerical abundance values ranged from 1235 ind m^{-3} at station 4 to 3092 ind m^{-3} at station 5. The maximum was recorded from station 6 (12040 ind m^{-3}) and the minimum from station 8 (1394 ind m^{-3}) in the northern zone.

Mean monthly variation of numerical abundance of rotifer recorded the minimum in August 2009 (44 indm^{-3}) and maximum in March 2010 (24249 ind m^{-3}). The mean numerical abundance of rotifer was high during the 2009-10 period (4269 indm^{-3}) compared to the 2010-11 period (1690 ind m^{-3}). The lowest abundance during the 2009-10 periodwas observed in August 2009 (44 ind m^{-3}) and the highest in March 2010 (24249 ind m^{-3}). During the 2010-11 period, the numerical abundance was lowest in January 2011 (76 ind m^{-3}) and highest in May 2011 (4829 ind m^{-3}).

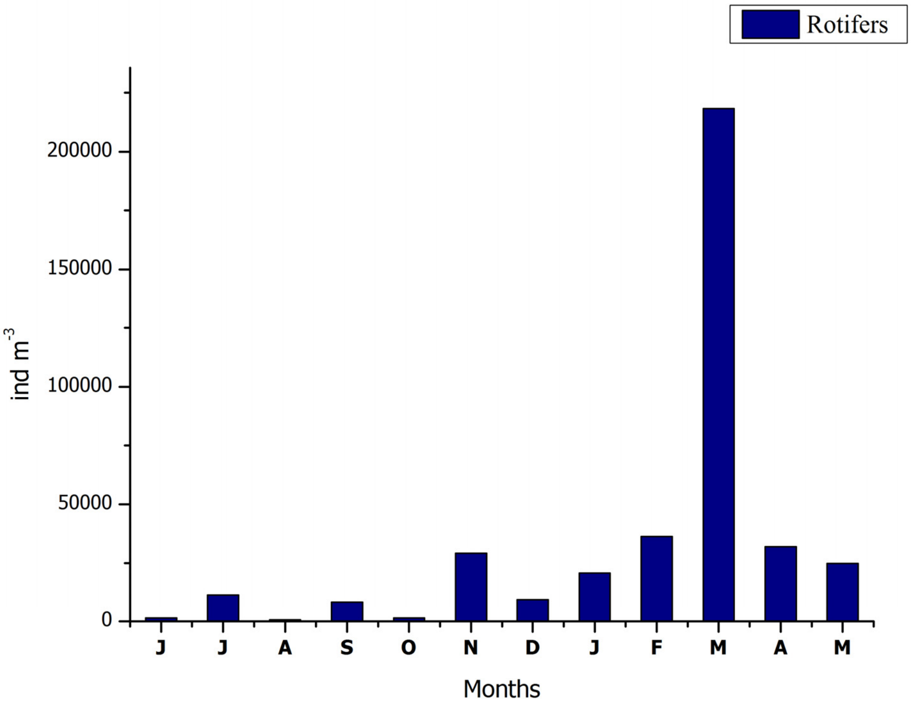


Fig. 5.8. Mean Monthly variation of numerical abundance of rotifers in Cochin estuary during 2009-11 period

5.4.3.4 Tintinnida

Tintinnids are ciliated protozoans. They occur from open ocean to mesohaline reaches of the estuary. A higher abundance of tintinnids was observed during the monsoon period (7.34%) and a lower value during the pre-monsoon period (3.67%). Zero values were recorded in all seasons. The highest values of the 2009-11 period were, 4800 ind m^{-3}during the monsoon period, 7040 ind m^{-3} during the post-monsoon period and 8000 ind m^{-3} during the pre-monsoon period.

The mean station wise percentage composition of tintinnids was highest at station 8 (10.35%) and lowest at station 6 (3.55%). In the central zone, the numerical abundance of tintinnids was the maximum, ranging from 1115 ind m^{-3} at station 1 to 1469 ind m^{-3} at station 4. The abundance was lowest in the northern zone of the estuary, where the values ranged from670 ind m^{-3} at station 7to949 ind m^{-3} at station 6.

The abundance of tinntinnids was higher during the 2010-11 period (1127 ind m^{-3}) compared to 2009-10 (815 ind m^{-3}). The highest abundance was recorded in January 2010 (3800 ind m^{-3}) during 2009-10 period, whereas in the 2010-11 period, the highest was in December 2010 (747 ind m^{-3}).

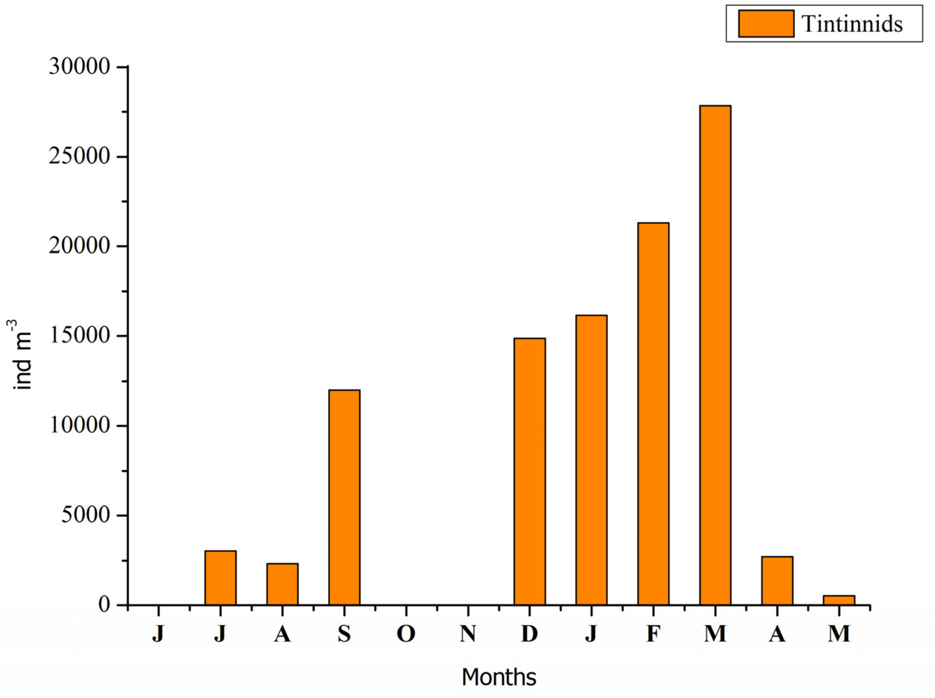


Fig. 5.9. **Mean monthly variation of numerical abundance of tintinnidsin Cochin estuary during 2009-11 period**

5.4.3.5 Ostracoda

Ostracods are small bivalved crustaceans. They are assumed to be opportunistic omnivores. The seasonal mean percentage composition of the ostracods in the monsoon period was 0.80%, in the post-monsoon period was 0.50% and in the pre-monsoon period, 0.45%. The station wise mean percentage composition of ostracods was highest at station 9 (1.92%) and lowest at station 1 (0.14%). The abundance of ostracods was maximum at station 9 (297 ind m^{-3}) and minimum at station 8 (19 ind m^{-3}). The numerical abundance of ostracods was low in the central zone of the estuary (44 ind m^{-3}) and higher in the southern zone of the estuary (172 ind m^{-3}). The mean annual variation of numerical abundance of ostracods was higher during the 2009-10 period, as compared to the 2010-11 period.

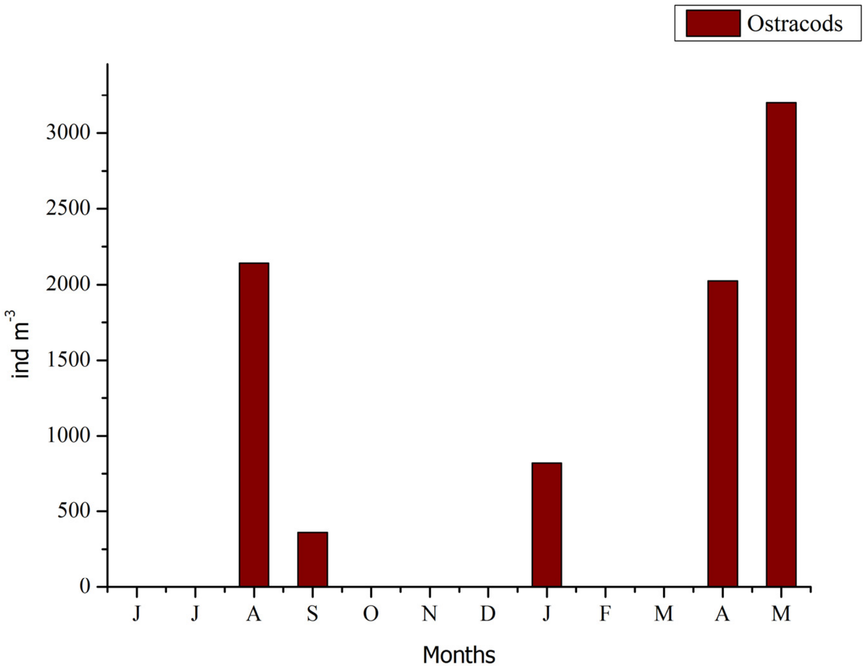


Fig. 5.10. Mean monthly variation of numerical abundance in Cochin estuary during 2009-11 period

5.4.3.6 Other zooplankton

The foraminiferans are single celled, heterotrophic protozoans and covered by an outer shell. Forams have multi-chambered shells, with or without fine radiating spines. They form a vital connection in the microbial loop, linking bacterial and nanoplankton production to larger zooplankton and fishes. Foraminiferans were abundant during the pre-monsoon period (1.64%), followed by the monsoon period (0.03%).They were completely absent during the post-monsoon period. The maximum abundance was recorded during March 2010 (1680 ind m^{-3}). Station wise variation of foraminiferans recorded the highest abundance from station 6 (529 ind m^{-3}) and lowest at station 1 (12 ind m^{-3}). The numerical abundance was high in the southern zone of the estuary.

The annelids mainly comprised of polychaete larvae. The number of polychaete larvae varied from 0 to 2240 ind m^{-3}. The maximum number of polychaete larvae was observed from station 1 in March 2010. Thepolychaete larvae were absent in station 2. The mean seasonal percentage composition of polychaete larvae was higher during the pre-monsoon period (0.64%) and lower during the monsoon period (0.10%).

Amphipods are laterally compressed crustaceans without carapace. They are important source of food for many coastal and estuarine fishes. Isopods lack a carapace they are often dorso-ventrally flattened. Isopods and amphipods were poorly represented. The mean seasonal abundance of amphipods ranged from 0 to 0.36% during the post-monsoon period. Mean seasonal abundance of isopods varied from 0.01% in the post-monsoon period to 0.08% in the pre-monsoon period. Amphipods and isopods were found at stations 1, 2, 3 and 5. Separately, isopods were observed from the samples of stations 8 and 9 while amphipods were present at station 6.

Many of the coastal and estuarine gastropods (snails) and bivalves (clams, oysters and scallops) have planktonic larvae. The maximum numerical abundance of gastropod veligers was observed at station 5 (568 ind m^{-3}). The numerical abundance was lowest at station 8 (15 ind m^{-3}). The maximum abundance of bivalve veligers was recorded at station

3 (2560 ind m^{-3}) and minimum at station 8 (60 ind m^{-3}). The seasonal mean percentage composition of bivalve veligers showed the minimum abundance during the monsoon period (0.69%) and maximum abundance during the pre-monsoon period (6.50%). For gastropod veligers, this ranged from 0.28% (monsoon period) to 0.93% (pre-monsoon period).

Barnacle larvae come under cirripeds of crustaceans. They are occasionally abundant in the marine and estuarine plankton samples. Barnacle nauplii were recorded from only two stations 1 and 4. They were present only in the pre-monsoon period (0.09%). Mysids are small shrimp like crustaceans. Mysids were observed at stations 3 and 7. Mysids were present only during the pre-monsoon period with a mean percentage composition of (0.02%).

Cumaceans are small crustaceans with large swollen anterior carapace and a thin forked tail. They are primarily benthic and enter the water column, where pairing and mating occur. Out of the nine stations, cumaceans were observed only from two stations. They were present in the pre-monsoon period (0.30%) and monsoon period (0.60%).

Insects are accidently caught during plankton sampling. Among the more common insects are dipterans and their larvae. Insects were present in all stations except 1, 3 and 6. Their representatives were present during the post-monsoon period (0.05%) and monsoon period (0.11%) period. Sagitta comes under the phylum- chaetognatha (arrow worms). *Sagitta sp* was recorded during the pre-monsoon period at station 7 in April 2011. *Sagitta sp* was present only in April 2011 at station 7.

Larvaceans such as *Oikopleura* is a holoplankton comes under the phylum urochordata. Planktivorous fishes (including many fish larvae), arrow worms and jelly fishes prey on larvaceans. *Oikopleura* were recorded from stations 1,2,4 and 6. *Oikopleura* were present only during the post-monsoon period (0.08%).

Icthyoplankton, fish eggs and larvae are common meroplankton in estuaries and near shore areas. Most fishes release eggs into the water column. Fish eggs are usually spherical from 0.5 to 2 mm and highly transparent. The number of fish eggs varied from 0 to 640 ind m^{-3}. The maximum numerical abundance of fish eggs were observed at station 1.The fish eggs were completely absent at stations 8 and 9. The seasonal mean percentage composition of fish eggs was minimum during the monsoon period (0.08%) and maximum during the post-monsoon period (0.70%).

The most characteristic larval stage of decapods is the zoea. The zoea were completely absent in the northern zone of the estuary. The zoea was present during the pre-monsoon period (0.07%) and post-monsoon period (0.07%) period.

Nematodes are non segmented benthic worms and frequently swept into plankton especially in shallow areas with high turbulence. Nematodes were higher on numerical abundance during the 2009-10 period (381 ind m^{-3}) compared to the 2010-11 period (233 ind m^{-3}). The mean seasonal percentage composition of nematodes varied from 0.54% during the pre-monsoon period to 2.88% during the post-monsoon period.

The class- actinopoda comes under the phylum protozoa. The actinopoda group was observed in only three months of the entire study period (March 2010, February 2010 and November 2009). They were present only in the post-monsoon period (0.96%) and pre-monsoon period (0.60%) periods.Vorticella is a genus of protozoa. They are stalked bell shaped ciliates.Vorticella was recorded only at station 9. They were present only in the post-monsoon period (0.01%).

Phylum echinodermata contains many coastal and estuarine echinoderms have a planktonic larvae namely pleuteus and bipinnaria. The members of the order-cladocerans are small semi transparent constantly swimming members of holoplankton. Echinoderm larvae and cladocerans were present at stations 3 and 7 respectively. The echinoderm larvae representatives were present only during the pre-monsoon period (0.01%). Cladocerans were observed at station 7 and only during the pre-monsoon period (0.01%).

5.4.4 Secondary productivity

5.4.4.1 Zooplankton carbon

The mean zooplankton carbon of the Cochin estuary was 254.55 ± 89.98 mgC m^{-3} during the 2009-11period. The seasonal fluctuations were not pronounced. The maximum value was recorded during the pre-monsoon period (287.96 mgC m^{-3}) and the minimum during the post-monsoon period (218.13mgC m^{-3}). Lowest zooplankton carbon in the monsoon period was observed at station 6 in August 2009 (57 mgC m^{-3}) and the same value was recorded from station 8 in June 2010 (57 mgC m^{-3}).

The maximum value recorded during the monsoon period was 1254 mgC m^{-3}. In the post-monsoon period, the zooplankton carbon ranged from 57.00 mgC m^{-3} at station 5 to 684 mgC m^{-3} at station 7, both the minimum and maximum was recorded in October 2009. In the pre-monsoon period, the zooplankton carbon was lowest in February 2010 at station 8 (28.50 mgC m^{-3}) and highest in April 2011 at station 5 (2280 mgC m^{-3}).

The zooplankton carbon was higher in the southern zone (289.59 ± 39.37 mgC m^{-3}) of the estuary and lower in the northern zone (217.40 ± 39.37 mgC m^{-3}) of the estuary. In the central zone the zooplankton carbon in station 1 was low (175.43 mgC m^{-3}) compared to stations 4 and 5. Stations 4 and 5 had similar values for zooplankton carbon (330.77 mgC m^{-3}; 335.98 ± 91.23 mgC m^{-3}). In the northern zone, zooplankton carbon was lowest at station 8 (139.34 ± 58.29 mgC m^{-3}). Mean station wise values showed the maximum at station 3 (336.13 ± 71.76 mgC m^{-3}) and minimum at station 8 (139.34 ± 71.76 mgC m^{-3}). The station wise variation of zooplankton carbon is presented in Table 5.5.2.

The zooplankton carbon was slightly higher during the 2010-11 period (286.20 ± 111.23 mgC m^{-3}) compared to the 2009-10 period (229.90 ± 48.69 mgC m^{-3}). Mean monthly values of zooplankton carbon ranged from 126.67 mgC m^{-3} in July 2009 to 532 mgC m^{-3} in April 2011. It ranged from 126.67 mgC m^{-3} in July 2009 to 289.43 mgC m^{-3} in March 2010 during the 2009-10 period. In 2010-11, the values ranged from 163.08 mgC m^{-3} in January 2011 to 532.00 mgC m^{-3} in April 2011.

ANOVA of zooplankton carbon was significant at 1% level between stations ($p \leq 0.01$) (Table 5.5.3).

Table 5.5.1 Mean season wise variation of zooplankton carbon in selected stations of Cochin estuary during 2009-11 period

Stations	Monsoon period (Mean±SD)		Post-monsoon period (Mean±SD)		Pre-monsoon period (Mean±SD)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
1	142.5±61.57	245.1±226.76	185.25±71.72	128.25±41.95	199.5±57	151.98±48.44
2	190.02±107.48	299.25±97.35	242.25±85.5	213.75±30.78	270.75±54.57	242.25±95.24
3	294.48±128.16	570±354.44	205.2±87.81	206.13±17.47	441.75±204.86	299.25±100.76
4	222.3±86.19	384.75±247.91	277.88±136.43	282.65±3.36	413.25±126.39	403.77±6.72
5	218.52±88.1	285±167.8	185.25±97.35	194.73±70.13	193.8±25.91	938.58±950.44
6	76.02±13.44	256.5±57	242.25±107.9	213.75±30.78	185.25±28.5	346.77±238.54
7	136.8±67.12	242.25±54.57	356.25±264.81	204.27±108.11	230.85±42.02	209.97±27.57
8	161.52±88.1	171±104.07	142.5±32.91	142.5±23.27	106.88±58.75	111.65±46.66
9	212.82±21.5	527.25±499.9	299.25±156.97	204.27±88.86	185.25±28.5	251.73±47.02

Table 5.5.2 Mean station wise variation of zooplankton carbon (minimum-maximum) in selected stations of Cochin estuary during 2009-11 period

Stations	Min	Max
1	68.40	570.00
2	114.00	399.00
3	79.80	1083.00
4	85.50	741.00
5	57.00	2280.00
6	57.00	684.00
7	68.40	684.00
8	28.50	285.00
9	85.50	1254.00

Table 5.5.3 ANOVA of zooplankton carbon in selected stations of Cochin estuary during 2009-11 period

Source	df	Mean Square	F
Model	26	82008.999	2.102
Season	2	88249.113	2.261
Station	8	123601.460	3.167**
Season * Station	16	60432.754	1.549
Error	189	39023.039	
Total	216		
R^2=0.224			

** Variation is significant at 1% level

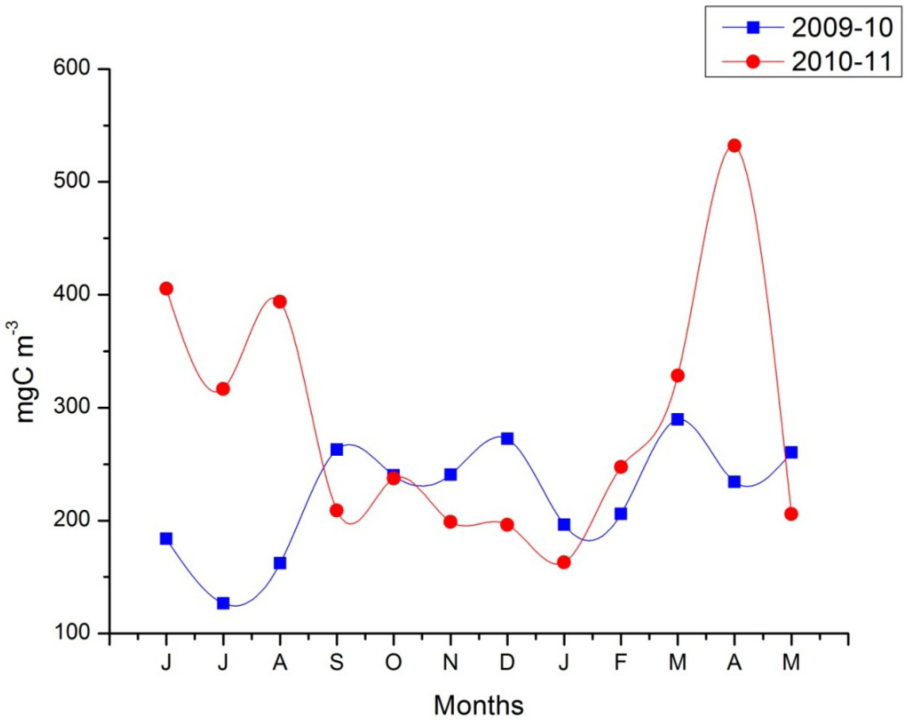


Fig. 5.11. Mean monthly variation of zooplankton carbon in Cochin estuary during 2009-11 period

5.4.4.2 Column secondary productivity

The secondary productivity was found to be higher during the pre-monsoon period (7.03±0.80 mgC m^{-2} d^{-1} and low during the post-monsoon period (5.04±0.80 mgC m^{-2} d^{-1}). During the monsoon period, the secondary productivity ranged from 3.19±1.35 mgC m^{-2} d^{-1} in July 2009 to 9.91±2.27 mgC m^{-2} d^{-1} in August 2009. During the post-monsoon period, it varied between 4.10±0.77 mgC m^{-2} d^{-1} in January 2011 to 6.85±0.78 mgC m^{-2} d^{-1} in December 2009. During the pre-monsoon period, the lowest secondary production was recorded in February 2010 (4.68± 1.12 mgC m^{-2} d^{-1}) and highest in April 2011 (12.96±3.57 mgC m^{-2} d^{-1}). The zooplankton secondary production was higher during the 2010-11 period (84.73 mgC m^{-2} d^{-1}) compared to the 2009-10 period (66.06 mgC m^{-2} d^{-1}).

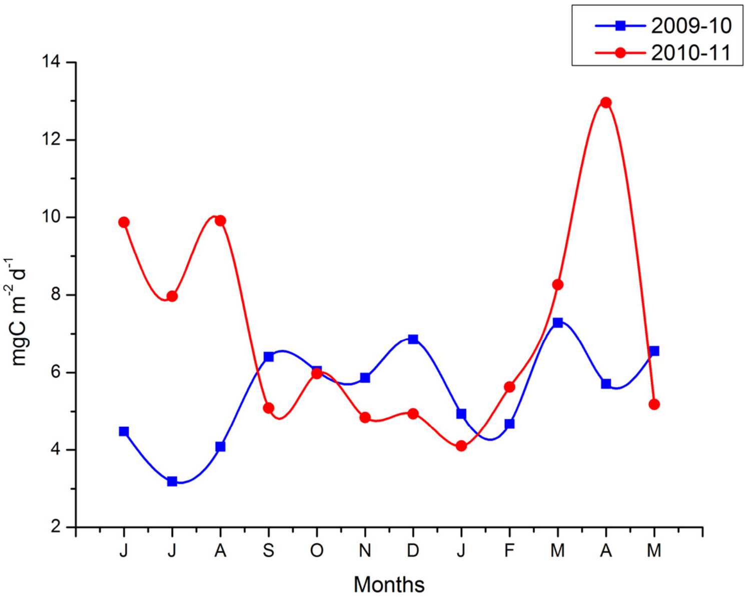


Fig. 5.12. Mean monthly variation of zooplankton carbon in Cochin estuary during 2009-11 period

5.4.5 Data analysis

5.4.5.1 Univariate analysis of zooplankton community structure

The station wise variation of diversity of zooplankton was compared (Fig.5.13). Maximum richness (d) and Shannon diversity index H'log (2) was recorded at station 7. The species richness (d) was minimum at station 8 but the evenness (J') was high. The evenness index (J') was lowest at station 2. The Shannon diversity H'log (2) was also lowest at station 2.

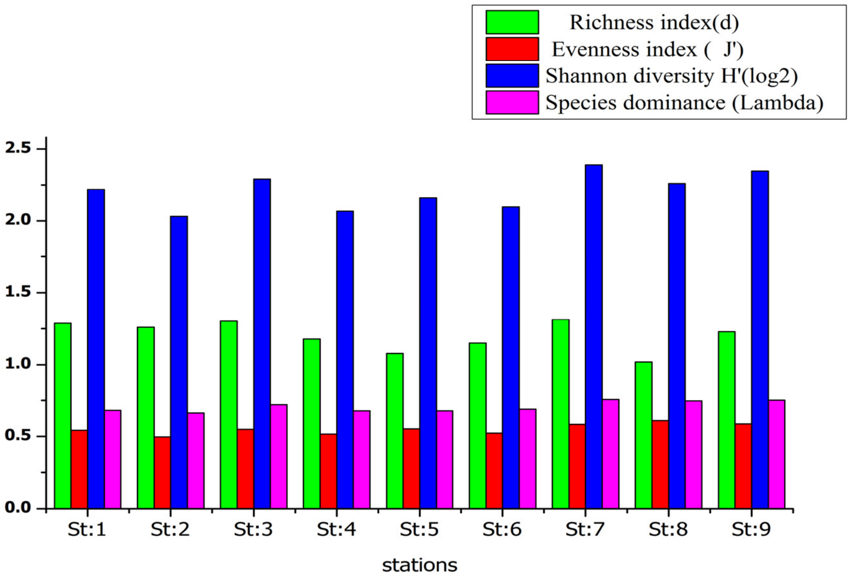


Fig. 5.13. Mean station wise variation of diversity indices of zooplankton abundance in nine stations of Cochin estuary during 2009-11 period

The mean monthly numerical abundance of zooplankton groups were analysed to understand the diversity of the study region (Fig.5.14). Richness (d) was higher in January and May (1.24) and lower in June (0.20). Evenness index (J') was maximum in October (0.80) and minimum in August and May (0.49). The Shannon diversity index, H'log (2) and the dominance index was minimum in June (H'log (2) =1.23; dominance index= 0.51). The Shannon diversity index H'log (2) is high in February (2.37); species dominance was high in February and November (0.77).

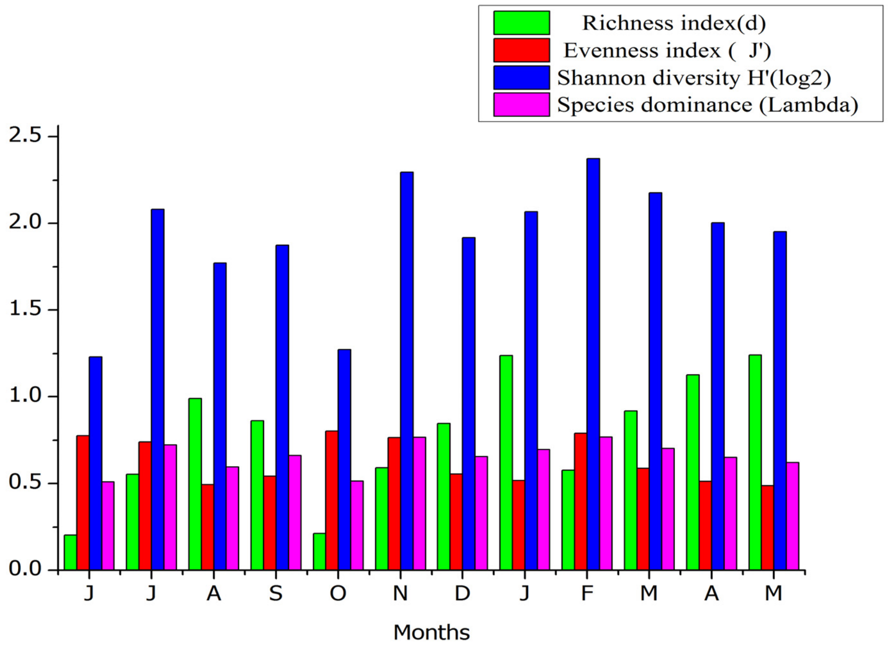


Fig. 5.14. Mean month wise variation of diversity indices of zooplankton abundance in nine stations of Cochin estuary during 2009-11 period

The mean seasonal numerical abundance of zooplankton groups were analysed to understand the diversity of the study region (Fig.5.15). The mean seasonal abundance of zooplankton showed the highest values of richness (d), Shannon diversity index (H'log (2) and species dominance in the pre-monsoon period (d=1.51, H'log (2) =2.36 and λ=0.75 respectively). Evenness index (J') was highest in the post-monsoon period (J'=0.54). All the diversity indices were lowest during the monsoon period (d=1.29, H'log (2) =2.01; λ=0.67; J'= 0.49).

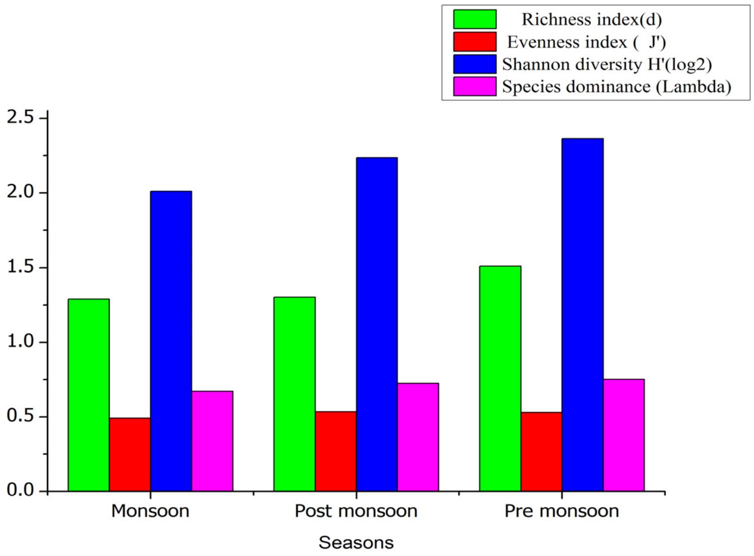


Fig. 5.15. Mean season wise variation of diversity indices of zooplankton identified from Cochin estuary during 2009-11 period

5.4.5.2 MDS analysis of zooplankton community structure

The MDS analysis of mean seasonal numerical abundance of zooplankton indicated the similarity between stations in different seasons (Fig.5.16). The two-dimensional plots had a stress value below 0.1 for pre-monsoon period and post-monsoon period, which corresponds to a good ordination. In the monsoon period, the stress value is below 0.2 which can also be used to represent good inter-relationships. In the monsoon period season, the stations2, 4 and 5 form one subset while stations 7 and 8 form another. In the pre-monsoon period, stations 2,3,4 and 5 form one subset while stations 6, 7 and 9 form the second subset. In the post-monsoon period, stations 1,2,3,4,5,6 and 8 form a single subset. The post-monsoon period showed the maximum similarity between stations, which may be influenced by the freshwater discharge from the northeast monsoon period.

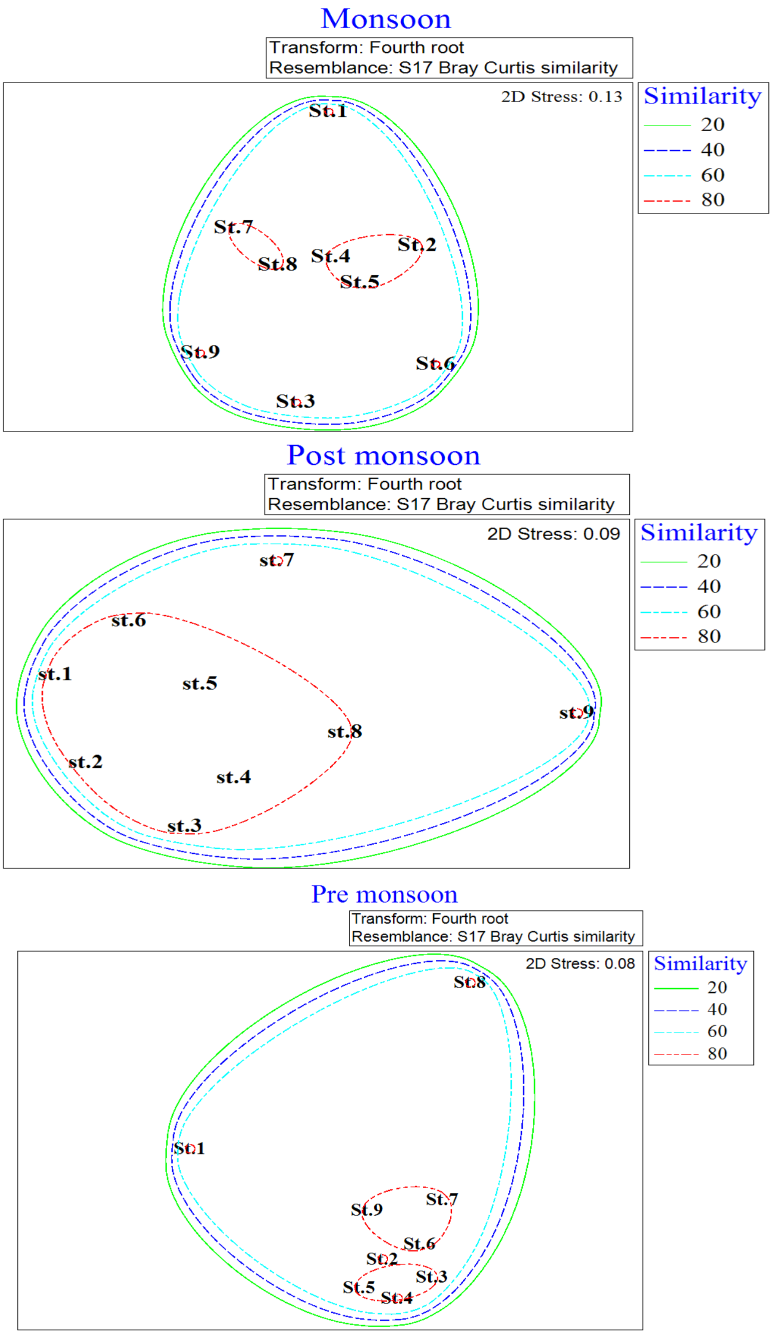


Fig. 5.16. MDS plot of mean season wise numerical abundance of zooplankton in Cochin estuary during 2009-11 period

5.4.5.3 BEST Analysis

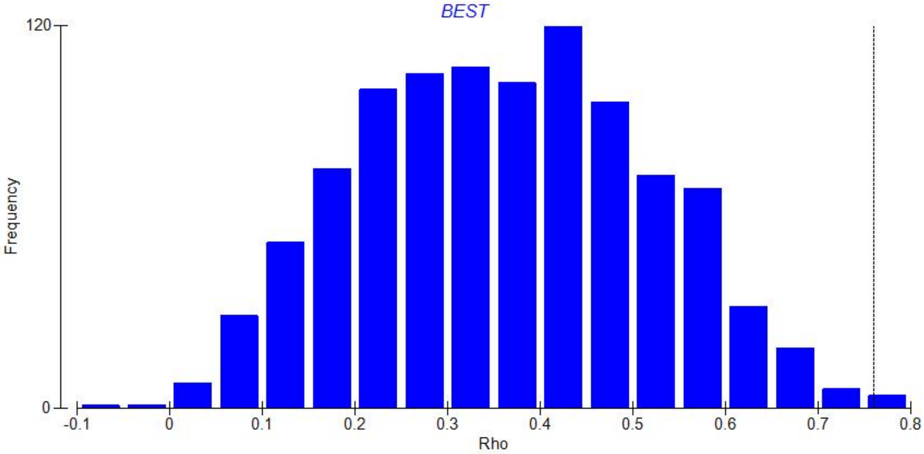
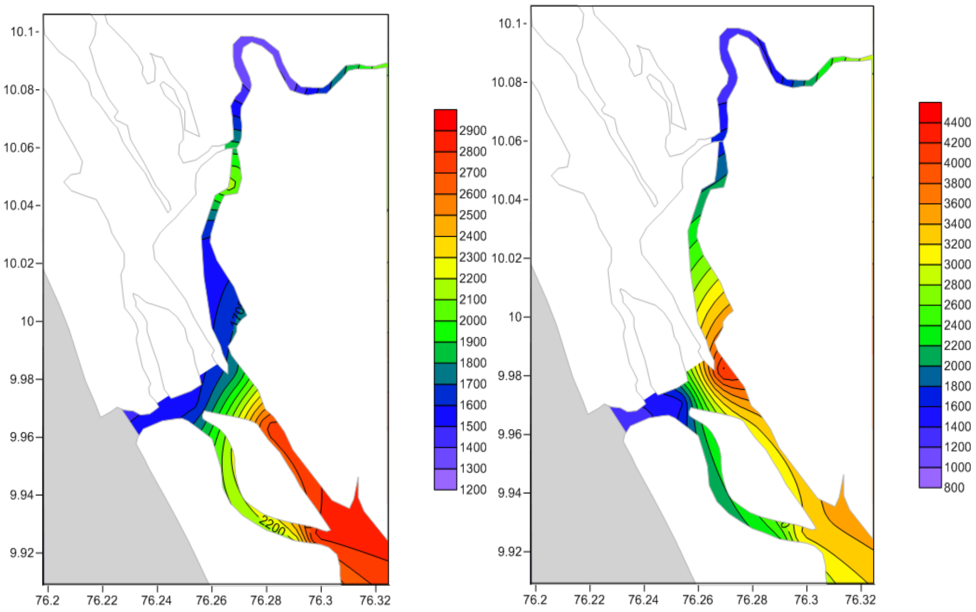


Fig. 5.17. BEST analysis of zooplankton with water quality parameters in the Cochin estuary during 2009-11 period

Table 5.6 BEST analysis of zooplankton with the water quality parameters in the Cochin estuary during 2009-11 period

	Variables	Variables selected	Best correlation values (Rho)
1	Water temperature	3,4,5,10	0.761
2	pH	2,3,4,5,10	0.753
3	Dissolved oxygen	2,3,4,10	0.750
4	Salinity	3,4,5,9,10	0.747
5	Turbidity	3,4	0.743
6	Biological oxygen demand	3,4,10	0.742
7	Phosphate	2,4,5,9,10	0.741
8	Nitrate	2,4,5,10	0.741
9	Ammonia	4,5,7,10	0.738
10	Chlorophyll a	2,4	0.733

The BEST analysis of zooplankton abundance with various environmental parameters such as water temperature, dissolved oxygen, salinity, turbidity, biological oxygen demand, phosphate, nitrate, ammonia and chlorophyll a was done. It showed that the interaction between the dissolved oxygen, salinity, turbidity and chlorophyll a significantly affected the zooplankton abundance and distribution, with a correlation value of 0.761. The second correlation value was 0.753, between pH, salinity, dissolved oxygen, turbidity and chlorophyll a. The environmental interaction between pH, dissolved oxygen, salinity and chlorophyll a were less significant in affecting the zooplankton distribution, with a correlation of 0.750. The analysis was found to be significant at 0.2% with a rho value of 0.761(Table 5.6).



2009-10 **2010-11**

Fig. 5.18. Distribution of annual variation of secondary production in Cochin estuary during 2009-11 period

Table 5.7 Composition, distribution and mean cell density of zooplankton in Cochin estuary during 2009-11 period

	J	J	A	S	O	N	D	J	F	M	A	M
Polychaete larvae	0	0	0	280	0	960	240	720	3000	2560	1060	626
Gastropod Veligers	0	0	765	0	0	0	960	510	0	0	5175	1440
Bivalve veligers	0	0	1543	360	0	0	880	780	0	20480	21715	14898
Foraminifera	0	0	80	0	0	960	0	0	6600	15040	482	1588
Tintinnids	0	3030	2333	12000	0	0	14880	16160	21300	27840	2715	540
Rotifers	1500	11340	598	8370	1500	29120	9440	20820	36300	218240	31845	24816
Ostracods	0	0	2143	360	0	0	0	820	0	0	2025	3200
Barnacle nauplii	0	0	0	0	0	0	0	0	0	0	750	80
Copepods	11100	19280	19748	34650	7200	43200	38240	69810	61200	98140	51355	26908
Mysids	0	0	0	10	0	0	0	0	0	0	0	80
Cumaceans	0	0	1650	0	0	0	0	0	0	0	0	1288
Isopods	0	0	85	80	0	0	0	10	0	0	200	260
Amphipods	0	0	0	10	0	1600	0	1760	0	640	40	220
Insecta	0	0	283	0	0	0	160	10	0	0	0	0
Sagitta	0	0	0	0	0	0	0	0	0	0	225	0
Oikopleura	0	0	0	0	0	0	240	160	0	0	0	0
Fish eggs	0	160	10	0	0	0	400	970	0	0	730	216
Crustacean nauplii	4800	14780	37200	50960	2400	38720	66720	66070	51900	79360	134335	101770
Zoea	0	0	0	0	0	0	0	160	0	0	300	170
Vorticella	0	0	0	0	0	0	0	10	0	0	0	0
Daphnia	0	2240	0	0	0	0	0	0	0	320	0	0
Nematods	0	780	0	2240	0	17920	2720	2560	5400	1600	0	0
Actinopoda	0	0	0	0	0	8320	0	0	3900	3520	0	0
Echinoderm larvae	0	0	0	0	0	0	0	0	0	320	0	0
cladocera	0	0	0	0	0	0	0	0	0	320	0	0

5.5 Discussion

Since the water mass of an estuary are in everchanging dynamic balance, depending on the interaction of river runoff and tidal currents. So the faunal composition of zooplankton in the estuaries varies from time and place. The faunal diversity of the zooplankton is greatly controlled by salinity. The zooplankton community plays an important role in maintaining the high productivity of estuaries by providing nutrients, by the decomposition of fecal pellets. They occupy an important position in the food web by transferring organic carbon from phytoplankton to higher trophic levels.

The biomass and the total count of zooplankton were not always correlated in the Cochin estuary during the study period. This was due to the occurrence of small organisms like crustacean nauplii and various larval forms which accounted for most of the numerical counts. Silas and Pillai (1975) recorded twenty three major zooplankton taxa from the Cochin backwaters. In the present study, twenty five groups of zooplankton taxa were identified**.**The mean monthly numerical abundance was maximum in March 2010 (187200 ind m^{-3}) and minimum in April 2009 (20 ind m^{-3}). Monthly mean abundance of total zooplankton varied remarkably, with the range from 20 ind m^{-3} to 19,600 ind m^{-3} in the Han river estuary in SouthKorea (Youn and Choi, 2008).

The total numerical abundance of zooplankton showed a significant relation between seasons, between stations and between seasons and stations. This indicates the abundance of zooplankton, is influenced by the run-off from the rivers and the exchange ratio; additionally, tidal currents transport plankton populations. According to Vargheese and Krishna (2009), the ANOVA test showed that zooplankton abundance varied significantly between stations. Pillai et al. (1975) reported that zooplankton counts were found to be highly significant between months. In the present study, spatial and seasonal variations were highly significant.

The zooplankton abundance was high during the pre- monsoon period. About 90% of the common species occurring in the estuary registered their peak abundance during this period (Vargheese and Krishna, 2009, Madhu et al., 2007, Haridevi et al., 2004, Karuppaswamy and Perumal, 2000, Vareethiah, 1999; Srinivasan and Santhanam, 1991, Madhupratap and Haridas, 1975, Rao et al., 1975, Nair and Tranter, 1971). In the present study, the same pattern of seasonal changes was observed. Madhupratap et al. (1978) reported that higher biomass and numerical abundance of zooplankton during the pre-monsoon period from the Cochin backwaters. It is mainly due to the homogeneous condition in vertical distribution of salinity, temperature and oxygen occurred during the pre-monsoon period and changes from the tidal influence were minimal during this season. Menon et al. (2000) reported that during the pre-monsoon period, higher temperature and salinity in the estuary allows the migration of a large number of marine species into the estuary. The migration of large number of species into the estuary contributes to total zooplankton. Zooplankton density decreased during the monsoon period as the water becomes practically fresh and renders it unstable for the sustenance of zooplankton, except for a few low saline species. Divakaran et al. (1982) reported the seasonal peak from the Ashtamudi estuary, during post- monsoon period.

During the succession of zooplankton, many groups and species appear in a sequence and a few communities among them tend to dominate in the estuary. The percentage of dominance may vary, but typically a few species together constitute the major component of the population. In the present study, crustacean nauplii showed the highest numerical abundance in all the seasons. The dominance of nauplii may be due to their wide range of salinity tolerance. According to Odum (1971), the whole sequence of communities that replace one another in a given area tends to modify the physical environments, making conditions favourable for other populations until equilibrium between biotic and abiotic factors is achieved. Succession of species result in a long term evolutionary development of the ecosystem, namely an increased control of, or homeostasis with the physical environment in the sense of achieving maximum protection from its perturbations (Odum,1971). Bijoy Nandan (1991) studied the seasonal succession of zooplankton in Kadinamkulam backwaters.

The dominance of copepods among the zooplankton groups were reported by several researchers (Pansera et al., 2014; Madhu et al., 2007; Qasim et al., 2005; Karuppaswamy and Perumal, 2000; Mishra and Panigraphy, 1999; Padmavati and Goswami, 1996; Devi et al., 1992; Nair and Azis, 1987; Nagarajaiah and Gupta, 1985; Sarkar et al., 1984; Haridas et al., 1980; Gajbhiye et al., 1981; Madhupratap, 1978; Wellershaus, 1974). But, Bijoy Nandan and Abdul Azis (1994) recorded rotifers and copepods as the major groups while studying the retting zones in the Kadinamkulam estuary. Patil et al.(2002) noticed that rotifers, nauplii, copepods and eggs were dominant in the Ulhas river estuary. Vargheese and Krishna (2009) reported that rotifers and copepods dominated in the Cochin backwaters. In the present study, the crustacean nauplii, followed by the copepods, dominated in the estuary. The dominance of zooplankton can be due to the type of the ecosystem under study, or due to the mesh size of the net used for collecting zooplankton (Vargheese and Krishna, 2009).Intxaustiet al. (2012)identified copepodian assemblages, cnidarians, appendicularians, meroplanktonic larvae (polychaetes, gastropods, bivalves, cirripeds and echinoderms)cladocerans, doliolids, tintinnids and rotifers from the Bilbao estuary. Most of these taxa were also identified from the Cochin estuary during the present study.

Polychaete larvae have also been related to hypoxic conditions in other areas such as the northern Gulf of Mexico, where they were found to be more abundant in the hypoxic bottom waters (Kimmel et al., 2010). Polychaete larvae were found to be one of the most sensitive meroplankton groups to environmental stresses in the Sevastopol Bay between Ukraine and Russia (Pavlova et al., 2007). The response of meroplanktonic groups in an estuary is influenced by the environmental stresses to that particular region. The presence of polycahete larvae in the study area may be an indication of environmental stress in the region. In the present study rotifers were abundant in the northern zone of the estuary. Rotifer abundance and diversity increase with decreasing salinity. The higher abundance of fish eggs was observed at station 1, near barmouth. It may be due to the fresh and salt water interface in the mouth of the estuary make a suitable spawning area for the adult fishes. Chaetognaths abundance during pre monsoon was reported in the earlier works by Gajbhiye et al. (1981) from the Narmada estuary and Naik et al. (2008) from the Chilka lagoon. In the present study also chaetognaths were abundant during the pre-monsoon period may be due to the high temperature and salinity.

In the present study BEST analysis of zooplankton distribution in the estuary is related with the water quality parameters like salinity, dissolved oxygen, turbidity and chlorophyll a. In most estuaries, common patterns of zooplankton variability are more consistent spatially than temporally, and are mainly related to salinity and distance from the mouth (e.g. Elliott and Kaufmann, 2007; Speckman et al., 2005), because different assemblages of species remain spatially segregated within the estuary. Salinity is the major factor controlling the distribution of zooplankton in the Cochin backwaters. The zooplankton numerical abundance was found to be very high during the pre-monsoon period season and minimum during other seasons in the Cochin estuary. The pre-monsoon period season was characterized by the weakening of estuarine flow, facilitating increased biological activities. The pre- monsoon period also transformed the estuary into marine conditions encouraging the proliferation of microzooplankton. This was observed by several researchers: Wellershaus(1974), Pillai et al.(1975), Rao et al. (1975), Natarajan and Gupta(1985), Madhupratap(1987), Madhu et al. (2007), Youn and Choi(2008); Vargheese and Krishna(2009). Salinity and temperature together control the distribution of organisms in the estuary by regulating the metabolism and osmosis (Kinne, 1967). Intxausti et al. (2012) reported that a higher abundance of smallzooplankton was correlated with the temperature and the amount of chlorophyll a in the Bilbao estuary.

In the present study, seasonally the dissolved oxygen values were higher during the post-monsoon period and low during pre- monsoon period in the Cochin estuary. The post- monsoon maxima of dissolved oxygen is coupled with the higher autotrophic production in the estuary, maximum gross production and mean cell density of phytoplankton was high during post-monsoon period. The dissolved oxygen minimum during pre-monsoon might be due to the enhancement of heterotrophic production in the estuary. Weakened river flow during this period resulted in the decrease in dissolved oxygen. This result was supported by the findings of Iriarte et al., 2010 from the estuaries of Bay of Biscay.

The inter-annual variation of zooplankton is greatly influenced by rainfall pattern, river flow and salinity zonation. The rainfall pattern controls the turbidity of the estuary.It was low during the pre-monsoon period and post-monsoon period. The temperature and phytoplankton biomass (chlorophyll a) may be the major factors driving the year-to-year variability in zooplankton abundance.

The biological production of herbivorous organisms that feed or graze on autotrophs is called secondary production. The secondary production by the zooplankton of the Cochin estuary was 75.40 mgC $m^{-2}d^{-1}$and the annual secondary production was 2287 mgC $m^{-2}y^{-1}$. The secondary production of our study area was 155.17 tonnes carbon y^{-1}. Madhupratap et al., 1977 and Selvakumar et al., 1980 estimated the secondary production of the Cochin estuary as 3770 tonnes carbon y^{-1}and 1078 tonnes carbon y^{-1}from the Mandovi-Zuari estuary. The highest rate of secondary productivity was observed during the pre-monsoon period season. Selvakumar et al., 1980 reported that the high salinity period of the Mandovi-Zuari estuary showed more secondary production compared to the low salinity period. Nair et al., 1983 observed that the secondary production of the Zuari estuary varied from 52 to 1388 mgC 100 m^{-3} d^{-1} with a mean of 218 mgC 100 m^{-3} d^{-1}. According to Gajbhiye et al., 1981 the zooplankton production in the Narmada estuary was 24.47 mgC m^{-3} d^{-1}, which can sustain an estimated fish potential of 25.33 × 10^{3} tonnes. Bhattathiri et al., 1976 reported a secondary production of 41 mgC m^{-2} d^{-}1 from the Mandovi-Zuari estuary. According to Selvaraj and Sreenivasan, 1996, the overall secondary production in the continental shelf and slope off the northeast coast of India was 0.430 gC m^{-2} d $^{-1}$. According to Mann, 2000 secondary production of net zooplankton in the range of 5-10 gC m^{-2} d $^{-1}$.

In the present study the annual column production was 2437.52 gC m^{-2} d $^{-1}$ and the secondary production by zooplankton was 2287 mgC m^{-2} y $^{-1}$. Clearly, net zooplankton is not utilizing a very large proportion of the phytoplankton production. The wide gap in the primary and secondary production indicates a large amount of primary production left in the estuary, which is not effectively utilized due to the lack of zooplankton herbivores. It sinks to the bottom and produces anaerobic conditions (Qasim et al., 1969). According to Mann, 2000 the gap in the phytoplankton production and zooplankton production in the estuaries may be due to various reasons: 1) net zooplankton feed on only a subset of the various sizes of phytoplankton, 2) estuarine zooplankton consume a lot of detritus, and 3) there is a mismatch between the time scales of events in the phytoplankton and zooplankton. Phytoplankton which under favourable conditions divide about once a day can make use of the short bursts of nutrient availability. The microzooplankton populations, made up of individuals that require a month or so to complete life cycle, are not able to enough to take the full advantage of short-term fluctuations phytoplankton availability. As a result much of the phytoplankton production sinks to the bottom and is utilized by benthic communities.

Zooplankton of the estuaries may be a better indicator of climate change than marine zooplankton because the estuarine environment is more affected by changes in air temperature and precipitation than the open sea (Intxausti et al., 2012). During our present study 2009-10 period was hotter than 2010-11 period with low rainfall and river discharge. The major nutrients in the estuary like phosphate, nitrite, nitrate and silicate) was high during 2009-10 period. The zooplankton biomass and column secondary production was low during 2009-10 period. It may have implications on the climatic fluctuations in the estuary. The water column contains high amount of nutrients, but the increased water temperature makes the inefficient utilization of it by the plankton communities, resulting in low biomass and secondary production at the secondary level. Increased heating can enhance existing stratification, reducing the availability of nutrients in the surface (Richardson and Schoeman, 2004). Under such conditions plankton community is dominated by picoplankton and flagellates, which are mostly grazed by heterotrophic protists, small crustaceans and gelatinous zooplankton (Ryther, 1969; Iverson, 1990; Pauly and Christensen, 1995; Richardson, 2008). This long and inefficient food web has lower nutritional quality, supporting less production at higher trophic levels. Summarising, nutrient concentration in the marine environment is the main factor defining the local food web, and water temperature is a valuable proxy for nutrient enrichment (Arias and Menendez, 2014).

The ratio of carbon transfer from phytoplankton to zooplankton was calculated. In the present study, it was high during the post-monsoon period, but very low during the pre-monsoon period. Madhu et al., 2007 reported that the transfer efficiency was quite high during monsoon period and post-monsoon period, but became low during pre-monsoon period. During the period of fresh water dominance, a substantial amount of carbon remains unconsumed due to the lack of grazers. Qasim et al., 1969 stated that the average rate of consumption from the daily net production works out as 10% of the production by the plants during the monsoon period months, 20% during the post-monsoon period months and 46% during the pre-monsoon period months. Our present study revealed that the transfer efficiency was high during the monsoon period season. The coefficient of energy transfer was 7.4% for Cochin backwaters and 6.6% for the Mandovi-Zuari estuaries (Selvakumar et al., 1980). In the present study, the transfer ratio was approximately 24%. During the last decades, the efficiency has increased significantly, which may be due to the reason that zooplankton communities exhibiting herbivory have shifted to omnivory or carnivory.

The mean monthly variation of numerical abundance of phytoplankton and zooplankton showed in Fig.5.19. The figure showed that phytoplankton abundance and carbon content was higher compared to zooplankton. The increased phytoplankton abundance may be due to release from grazing pressure. On an annual basis, the zooplankton community grazed approximately 38-45% of daily phytoplankton production (Mallin and Paerl, 1994). The zooplankton grazing in the Cochin estuary was not studied in the present study. In a planktonic system dominated by easily grazed and assimilated phytoplankton species, trophic efficiency should be high, which should contribute to greater secondary and tertiary production (Ryther 1969). According to Palmeri et al., 2014, the lagged oscillation of predator (zooplankton) and prey (phytoplankton) abundance is typical feature of top-down dynamics. Grazing of zooplankton limit the population of primary producers is called top-down control. The opposite situation is that bottom-up control by primary producers on grazers, meaning that the biomass of herbivorous organisms is limited by the availability of food. The bottom-up control of pelagic ecosystem was an unchallenged dogma for decades. Now the presence of top-down control by zooplankton on phytoplankton has been demonstrated in large marine ecosystems (Daskalov, 2002). The present observation revealed the top-down control of Cochin estuary.

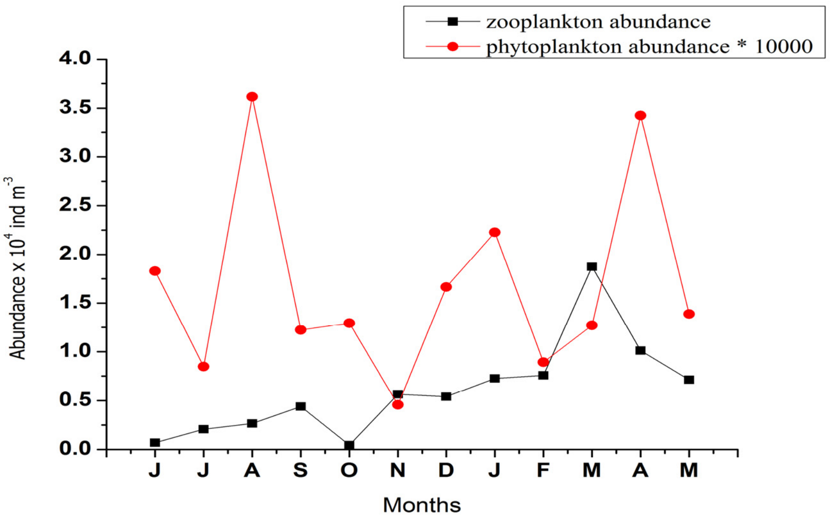


Fig. 5.19. Mean monthly variation of phytoplankton and zooplankton numerical abundance in Cochin estuary during 2009-11 period

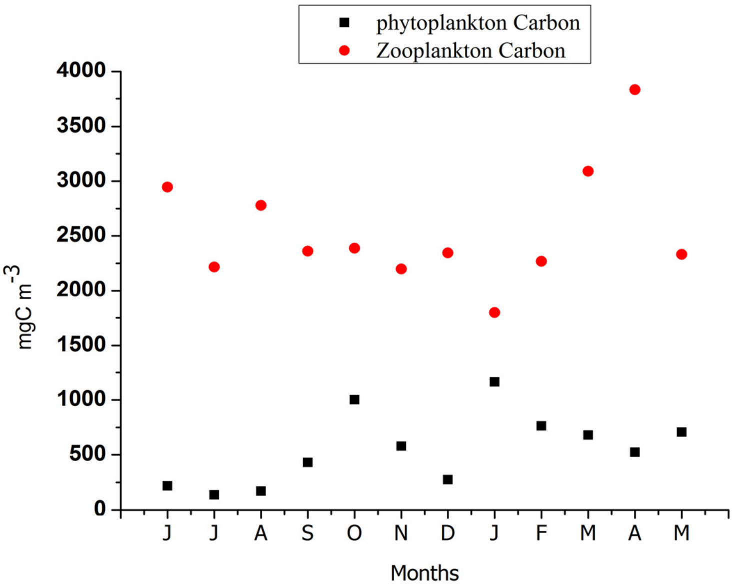


Fig. 5.20. Mean monthly variation of phytoplankton and zooplankton carbon in Cochin estuary during 2009-11

The mean monthly variation of zooplankton carbon and phytoplankton carbon is presented in the Fig.5.20. The zooplankton carbon content was high compared to phytoplankton carbon, might be due high biomass of zooplankton, contribute to high carbon content. The phytoplankton carbon content is kept by a delicate balance with the zooplankton carbon; there is a considerable time lag between increase in phytoplankton and the rise in zooplankton. By considering secondary production of herbivorous zooplankton alone in the Cochin estuary give more details into the trophic structure of the system than taking zooplankton as whole.

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Chapter 6

FISHERY PRODUCTION AND TERTIARY LEVEL ENERGY TRANSFER IN COCHIN ESTUARY

Contents

6.1 Introduction

Coastal ecosystems support a rich variety of fishes, providing breeding and feeding grounds to a large proportion of fishery species. Approximately 8% of the world's aquatic primary production is utilized to sustain the global fisheries. The bulk of the aquatic productivity occurs in the open ocean (75%). Of the remaining, only 8.3% was estimated for coral reef and coastal ecosystems.

The environmental issues related with the coastal ecosystems have significantly affected the fishery production. Eutrophication in estuarine ecosystems will increase the productivity up to a threshold, beyond which secondary productivity and tertiary production decline. The high valued species are caught in excess of twice the sustainable yield (overexploitation), decreasing the estuarine fish landings around the world. The ongoing climate changes such as global warming and changing rainfall patterns will affect the estuarine-dependent species, especially species like Mullets and some penaeid prawns.

Herbivores provide food for the first rank carnivorous animals is called tertiary production. In general, primary production is greater than secondary production, which in turn is greater than tertiary production. Organisms utilize a portion of the assimilated energy for respiration and growth. The energy lost in respiration is not available to the next trophic level. On an average, carnivorous lost about 60% of assimilated energy consumed for respiration. In aquatic ecosystems, trophic transfer efficiency can vary between 2% and 24% and an average of 10% efficiency was expected at each trophic level.

The high tertiary production of estuaries is largely supported by the primary production from phytoplankton. In mesotrophic and eutrophic systems, a large proportion of the system's energy moves along the classical food chain of phytoplankton-zooplankton-fish (Fenchel 1988). The composition, distribution and abundance of fishes were estimated in order to understand the trophic level and the major feeding pattern in the Cochin estuary, and the tertiary production potential and yield of the estuary was also estimated.

6.2 Review of literature

Fishery potential of the area has been studied by different authors. There are a few reports are available on the direct correlation of pelagic fishery to zooplankton and phytoplankton production. Ryther, 1966 used primary production estimates to calculate fishery potential of open ocean, coastal and upwelling regions. Cushing (1971) estimated the primary secondary and tertiary production in the upwelling areas. Trends in global and United States estuarine fishery yield were examined by Houde and Rutherford (1993). Hamerlynck and Hostens (1994) found out that the construction of a storm-surge barrier at the mouth of the Oosterschelde Estuary resulted in a decrease in the number of anadromous fishes in that system. Pauly and Christensen (1995) reported that the primary production required to support the fishery is 23.6% for tropical lakes and rivers. Marshall and Elliott (1998) used multivariate techniques to study the fish assemblages and its relation to the environmental parameters in the Humber estuary. The fish assemblages in the estuary are mainly influenced by salinity and temperature.

Pauly et al. (1998) introduced a new process in the fishery science, known as the “fishing down the marine food webs”. The process is that we first harvest the top food web species (high trophic level) and when they are depleted we move on to the bottom food web species (low trophic level species). Sumaila et al. (1998) reported that we cannot solely rely on the catch statistics from the market, to explain the fishing down process. Loneragan and Bunn (1999) reported that river flow is a key factor in determining the coastal fishery. Blabber et al.(2000) have taken a global perspective in synthesizing the effects of fishing on estuaries and coastal waters. Whitfield and Elliott (2002) conducted a study using fishes as indicators of ecological and environmental changes in the British estuaries.

In the four coastal lagoons of the Nile Delta, nutrient enrichment (especially DIN concentration) up to100µm helped in the enhancement of fishery landings. The landings declined exponentially beyond this threshold nutrient concentration. This may be due to the low dissolved oxygen concentration during the eutrophication period (Oczkowski and Nixon, 2008). Moreau et al. (2008) used the Ecopath model to study trophic interactions in Lake Kivu and to describe the possible impacts of exotic species in this ecosystem. Cardoso et al.(2011) used four multi-metric fish assemblage indices to examine the ecological status of five small estuarine systems from the Portuguese coast; and also to test if they reflected the level of anthropogenic pressures. Planktonic food webs dominated by small autotrophic cells channelled most of their available carbon to pelagic fish production, whereas food webs dominated by large phytoplankton were better suited to benthic communities with a large loss of carbon through sedimentation (Marquis et al., 2011).Wasserman and Strydom (2011) studied the estuarine head waters as nursery in estuaries of South Africa.

Becker et al. (2013) studied the effects of boat traffic on fish assemblages in estuaries. They reported that regular boat trafficking in estuaries significantly affected the displacement of mid-sized fish (301–500 mm). Blabber (2013) reviewed the fishes and fisheries in tropical estuaries for the period 2002-2012. Abrantes et al. (2015) reported that habitat-specific food web and trophic interactions supporting rich coastal fisheries.

Prasad and Nair (1963) investigated the organic production in the Gulf of Mannar. Murty(1985) reported that the pelagic fisheries along the Kerala-Karnataka coast are related with the zooplankton biomass and upwelling. Mannar and Goswami et al. (1985) made a check list of estuarine and marine fishes of Digha in West Bengal and identified 168 species from the region. Fishery potential along the Indian coastal waters between Ratnagiri and Porbandar was assessed by Gajbhiye et al. (1994). The impact of industrial effluent disposal on fishery resources of the Amba estuary in Maharashtra was studied by Gajbhiye et al. (1995). Sinha et al. (1996) studied the impact of Farakka barrage on the Ganga River on the hydrology and fishery of Hooghly estuary. Mathew et al. (1990) estimated the secondary production and tertiary production of the EEZ of India. An assessment of zooplankton biomass, secondary production and potential fishery resources of the EEZ of India was done by Goswami (1996). Bhargava (1996) computed the regional and seasonal biological production in the EEZ of India. Subramanian (2002) studied the prawn fishery along the Chennai coast in North Tamil Nadu. *Metapenaeusdobsoni* (664t, 20.5%), *Penaeusindicus* (491t, 15.20%), *Penaeusmaxilipedo* (392t, 12.10%), *Metapenaeusmonoceros* (305t, 3.45%). The magnitude and abundance of *Penaeusmaxilipedo* is unique. Vivekanandan et al.(2003) used the Ecopath model to study the trophic interactions in the southwest coast of India.

Nair and Krishnankutty(1975) demonstrated the physiological mechanism involved in the seaward migration and maturation of *Penaeusindicus*. Kuttyamma (1980) reported that major portions of the prawn catches of Kerala were comprised of *Penaeusindicus, Metapenaeusdobsoni*and *Metapenaeusmonoceros.*Nair et al. (1983) identified 67 species of fishes from the Kadinamkulam estuary and 97 species from the Ashtamudi estuary. A complete systematic list of the fishes of the Vembanad Lake and their frequency of occurrence was presented by Kurup(1982).Kurup and Samuel (1987) observed that when the salinity gets reduced rapidly during monsoon period, an abrupt reduction in the diversity of marine migrants occurs.

Apart from finfishes, Cochin backwaters also support rich shellfish fisheries. Kurup et al. (1990a) reported the occurrence of *Penaeussanguinolentus*in high saline areas. The molluscan and clam fishery of the VembanadLakewas studied by Kurup et al., (1990b,c). Pauly (1991) exclusively studied the commercially important fishing gears of the Vembanad Lake. Kurup et al. (1993) studied the exploited fishery resources of Vembanad Lake. Bijukumar and Sushama (2000) gave the first report on the icthyofauna of the Ponnaniestuary. Kurup and Harikrishnan (2000) discussed the reasons for the decline and revival of *Macrobranchiumrosenbergii* fishery in the Vembanad Lake. Thomas and Hridayanathan (2003) discussed the seasonal usage of different mesh sizes, species composition, size composition and proportion of the juveniles in the catch from canoes operating off Cochin estuary.

Kripa et al. (2004) studied the clam fisheries in the Vembanad Lake. Nandakumar et al. (2004) gave a general account on the shrimp fishery of the Cochin backwaters, based on the stake net catch landed at Thoppumpady and Vypin during a year. Thomas and Kurup (2004), investigated the padal fishing method in Ashtamudi estuary. Raju Kumar (2005) recorded 38 species of fishes from the Anchuthengu backwaters. Bhargavan et al. (2008) recorded 37 species from the Thottappally backwaters in Alleppey. The Vembanad backwater has been extensively studied on the composition, distribution and gear-wise catches of major fishery by Bijoy Nandan and Unnithan (2007). Mean trophic index of fish fauna in the trawl by catch of Kerala was estimated by Bijukumar and Deepthi (2009). Mid-level carnivores dominated in the trawl by catch, indicating the removal of top level predators from the ecosystem.

Girijakumar et al. (2011) presented the icthyofaunal diversity of the Sasthamkotta Lake. Harikrishnan et al. (2011) studied the exploited fishery resources of the Azheekode estuary. Renjithkumar et al. (2011) reported that, the annual average landings of Pamba River was estimated to be 394.22t. Highest landings were recorded during the pre-monsoon season and lowest in monsoon. Temporal changes in the fish landing pattern of Kodugallur-Azhikode estuaries were mainly due to environmentalvariability, habitat modification and fish migration; under the influence of south west monsoon period and anthropogenic activities in the Kodugallur-Azheekode estuary by Bijoy Nandan et al.(2012). Jayachandran et al. (2013) studied the influence of environmental factors on the fish assemblages in the Kodugallur-Azhikode estuary and observed that salinity, transparency and pH had a significant influence on the fish community. Asha et al. (2014) reported a drastic decline in the fishery stocks in the Vembanad estuary due to the lack of appropriate fishery resource management in the system. Nansimole et al. (2014) reported about 134 species of finfishes from four estuaries (Pozhiyoor, Adimalathura, Poonthura, Kappil) in the Trivandrum district of Kerala. Raj et al.(2014) reported that pollution, sand mining, loss of mangrove habitats and destructive fishing methods were the main reasons for loss of fishery diversity in AshtamudiLake. The market structure of Champakkara, Thoppumpady and Thevara were analysed by Salim and Rahman (2014). Monsoonal flood plain fishery and traditional fishing methods in Thrissur district, Kerala was studied by Shaji and Laladhas (2013). Approximately 8% of the total nine hundred and five species of fishes in Kerala were listed as threatened by the IUCN red list (Bijukumar and Raghavan, 2015).

6.3 Materials and methods

6.3.1 Fishery

Landing centre based data collection method and catch yield was used for the fish landing estimation (Sparre and Venema, 1992; Kurup et al., 1993; Gupta et al., 1997; Bijoy Nandan et al., 2012; Jayachandran et al., 2013). Fish landing data was collected fromnine major fish landing centres. Ernakulum Market, Thoppumpady, Champakkara, Thevara, Narakkal, Varapuzha, Arookutty, Fort Kochi and Kalamukku, around the estuary were selected for the monthly collection. The total catch in the landing centre were sorted into fin fishes and shell fishes. Catch composition and gear wise catch were also estimated. The species-wise identification of fish and shell fishes was done based on standard works of Talwar and Jhingran, 1991; Bijoy Nandan, 2012; and Fish Base 2015, www.fishbase.org).

Catch per unit effort (CPUE) was defined as one tow of the net operated once per site and expressed as kg.hr^{-1}. It was computed for the monthly and annual values and used as index of relative abundance (Sparre and Venema, 1992; FAO, 2002). Landings from all gears and fishing methods were computed by following equations Kurup et al., 1993; Gupta et al., 1997).

$$W = (w/n) \times N$$

Where W = total weight of fish
w = total weight of fish from gears sampled
n = number of gear sampled
N = total number of similar gears operated

Monthly catch was calculated by multiplying the daily catch with total number of fishing days and pooled to arrive at seasonal trends.

6.3.2 Tertiary production

Tertiary production in terms fishery potential was calculated based on the primary production. The primary production estimates were converted to wet weight of fish production by using a conversion factor of 7.41 (Vinogradov, 1953), which was applied in the Vemband Lake by Madupratap et al., 1977. According to ware (2000), fish production varies between 0.3 to 0.6% of the primary production. Generally 25-40%

of the total fish production can be taken as the sustainable catch (Qasim et al., 1978; ware, 2000; Renjith, 2004).

Fishery potential was estimated from the secondary trophic level (Cushing, 1973; Qasim and Ansari, 1981; Mathew et al., 1990), assuming that tertiary production is equal to 10% of the secondary production.

6.3.3 Trophic Level

The trophic level or trophic position of a species is a measure of the number of predator- prey interactions that separate it, on an average from primary producers or detritus (dead organic matter). The trophic level depends on an organism's diet. Tropical estuarine fishes have different feeding patterns such as herbivores, omnivores, macro carnivores, zooplanktivores, benthivores, insectivores and detritivores. The mean trophic level of individual fish was obtained from Fish Base 2015, www.fishbase.org (Froese and Pauly, 2007). Mean trophic level MTL_i, for year *i* is estimated by multiplying the landings (Y_{ij}) by the trophic levels of the individual species groups *j*, then taking a weighted mean, that is,

$$MTL_i = \sum_{ij} TL_j Y_{ij} / \sum Y_{ij}.$$

Where

TL_j = trophic level of individual species j

Y_{ij} = biomass of that species

ij is the summation of $TL_j \times Y_{ij}$

$\sum Y_{ij}$ is the total weight of all species.

6.3.4 Data analysis

PRIMER v6 was used to analyse multivariate methods, MDS Plots (Non-metric multi dimensional scaling), BEST analysis and univariate methods (Margalef's index, Pielou's index, Shannon-Weiner index, Simpson's index) as described previously.

6.4 Results

6.4.1 Fish production and catch structure

The annual exploited fishery of the Cochin estuary was estimated at 1997.24t during the 2009-11 period. The fishery catch comprised of 940.58t of fishes, 498.89t of penaeids, 187.98t of palaemonids, 112.89t of crabs and 256.90t of molluscs. Finfishes accounted for about 47.09% of the annual landings, followed by penaeids (24.98%), palaemonids (9.41%), crabs (5.65%) and molluscs (12.86%). Fish catch was composed of 57 species of finfishes, 6 species of penaeid shrimps, 1 species of palaemonidae, 3 species of crabs and 4 species of bivalves. *Mugil cephalus* constituted a maximum catch of 245.67t, followed by *Etroplus suratensis* (237.68t), *Ambassis thomassi* (227.78t), *Heteropneustes fossilis* (34.15t), *Etroplus maculates* (23.74t), *Anabas testudineus* (18.76t), *Ambassis commersonii* (18.48t) and *Liza macrolepis* (14.13t). Occurrence and distribution pattern of finfishes species in Cochin estuary during 2009-11 period is showed in Table 6.1.

Shrimps constituted a major share in estuarine fishery, of which *Metapenaeus dobsoni* was the dominant group contributing to the capture as well as traditional culture fisheries. *Macrobranchium rosenbergii*, *Fenneropenaeus indicus, Penaeus semisulcatus*, *Penaeus monodon*, *Penaeus canaliculatus*, *Metapenaeus monoceros*, *Metapenaeus dobsoni* and *Metapenaeus affinis* were contributed to the catch. *Metapenaeus dobsoni* dominated the landings of shrimps during the study period with an average catch of 451.90t, followed by *Fenneropenaeus indicus* (136.89t) and *Metapenaeus monoceros* (76.45t).

Scylla serrata, Portunus pelagicus and *Portunus sanguinolentus* formed the major crab resources in Cochin estuary. *Scylla serrata* contributed an average of 85.78t to the annual landings. The molluscan fishery of Cochin backwaters mainly comprised of *Villorita cyprinoides*, *Meretrix meretrix*, *Meretrix casta* and *Paphia malabarica*. The catch for *Villorita cyprinoides* was estimated at 256.90t during the study period. The fish landings was higher during 2010-11 period (754.93t) compared to 2009-10 period (186.53t). The inter-annual variation of mean percentage composition of fishes in the Cochin estuary is presented in Fig: Highest landings were observed during the pre-monsoon period (2010-11) followed by the post-monsoon period (2010-11) and monsoon period (2010-11). Relative abundance and habitat of the shell fishes contributing to the fishery of Cochin estuary during 2009-11 period is showed in Table 6.2.

Table 6.1 Occurrence and distribution pattern of finfish species in Cochin estuary during 2009-11 period

Family	Species	Habitat	Environment	Occurrence	Trophic level
Belonidae	*Strongylura leiura leiura*	E,M	Pelagic-neritic	*	3.9
Hemiramphidae	*Rhynchorhamphus georgii*	E,M	Pelagic-neritic	*	3
Clupeidae	*Sardinella longiceps*	M	Reef associated	*	2.4
	Sardinella gibbosa	M	Pelagic-neritic	*	2.9
	Dussumieria acuta	M	Pelagic-neritic	*	3.4
	Ilisha melastoma	M,B	Pelagic-neritic	*	3.5
Engraulidae	*Stolephorus commersonnii*	E,M	Pelagic-neritic	***	3.1
	Stolephorus indicus	M,B	Pelagic-neritic	**	3.6
	Stolephorus waitei	M,F,B	Pelagic-neritic	***	3.3
	Stolephorus insularis	M,B	Reef associated	*	3.2
	Thryssa mystax	M,B	Pelagic-oceanic	*	3.6
	Thryssa setirostris	M,B	Pelagic-neritic	***	3.3
Elopidae	*Elops machnata*	E,M	Pelagic-neritic	***	4
Megalopidae	*Megalaspis cordyla*	F,E,M	Benthopelagic	*	3.9
Chanidae	*Chanos chanos*	F,E,M	Benthopelagic	**	2.4
Mugilidae	*Chelon macrolepis*	F,E,M	Demersal	***	2.6
	Chelon subverdis	M,F,B	Demersal	***	2.7
	Mugil cephalus	F,E,M	Benthopelagic	***	2.5
	Valamugil speigleri	F,E,M	Demersal	***	2.2
	Moolgarda seheli	M,F,B	Reef associated	**	2.3
Polynomidae	*Eleutheronema tetradactylum*	M,F,B	Pelagic-neritic	*	4.1
Ambassidae	*Ambassis ambassis*	F,E,M	Demersal	***	3.7
	Ambassis thomassi	M,F,B	Demersal	***	3.5
Carangidae	*Carangoides praeustus*	M	Demersal	**	3.9
	Caranx hippos	M,B	Reef associated	**	3.6
	Alepes djedaba	M	Reef associated	*	3.3
Anabantidae	*Anabas testudineus*	F, E	Demersal	***	3

Channidae	*Channa striata*	F,E	Benthopelagic	***	3.4
Cichlidae	*Etroplus maculatus*	E,M	Benthopelagic	***	2.7
	Etroplus suratensis	E	Benthopelagic	***	2.9
	Oreochromis mossambicus	F,E	Benthopelagic	***	2.2
Eleotridae	*Bunaka gyrinoides*	F,E,M	Demersal	*	3.5
	Butis butis	F,E,M	Demersal	***	4
	Eleotris fusca	F,E,M	Demersal	*	3.8
Gereidae	*Gerres abbreviatus*	M,B	Reef associated	**	3.3
	Gerres filamentosus	F,E,M	Demersal	***	3.3
	Gerres setifer	E,M	Benthopelagic	**	3.3
Gobidae	*Gobiopsis macrostomus*	E,M	Demersal	***	3.8
	Taenioides buchanani	E,M	Demersal	*	3.9
	Taenioides cirratus	F,E,M	Demersal	***	3.9
	Trypauchen vagina	E,M	Demersal	**	3.5
Siganidae	*Siganus canaliculatus*	E,M	Reef associated	*	2.8
Latidae	*Lates calcarifer*	F,E,M	Demersal	***	3.8
Lutjanidae	*Lutjanus rivulatus*	M	Reef associated	*	4.1
	Lutjhanus johnii	M,B	Reef associated	**	4.2
Mullidae	*Upeneus vittatus*	E,M	Reef associated	*	3.6
	Upeneus sulphurus	E,M	Demersal	*	3.1
Sciaenidae	*Johnius belangerii*	E,M	Demersal	*	3.3
Soleidae	*Solea ovata*	M	Demersal	***	3.5
	Synaptura commersonnii	M,B	Demersal	*	3.5
Cynoglossidae	*Cynoglossus macrostomus*	E,M	Benthopelagic	**	3.3
Pralichthyidae	*Pseudorhombus arsius*	E,M	Demersal	***	4.2
Platycephalidae	*Platicephalu sindicus*	E,M	Reef associated	***	3.6
Bagridae	*Horabagrus brachysoma*	F,E	Demersal	**	3.1
	Mystus oculatus	F,B	Demersal	*	3.3
	Mystus malabaricus	E,M	Demersal	**	3.3
Siluridae	*Ompok bimaculatus*	F,B	Demersal	**	3.9
Hteropneustidae	*Heteropneustes fossilis*	F,E	Demersal	***	3.6

***common**abundant*Rare F-Freshwater E-Estuarine M-marine B-Brackish

Table 6.2 Relative abundance and habitat of the shell fishes contributing to the fishery of Cochin estuary during 2009-11 period

	Species	Habitat	Occurrence
Palaemonidae	*M. rosenbergii*	F,E	***
Penaeidae	*F. indicus,*	E,M	***
	P.semisulcatus,	E,M	*
	P.monodon,	E.M	**
	M.monoceros,	E,M	**
	M.dobsoni,	E,M	***
	M.affinis,	E,M	*
Portunidae	*S.serrata*	E,M	***
	P. pelagicus	E,M	**
	P.sanguinolentus	E,M	*
Corbiculidae	*V. cyprinoides,*	E	***

***common**abundant *Rare F-Freshwater E-Estuarine M-marine B-Brackish

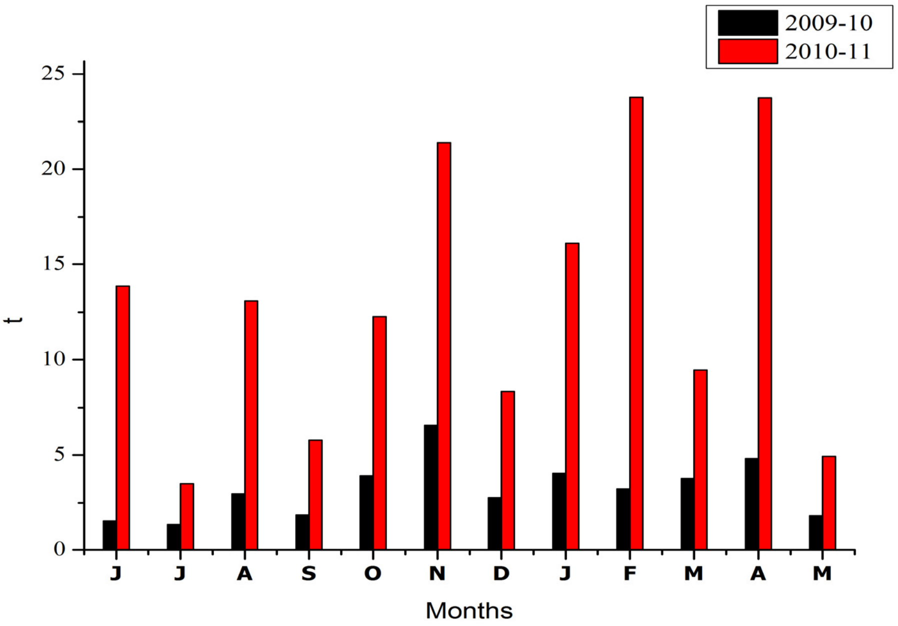

Fig. 6.1. Mean monthly variation of fish landings in Cochin estuary during 2009-11 period

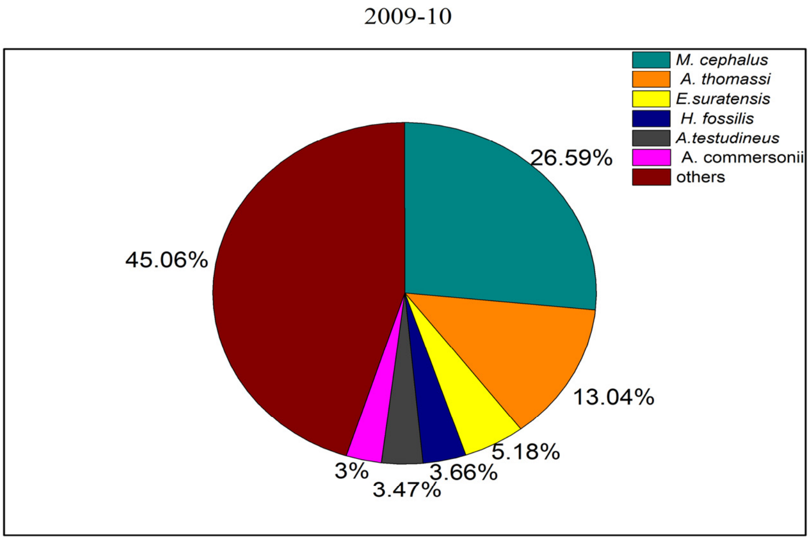

Fig. 6.2. Mean percentage abundance of major fishes in Cochin estuary during 2009-10 period

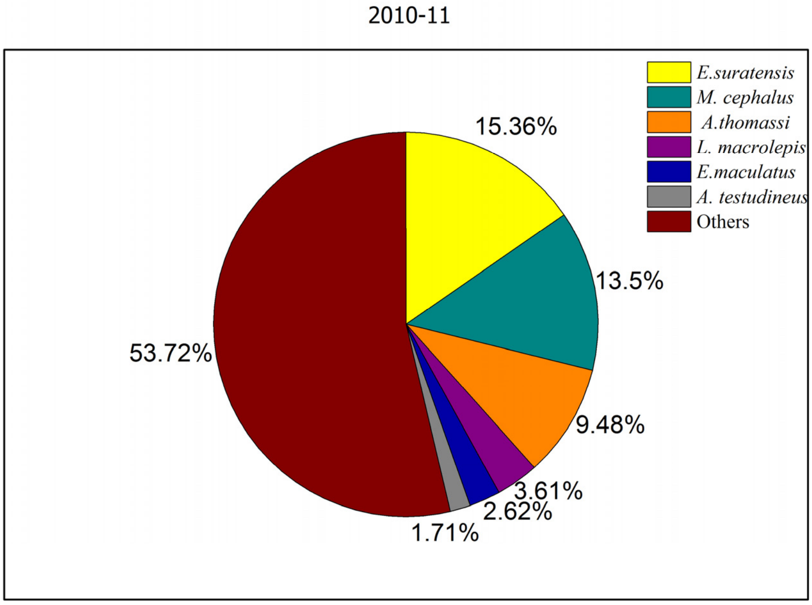

Fig. 6.3. Mean percentage abundance of major fishes in Cochin estuary during 2010-11 period

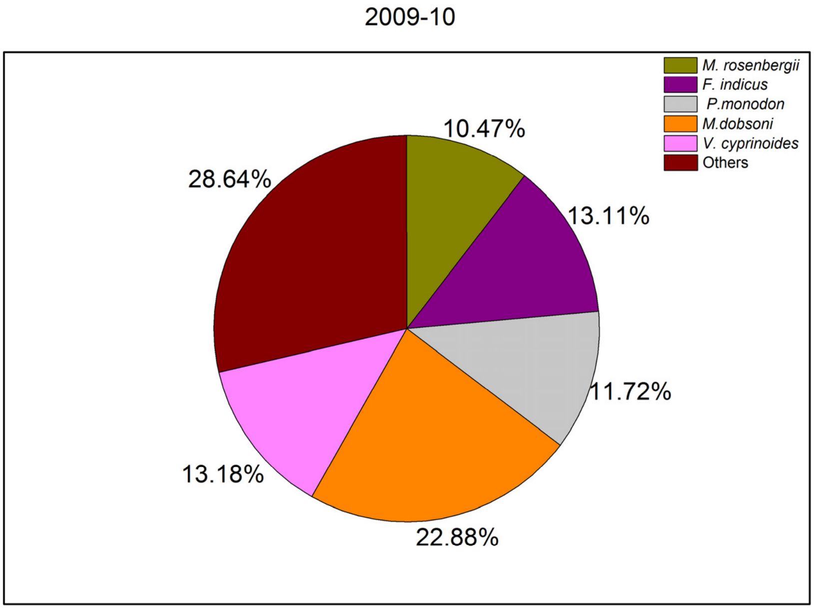
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Fig. 6.4. **Mean percentage abundance of shell fishes in Cochin estuary during 2009-10 period**

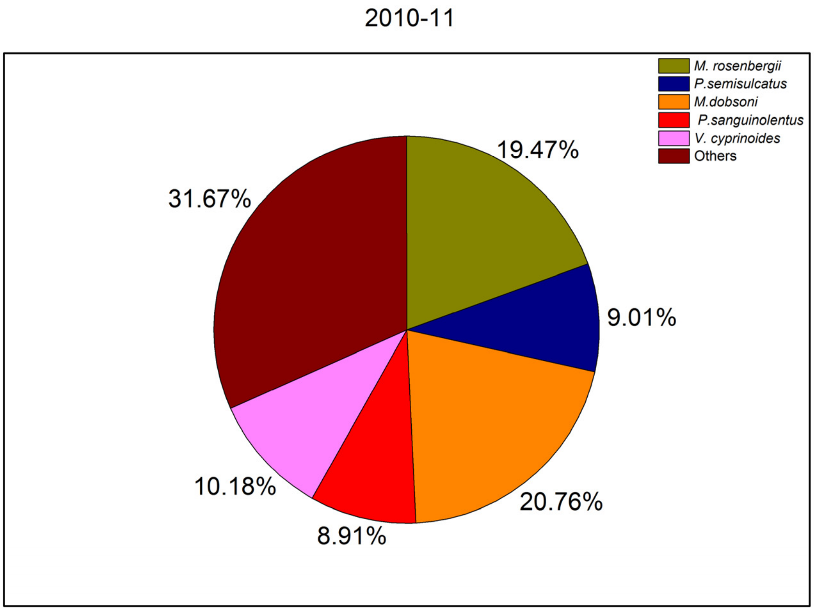
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Fig. 6.5. **Mean percentage abundance of shell fishes in Cochin estuary during 2009-10 period**

6.4.2 Gear wise production and Catch per Unit effort (CPUE)

The major catch of the landings were obtained from gill nets, stake nets and Chinese dip nets. Long line fishing and other indigenous fishing methods contributed a small share of the total fish landings. Gill nets contributed a share of 45.39% to total landings followed by stake nets (21.45%) and Chinese dip nets (17.5%). The CPUE value of seine net was 16.54 kg unit^{-1}hour^{-1}, which was due to the indiscriminate fishing with fine meshes of the gear, harvesting the juveniles of prawn and fishes. The catch per unit effort value of stake net was 10.05 kg unit^{-1}hour^{-1} and the gill net showed a CPUE value of 8.90 kg unit^{-1}hour^{-1}.

Table 6.3 CPUE of different gears and its contribution to total landings during the period 2009-2011

Gears	CPUE (kg unit^{-1}hour^{-1})	Contribution to total landings (%)
Gill net	8.9	45.39
Cast net	6.43	7.23
Stake net	10.05	21.45
seine net	16.54	4.68
Trap	1.94	1.27
Chinese dip net	10.81	17.5
Ring net	2.93	2.98

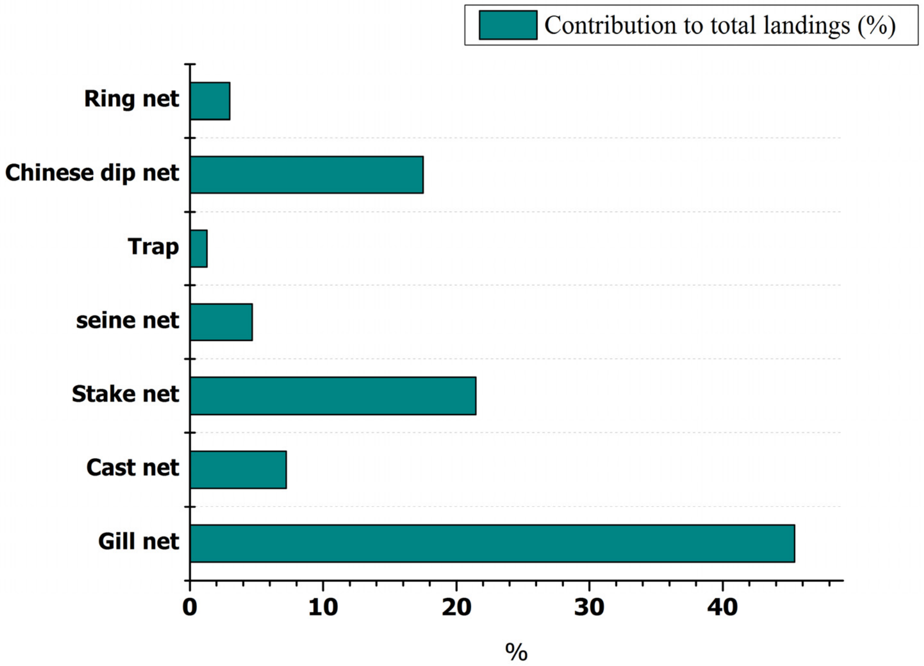

Fig. 6.6. Percentage contribution of fishing gears to total landings in Cochin estuary during 2009-11 period

6.4.2 Tertiary production

Based on the primary production, the wet weight of the fish production comes to be about 1,2,25,510 t by using a conversion factor of 7.41 (Vinogradov, 1953), which was applied in the Vembanad Lake by Madhupratap et al., 1977. According to ware (2000), fish production varies between 0.3 to 0.6% of the primary production. Based on this, the actual tertiary production was estimated at 7353.06 t in Cochin estuary. Generally, 25-40% of the fish potential can be taken as the sustainable catch (Qasim et al., 1978; Ware, 2000). So the sustainable catch from the study area was 2941.22 t year^{-1}.

Fishery estimates of the study region was calculated from the literature of Kurup et al., 1989 and Renjith et al., 2004.The fish catch from our study area was worked out to be about 1997.24t. Since the catchment from the area is also sold through alternate ways, an additional 12 t is also considered, making the total annual catch to be about 2009.24 t.

During the study period, the total fish landing of the zone was taken as 2009.24 t year^{-1}. Assuming the average protein content of fish to be 20%, of which 50% could be reckoned as carbon, i.e. 10% of the wet weight of the fish (Vinogradov, 1953). So the realised tertiary production in the Cochin estuary was 294.12 tC year^{-1}, but the actual tertiary production was estimated as 200.94 tC year^{-1}. The total annual primary production in the estuary was 165386 t of C year^{-1}and the fish production was 200.94 tC year^{-1}.

Estimation of fishery potential is based on the assumption that ecological efficiency from the secondary trophic level to the tertiary level is about 10% (Pauly and Christensen, 1995). Tertiary production was calculated as 1% of the primary production. Based on the secondary production estimated from the estuary, the actual fish production potential was 15.52 tC year^{-1}.

6.4.2 Trophic level

The trophic level of analysis of fishes from Cochin estuary showed that mid-level carnivory (3.5-3.99) and carnivory (3-3.49) dominates in the estuary. The top-level carnivory (4.0-4.5) constitute about 10.34%. The herbivorous fishes feeding on phytoplankton and plant matter formed the lowest percentage of 8.34%. The removal of top level predators in the ecosystem indicates the prevalence of overfishing in the ecosystem. The trophic level of fishes ranged from 2.2 to 4.2. The lowest trophic value of 2.2 was observed for two species of fishes, *Valamugil speigleri* and *Oreochromis mossambicus*. The highest trophic value of 4.2 was recorded for two species of fishes, *Lutjhanus johnii* and *Pseudorhombus arsius.*

Table 6.4 Mean percentage composition of fishes in Cochin estuary at different trophic levels

Feeding	Trophic level	% composition
Herbivory	2-2.49	8.62
Omnivory	2.5-2.99	12.07
Carnivory	3-3.49	31.03
Mid level carnivory	3.5-3.99	37.93
Top level carnivory	4.0-4.5	10.34

In the Vembanad Lake, only 45% of total fishes constituted by herbivorous fishes and 7% are carnivorous fishes (Kurup et al., 1989). So the total catch of the plankton feeding fishes is 898.76t. In the present study, 8.62% is constituted by herbivoruous fishes and 80% of fishes were carnivorous.

6.4.5 Data analysis

6.4.6 Univariate analysis of fish community structure

The mean monthly landings of fishes were analysed to understand the diversity of study region (Fig.6.7). Richness (d) was higher in August (4.00) and lower in March (3.10). Evenness index (J') was maximum in

September (0.66) and minimum in June (0.34). The dominance index was maximum in June (0.50) and minimum in September (0.12). The Shannon diversity index H'log(2) is high in September (3.73); and low in June (1.97).

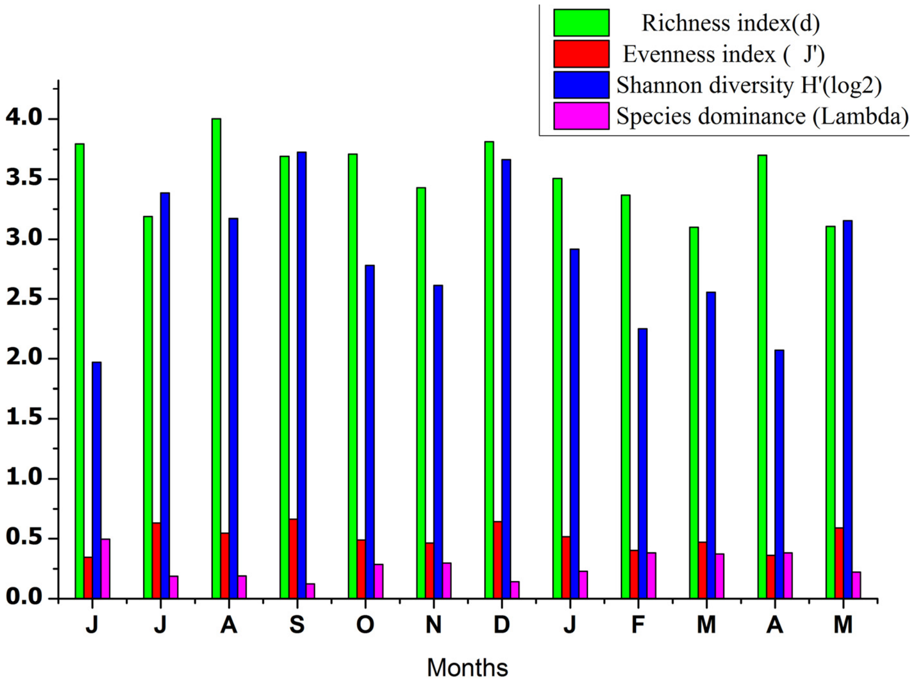

Fig. 6.7. Mean month wise variation of diversity indices of fishes in Cochin estuary during 2009-11 period

The mean seasonal variation of diversity indices of fishes in Cochin estuary during 2009-11 period is given in Fig.6.8.The mean seasonal landings of fishes recorded the highest richness (d) and Shannon diversity index (H' log (2) and evenness index in monsoon period (d=4.27, H' log (2) =3.18; J' =0.54). Species dominance (λ= 0.23) was high in post-monsoon period. The richness index and species dominance were low in post-monsoon period (d=4.10, λ =0.21). The evenness index and Shannon diversity were low in pre-monsoon period (J' = 0.47; H' log (2) = 2.76).

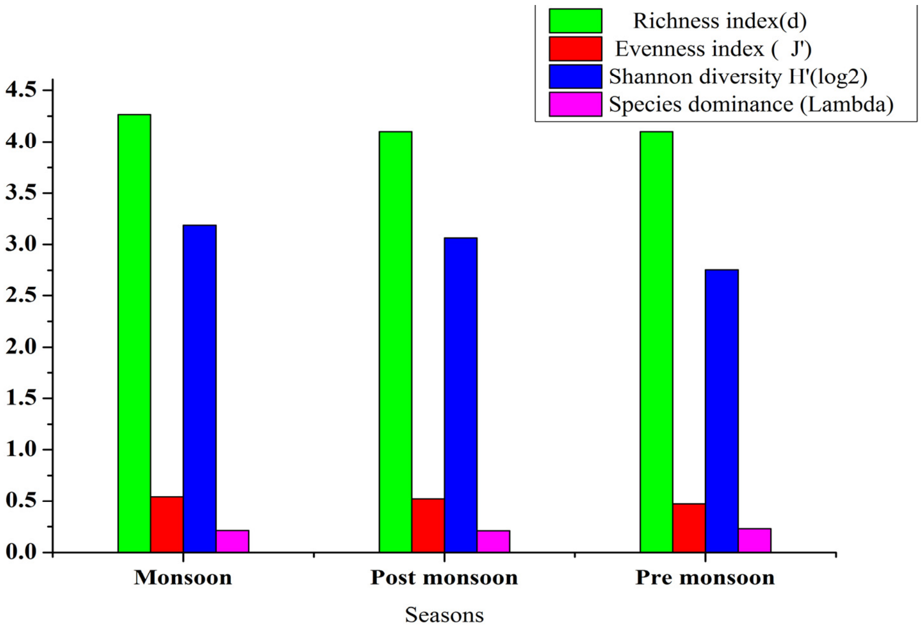

Fig. 6.8. Mean season wise variation of diversity indices of Cochin estuary during 2009-11 period

6.4.7 MDS analysis

The MDS analysis of monthly fish landings showed the similarity between different months (Fig.6.9). The Two dimensional plot has a stress value below 0.2 indicates a good interrelationships can be drawn from the plot. June and May form a subset and all the other months are very similar and they form another subset with 80% similarity.

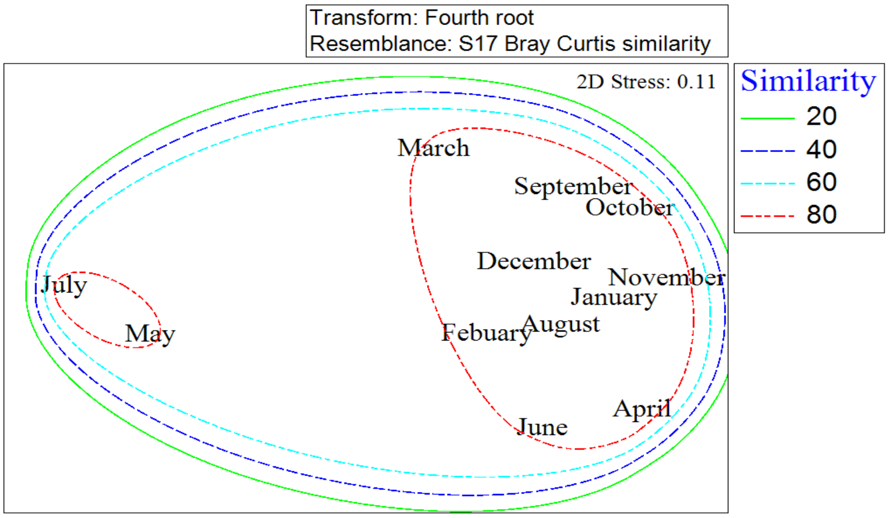

Fig. 6.9. MDS plot of mean monthly variation of landings of fishes in Cochin estuary during 2009-2011

6.4.8 BEST Analysis

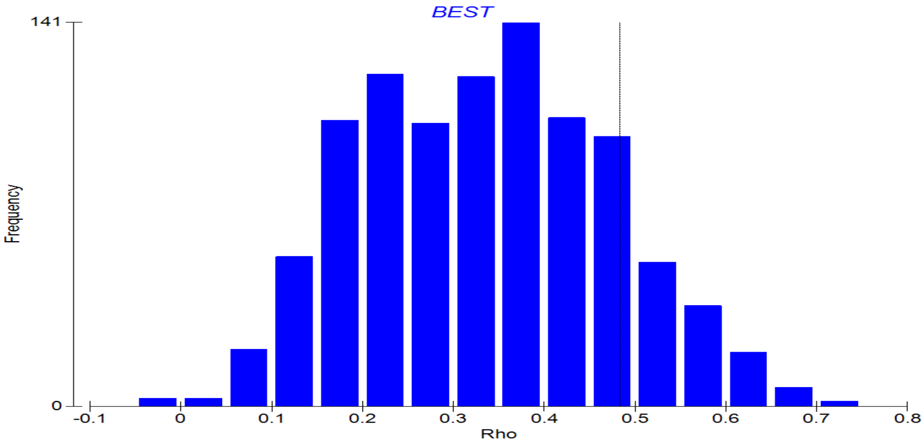

Fig. 6.10. BEST analysis of fishes with environmental parameters in the Cochin estuary during the 2009-11 period

Table 6.5 BEST analysis of fishes with the environmental parameters in the Cochin estuary during 2009-2011

	Variables	Variables selected	Best correlation values (Rho)
1	Water temperature	2,3,7,10	0.483
2	pH	2,3,5,7	0.474
3	Dissolved oxygen	2,3,10	0.469
4	Salinity	2,3,5	0.465
5	Turbidity	2,3	0.46
6	Biological oxygen demand	2,3,7,8,10	0.454
7	Phosphate	2,3,5,7,10	0.453
8	Nitrate	2,3,7	0.448
9	Ammonia	2,3,4,5,7	0.445
10	Chlorophyll a	2,3,5,10	0.442

The BEST analysis of fish landings with various environmental parameters like water temperature, dissolved oxygen, salinity, turbidity, biological oxygen demand, phosphate, nitrate, ammonia and chlorophyll a was done. The results showed that the environmental parameters like pH, dissolved oxygen and chlorophyll a influences the fish assemblages in Cochin estuary with a rho value of 0.483. The second correlation which influences the distribution of fishes was pH, dissolved oxygen, turbidity and phosphate. The interaction of pH, dissolved oxygen and chlorophyll a influences the distribution with a rho value of 0.469 (Table 6.5).

6.5 Discussion

The Cochin estuarine system is a nursery ground for many of the important commercial fishes and shell fishes. The annual prawn landings of Cochin estuary during 2009-11 period was 686.87t. The annual prawn landings in Hooghly-Matlah estuary varied from 857t in 1965-66 to 1799t in 1975-76. Prawns contributed to about 12.4% in Mahanadi estuary of the total landings during 1960-64 with their annual landings varied from 114t in 1962-63 to 55t in 1963-64. In Chilka lake prawn landings varied from 548t in 1964 to 1863t in 1965.Annual average catches of the Godavari estuary varied from 82% in 1969 to 66% in 1976. The landings for the entire Krishna estuary was estimated at 970t annually. Annual prawn landings of the Pulicat lake varied from 379-635t during 1967-71. In Vellar River, stake net (49.5%), cast net (28.9%) and drag net (21.6%) contributed to the prawn landings. Annual average catch of the Korapuzha estuary was 262t. The prawn landings in Mangalore were 22.1t in 1973.The total estimated prawn landings of Cochin estuary in 1973 was 898t. The total landing of penaeid prawns by stake net was 292t during 1996-97 in Thevara with CPUE of 3.8Kg. *Metapenaeusdobsoni* predominated fishery contributing 72.4% of total landings. The landings of Penaeid prawns was 212.7t during 1997-98 and 280.8t during 1998-99 with CPUE 4.29Kg (Manisseri and Rao, 2000). The landings of commercially important fish and shrimps from the backwaters was about 15000-21000t per annum with an annual average of 18000t (Sanjeevaghosh, 1993). Kurup et al. (1993) conducted a study during 1988-89 in the Vembanad Lake and estimated the annual yields of fishes and crustaceans as 7202t. Unnithan et al. (2007) reported that the total landings from different backwaters varied 96.8t from Mahe to 2899t from Ashtamudi. The average yield/ha varied from 410kg in Anchuthengu to 2747.3t in Azheekode estuary. Manna and Gowsami et al. (1985), identified 168 species of fishes from the west Bengal. Totally 150 species of fishes belonging to 100 genes under 56 families were identified from Cochin backwater areas in the study ecosystem modelling of Cochin backwaters conducted by ICMAM, 2002. In the present study, 71 species of fishes and shell fishes were identified from the study region. Raj et al., 2014 identified 91 species of fishes and shell fishes from the Ashtamudi lake.

The estimated fishery production of the Vemband Lake indicated an annual landing of 4387.31t, in which 480.98t and 3906.33t contributed by southern and northern zone (Asha et al., 2014). The reduction in the fish landings in the Vembanad estuary was due to the construction of Thannermukkom barrage, changed the estuary into fresh water zone on the south and brackish water zone in the north. The construction of Farakka barrage on the Ganga river estuary significantly changed the plankton dynamics and fishery of the Hooghly estuary. The construction of barrage affected the salinity pattern and leads to a decline in annual fishery landings (sinha et al., 1996). The decline in fish landings may be due to the low dissolved oxygen concentration associated with the eutrophication in the study region. The decline in fishery may be due to overharvest; cessation of fishing can protect the population of fishes and increase the abundance.

Jacob et al., 1981 observed that pelagic fisheries and zooplankton biomass relationships was very strong in the inshore waters of Vizhinjam. In our study region the zooplankton biomass fluctuations were not correlated with fishery production. The fishery production peaks coincide with the zooplankton production only in some months. In most of the months the relationship was not observed in our study region.

In the Ernakulam district of Kerala, a total of 8229 stake nets and Chinese dip nets were found to be operating, in which only 4583 nets were licensed to catch the fishes. 3646 nets were non-licensed. The total number of licensed stake nets in the district was 3639 and the number of licensed Chinese nets was 944. Illicit stake nets and Chinese dip nets in the region were 2804 and 842 respectively. The mesh size of the fishing gears is of great concern in sustainable fishery management. Recommended mesh size of the nets were not only less than 20mm, usually fishermen in this region using a mesh size of 10-14 mm. This will entrap the juveniles in sizeable quantities. Coracle fishing is a licensed fishing practice under the Inland act, 2002. It comes under the category including free net operation. Padal system is an illegal fishing practice, but was widely observed in the Varapuzha region. Narakkal, Varapuzha and Eloor are the illicit landing centres in our study area. The *Ettamkettu* or trapping fishes in landward side during high tide had been observed in some places. Electrocution, poisoning and explosives were common in this Ramsar site (Anon, 2014).

The actual number of fishing days in a year is 120 days and the operation of fishing activities is generally restricted to full moon and new moon. The fishery yield was maximum during the post-monsoon period and in the early pre-monsoon period. During the monsoon period, the fishery activity decreases and then attains peak values. The observed reduction in the fish landings during southwest monsoon period was not only due to environmental stress, but also due to decreased fishing days, marked by heavy rains. In this ever changing environment, salinity also has an important role, not only in determining the distribution of fishes within an estuary, but also in the abundance and diversity of icthyofauna. Salinity was comparatively high during the pre-monsoon period months and it substantially reduced during the southwest monsoon period. The salinity variation in the water column could have resulted in the reduction of total fish landings. This corroborates with the studies done by Bijoy Nandan et al., 2012 from the Kodungallur-Azhikode estuary. On the other hand, some fishes are attracted to the estuary during the monsoon period. This is due to physiological/behavioural attraction to river discharge and precipitation, owing to a preference of lower salinity for part or whole of the lifecycle (Day, 1889).

The influence of environmental parameters on the fish assemblages in the Kodungallur- Azhikode estuary was analysed using CCA, showed that salinity, transparency and pH play a key role in the distribution of fishes (Jayachandran et al., 2013). The fish assemblage in the Humber estuary is mainly influenced by salinity and temperature (Marshall and Elliott, 1998).

The primary production in the estuary was not fully converted to tertiary production. This indicates that a major portion primary production enters the detritus food chain (Madhupratap et al., 1977). Based on this assumption the fishing efforts in the estuary can be safely increased in a sustainable manner. The ratio of total annual primary production to fish production shows a difference of about 1000 fold. This is because the fish being harvested are several stages removed the primary production, undergoing about 90% reduction at different trophic levels. The fishes occupy the top most level in the trophic food chain and in each trophic level about 10% transfer occurs in next level. So a very small amount of primary production reaches the tertiary level and a greater part of the phytoplankton production goes to the detritus based food chain.

The tertiary production assessed from the primary and secondary level showed that the estuarine fishery catches were over exploited. In the present study, the dominance of carnivorous fishes in the Cochin estuary support the above statement. However, as these estimates were made assuming that all the energy is passing through the successive food, any deviation from this will alter the average yield at the tertiary level (Bhattathiri et al., 1976). The primary production estimates clearly depicts the over exploitation of the fishery resources. The unscientific methods of fishing practices in the estuary should be regulated, in order to sustain the fishery resources. Mathew et al., 1990 estimated the tertiary production of EEZ of India as 7.46 million t.

Most of the food chain in an ecosystem is limited to three or four “links” because the shorter food chain, or nearer the organism to the primary producers, the greater the available food energy. The trophic level analysis of fishes in Cochin estuary showed that nearly 80% of the fishes occupy the trophic level of 3 to 4.5.

Planktivorous fish occupy the third trophic level in the foodweb, as generally assumed, it would mean that fish production would not exceed 1% of primary production. But the catch structure analysis of trophic level occupies more carnivorous fishes. So the transfer efficiency was taken as 0.1% of the primary production, supported the overfishing in the Cochin estuary.

Elimination of predatory fish communities has been reported from the oceans around the globe due to overfishing activities and it has a greater impact on the ecosystems. Fishing down marine food webs explained the dominance of carnivorous fishes in the ecosystem might be due to the overfishing of top level predators in the ecosystem. Bijukumar and Deepthi, 2009 observed that more than 50% of the total fishes in the trawl bycatch was constituted by mid level carnivores. Vivekanandan et al., 2005 recorded higher landings of top level predators along the Indian coast during 1950-2002. The trophic level analysis of our present study revealed the dominance of mid level carnivorous fishes. A trophic cascade triggered in the Black sea, when the predatory fishes were overexploited, zooplanktivorous fishes increased in abundance, zooplankton biomass was lowered and phytoplankton biomass increased due to the reduction in the grazing pressure (Daskalov, 2002). Similar conditions were observed in the study region because the carnivory dominated in the system with low secondary production and increased primary production.

Sumaila et al., 1998 pointed the shifts in trophic level from low trophic level to high trophic level was associated with the fishers need to make profit. We cannot solely depend on the catch statistics data from the markets because they try to mask the real economic and biological effects of fishing down marine food webs. The fishers try to provide maximum fishes in the context of increasing price of fishes by changing the gear technology.

6.6 Trophic level production and energy transfer in Cochin estuary

A conceptualised planktonic food web of Cochin estuary is showed in Fig.6.11. The fate of primary production depends on the path carbon takes within the planktonic food webs. The two types food web are the grazing and microbial food chain depends on the size of the primary producers. The biogenic carbon is transported most effectively in the grazing food chain. So it supports a good fishery compared to the microbial food web systems. The planktonic food web dominated by small autotrophs channelled the biological carbon to higher trophic levels (Marquis et al., 2011). In the Cochin estuary, the nano and picoplankton contribute a major share in the primary production compared to microphytoplankton. Primary producers and detritus are assigned trophic level one, because they produce energy for the entire ecosystem. The detailed study of nano and pico phytoplankton will give more insight to the food web structure of the estuary. In the present study they were not taken in to account. The total annual gross production of the Cochin estuary was estimated to be 165386 tonnes of Carbon per year.

In the grazing food chain primary production by the microphytoplankton is transferred to secondary producers. Grazers such as (microcrustaceans, such as copepods, cladocerans and jelly fishes, etc), herbivorous fishes, filter feeding benthos consuming microalgae and other bottom invertebrates (sea-urchins, which mainly consume algae). The herbivorous organisms which feed on primary producers occupy trophic level two. Assuming that about 10% of the primary production is available to the herbivores. In the present study the actual secondary production much lower than the realized. In the present study the secondary production of all the grazers was not taken into account. Feeding behaviour of dominant organisms gives a good idea about the food web operating in the estuarine system. Omnivorous feeding mechanisms of secondary producers make the food web more complex to derive. Based on the available data, the predator-prey interactions (Phytoplankton-zooplankton) relationship showed that top-down mechanism operates in the estuarine system. The top level predators control population of lower group of animals.

Predators feeding on herbivores occupy trophic level three. The tertiary production derived from secondary production showed that fishery resources in the estuary were over exploited. The trophic level analysis of fishery catch showed the dominance of carnivory rather than herbivory. A trophic cascade takes place when the effect of a change in predation pressure propagates across consecutive trophic levels in the food web. If the predatory fishes were overexploited and decreased in abundance, thus the zooplankton abundance was reduced but with an increase of phytoplankton abundance.

Food web links are intricate to derive, based on the available data the generalised planktonic food web in relation with fishes of the Cochin estuary was presented in Fig. 6.11

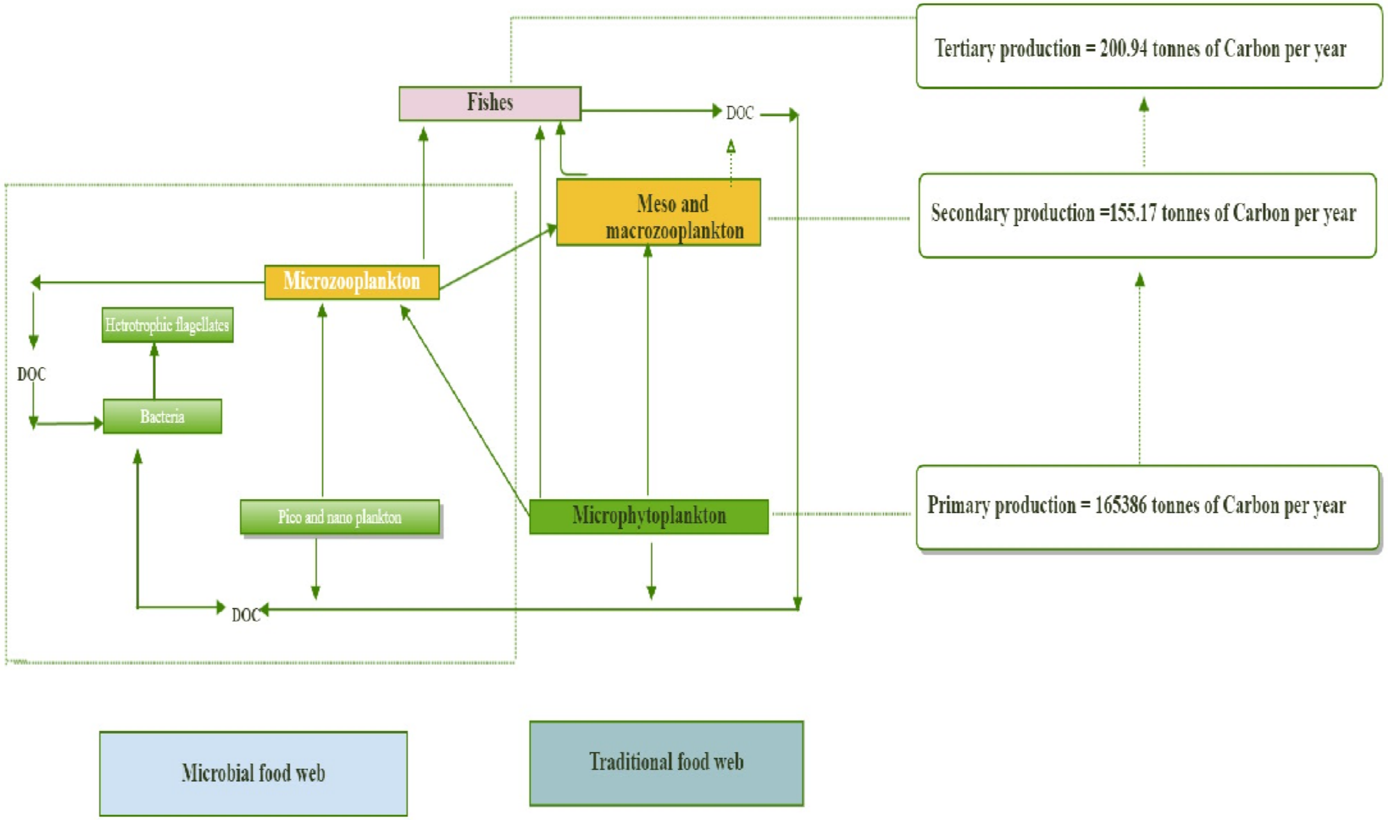

Fig. 6.11. A conceptualised planktonic food web of Cochin estuary

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SUMMARY AND CONCLUSION

It is well known historically that coastal plains and estuaries are the most populated areas in the world. The increase in human population resulted in the degradation of estuarine and coastal waters through pollution, eutrophication, increased turbidity, and overfishing and habitat destruction. Cochin estuary, forming the northern part of Vembanad wetland, a Ramsar site of international importance is noted for its valuable biotic resources and strong endemic character. The estuary is facing severe environmental stress for the last few decades due to plethora of human induced activities like mining, industrial pollution, unscientific fishing practices and dredging activities. However, there is limited scientific information available on the basic production process, its dynamics and energy transfer in the trophic system in Cochin estuary for precisely developing any future management action plans for the wetland system. So the present study is an attempt to evaluate the productivity pattern in Cochin estuary with respect to all these changes.

Water temperature showed an increasing trend, compared to previous years possibly indicating the effects of climate change.The monthly variation of water temperature in Cochin estuary was low during the study period. Depth of the estuary has reduced in the past fifty years. The entire estuary was shallow in nature with an average depth of 3.67 m.

The annual variation in transparency showed a direct relation with the rain fall and river discharge. The secchi disc depth in the estuary 0.55 to 1.14m and it was lower compared to the earlier works. Salinity of the estuary showed an oligo-mesohaline nature, vertical stratification of salinity was not observed. Salinity was lower during monsoon period due to the fresh water input and was higher during post-monsoon period that might be due to increased rate of evaporation and sea water ingression. TDS was higher during the monsoon period and lower during the pre-monsoon period. The water column turbidity was higher in the southern zone of the estuary. Mean station wise turbidity in the Cochin estuary ranged from 4.25 to 13.51 NTU. The higher oxygen concentration during post-monsoon period season was due to the higher primary production occurring in the surface layers during this period. Low dissolved oxygen values in the bottom waters might be due to the increased organic inputs from the urban area as well as the industrial effluents and excess nutrient loading and decrease in top down control of primary production.

The surface and bottom water pH in the study region showed variations. It was low in the bottom waters may be due to the oxidation of organic matter. The northern zone was slightly acidic, while the southern zone and central zone were alkaline in nature. Carbon dioxide values were higher in the estuary. The alkalinity showed wide seasonal fluctuations. The total hardness showed a two to three fold increase in the pre-monsoon and post-monsoon season, which might be due to the high rate of evaporation and reduction in the freah water runoff. Increased biological oxygen demand (BOD) values were observed in some stations that could be due to the higher biological production coupled with the sinking of organic matter, discharge of untreated effluents and waste from aquaculture and agriculture fields.

In the present study, the average concentration of ammonia (11.48 µmol L^{-1}) was very high compared to the earlier observations. The presences of higher levels of ammonia indicate the increased sewage input and agricultural runoff into the surface waters. The spatio-temporal variations on nitrite showed a trimodal cycle, with the peaks occurring when the system remains dominated by freshwater. The nitrate-nitrite values showed a clear positive correlation with the river discharge. The phosphate concentration was higher in the northern zone of the estuary may be due to the industrial effluent discharge and domestic sewage containing detergents and fertilizers used in the agricultural fields. Silicate concentration was higher during monsoon period in the surface waters might be due to heavy rainfall and increased surface runoff.

Hydrogen sulphide was found to be higher in the bottom waters of the estuary that may be due to organic matter degradation. Phosphate, nitrite and ammonia were found to be higher during the pre-monsoon period. Silicate and nitrate showed the peak concentration during monsoon period. The heavy rainfall and the increased surface runoff during the monsoon period could be attributed to higher values of silicate in the surface waters during monsoon period. Water quality parameters showed eutrophication in the estuary. Our present study showed that water quality is extremely deteriorated. The Red field ratio in the estuary showed a nitrogen limiting condition. Southern zone and Central zone had similar hydrography. Give about the zones above in 1-2 lines. Northern zone have a fresh water hydrography.

Highest gross primary production (GPP) and net primary production (NPP) was observed during post-monsoon period. The increased respiration in the Cochin estuary indicates that heterotrophic organisms dominated during the study period. So the esturine system consumes more organic carbon than they produce. It may be due to the input of large allochthonous organic matter to the system particularly from adjacent marshes and mangroves. The abundance of phytoplankton in the post-monsoon period may be due to the stability of the water column. The chlorophyll ‘a’ concentration was higher in the northern zone of the estuary. Seasonal variation of chlorophyll ‘a’ showed the peak during the pre-monsoon period followed by the post-monsoon period and monsoon period. The chlorophyll ‘b’ values were higher during post-monsoon period and lower during pre-monsoon period. The total phytoplankton cell density, chlorophyll ‘a’ and gross primary production showed a similar pattern in all the seasons. It showed the peak during post-monsoon period may be due to the stability of the water column and availability of nutrients. The present study showed that the annual column production and photosynthetic efficiency of the estuary decreased which showed that the stress on the ecosystem decreased the efficiency of production. The BEST analysis of the microphytoplankton showed a strong relation with the environmental parameters like salinity, turbidity, dissolved oxygen, Chlorophyll ‘a’ and GPP. The spatio-temporal variation of the TRIX index in the present study was noticd bad water quality with high level of eutrophication.

Zooplankton groups mainly comprised of crustacean nauplii, copepods and rotifers. Zooplankton density showed a peak during pre-monsoon period with respect to changes in salinity. Crustacean nauplii, copepods, rotifers and tintinnids were the dominant group in the study area. BEST analysis of zooplankton showed a strong correlation with the environmental parameters, dissolved oxygen, salinity, turbidity and chlorophyll *a*. Secondary production was not limited by primary production in the estuary. The secondary production of the Cochin estuary was 75.40 mgC m^{-2} d^{-1}. The wide gap in the primary and secondary production indicates a large amount of primary production, which is not effectively utilized due to the lack of zooplankton herbivores. It sinks to the bottom and produce anaerobic conditions. The transfer of phytoplankton carbon to zooplankton carbon was high during monsoon. During the period of fresh water dominance, a substantial amount of carbon remains unconsumed due to the lack of grazers. The lagged oscillation of predator (zooplankton) and prey (phytoplankton) abundance is a typical feature of top-down dynamics in the study area.

The annual exploited fishery of the Cochin estuary was estimated as 1997.24 tonnes during 2009-11 period. The fishery catch showed a declining trend compared with the earlier works. The trophic level analysis of the fishery landings showed the dominance of mid level carnivory indicating the removal of top level predators in the food web due to overfishing. The fishes occupy the top most level in the trophic chain and in each trophic level about 10% transfer occurs in the next level. So a small amount of primary production reaches the tertiary level.

The primary production and secondary production estimates clearly depicts the over exploitation of the fishery resources. The unscientific methods of fishing practices like padal fishing, *Ettamkettu* or trapping, use of small mesh size of nets and juvenile fishing in the estuary should be regulated, in order to sustain the fishery resources.

However the human impacts on the ecological health of estuarine and coastal waters depend on factors like estuarine flushing. Several stretches of the estuary that is severely impacted by different sources of pollution needs to be remediated. The 'ecohydrobiology' principles can be applied to mitigate the human impact on estuaries and coasts. This low cost technology enhances the natural capacity of water to absorb and processes with no resulting estuarine degradation. The level of degradation of the estuarine ecosystem depends on two key factors: The ratio between the nutrient flux and the flushing time and the robustness of the system. The robustness of the estuary depends on various parameters: residence time, estuarine food web, buffering capacity of water and the habitat provided by the fringing wetlands (mangroves and salt marshes).

In addition a restrained approach for the wise of estuary its environmental and biotic production is to be followed on an urgent basis. The different environmental and non governmental agencies have a solemn duty to protect and preserve this wetland and its heritage for future generation. Political decisions in favour of the scientific findings will definitely help to protect the estuary.

Based on the study the following recommendations are put forth for proper management of the Cochin estuary

- The study has established that the water quality and productivity pattern in Cochin estuarine system has been seriously impacted in the Thevara, Fishing Harbour and Eloor-Edayar region due to various anthropogenic issues like reclamation, dredging, sand mining, sewage and waste disposal.
- Isolated eutrophication resulting in higher trophic index, low dissolved oxygen with nutrient limiting condition was observed in Thevara, Eloor-Edayar, Chitoor, Moolampilly-Pizhala and Eloor-Edayar region of the estuary. The sagging of dissolved oxygen concentration in the northern zone of the estuary can be regulated by the deepening of shallow regions, control of non point sources of pollution and manipulation of dissolved oxygen concentration by large scale destratification and aeration.
- The annual column primary production and secondary production showed a decreasing trend in the Cochin estuary. The realised and actual energy transfer showed a wide gap between the primary and secondary level. The Cochin estuary was shifting from autotrophy to heterotrophy, it consumes more organic carbon than the system produce and the top-down dynamics control the estuarine trophic relations. These findings showed the changing trophodynamic structure of the estuary due to various anthropogenic activities. Cochin estuary and adjoining water bodies should be taken into consideration for any future master plan of Cochin city.

- The industrial pollution needs to be regulated by effective and transparent monitoring of industrial activities in the Eloor-Edayar region. Government should monitor the violations of the prescribed water quality guidelines laid down by the Central and State pollution Control Board.
- Urbanisation and developmental activities in the Thevara, Vallarpadam-Bolgatty, Moolampilly-Pizhala resulted in the encroachment of the estuary by violating and regulating the coastal regulation zone (CRZ) norms. National Green Tribunal can enforce laws to prevent the reclamation in the estuaries.
- Several patches of mangroves have been denuded for the construction and developmental activity in the Vallarpadam-Bolgatty area. So urgent afforestation measures have to be implemented in the region to maintain the *green lung cover* of the city.
- The hydrology and regular flows from rivers into the estuary has been seriously affected unplanned developmental activities in the Cochin city. So detailed studies on the hydrobiology of the backwater, salinity, inorganic nutrient regime in different zones, river flow patterns are to be undertaken before any future developmental programs are implemented.
- Since tourism activity is on the rise in Cochin estuary, urgent action is required to restrict various pressure associated with this on the wetland and its resources. A carrying capacity based model needs to be developed to protect the ecosystems from any modification.

- Over exploitation of fishery resources was widely observed in the Cochin estuary. Unscientific method of fishing practices and use of destructive gears should be prohibited. There is a need to restrict the mesh size of stake net, gill net and Chinese dip net to ensure more growing period to the young ones. The registration of fishing craft and gear including stake net are to be strictly implemented. Several of the stake nets are being deployed during tidal incursion in the backwater against the norms. This enforcement machinery is to be strengthened to ensure that stake nets are deployed only during receding phase.
- Cochin estuary is a part of the larger Ramsar site, Vembanad wetland system on the southwest coast of India. However, the changes in environmental and biotic production potential as is evident from the present study is to be seriously considered. So that it could be integrated with the management measures adopted by Ramsar convention for the region under the Vembanad wetland.

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