Benthic Biocoenosis in the Tropical Mangrove Stands of Kerala

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Certificate

This is to certify that the thesis "**Benthic biocoenosis in the tropical mangrove stands of Kerala**" is an authentic record of research work carried out by Mrs. Philomina Joseph (Reg. No. 4393) 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. There is no plagiarism in the thesis and that the work has not been submitted for the award of any degree/diploma of the same Institution where the work was carried out, or to any other Institution.

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Declaration

I hereby declare that the thesis entitled **"Benthic biocoenosis in the tropical mangrove stands of Kerala"** 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 **Philomina Joseph**

January 2019

In loving memory of…….

My parents in Heaven

I will instruct you and teach you in the way you should go; I will counsel you with my eye upon you. *Psalm 32:8*

Dedication

To all those who lighted my path with prayers and deeds to achieve my goal….

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Give thanks to the LORD, for he is good; his love endures forever.........(Psalm 118:1)

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Philomina Joseph

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LIST OF ACRONYMS & ABBREVIATIONS

%	percentage
<	less than
>	greater than
°C	degree Celsius
ABC	abundance biomass curve
ANOSIM	analysis of similarities
ANOVA	analysis of variance
BDL	below detectable level
CF	contamination factor
DO	dissolved oxygen
EF	enrichment factor
EG	ecological groups
ERL	effect range low
ERM	effect range medium
et al.	et alli (Latin word, meaning 'and others)
g kg^{-1} or g/kg	gram per kilogram
g m-2	gram per square metre
ha	hectare
Igeo	geoaccumulation index
ind.ha^{-1}	individual per hectare
ind.m-2	individual per square metre
L	litres
mg kg^{-1} or mg/kg	milligram per kilogram
mg L^{-1} or mg/L	milligram per litre
mm	millimetre
Mon	monsoon
mV	millivolt
NTU	nephelometric turbidity units

OM	organic matter
PC	principal components
PCA	principal component analysis
PLI	pollution load index
Pom	post-monsoon
ppm	parts per million
Prm	pre-monsoon
PSU	practical salinity unit
S1	station 1
S2	station 2
S3	station 3
S4	station 4
S5	station 5
S6	station 6
SIMPER	similarity percentage
SIMPROF	similarity profile analysis
sp.	species (singular)
sp.nov	species nova (new species)
spp.	species (plural)
Sq.km or km^2	square kilometre
SQG	sediment quality guideline
TOC	total organic carbon
TP	total phosphorus
TS	total sulphur
v	version
Vis-à-Vis	in relation to
µm	micrometer

Chapter 1

GENERAL INTRODUCTION

"Ecosystems are the productive engines of the planet, providing us with everything from the water we drink to the food we eat and the fibre we use for clothing, paper or lumber".

Jonathan Lash

Coastal ecosystems are regions of remarkable biological productivity along the continental margins where land, sea and atmosphere interact and interplay continuously. These regions encompass diverse array of habitat types such as mangroves, coral reefs, estuaries, tidal wetlands, seagrass beds, mudflats, salt marshes, barrier islands, peat swamps and a variety of other habitats. Each of these habitats provide multitude of services and goods, harbouring a wealth of species and genetic diversity. The economic benefits and services provided by these dynamic systems attracted the world's population towards the coastal regions not only to live but also for leisure, recreational activities and tourism. Due to the gradual expansion of different human activities, this valuable ecosystem has become a "finite resource". The definition of coastal ecosystem by Hinrichsen (1999) projects the vulnerability of this transitional zone due to its interaction with land and sea as "*that part of the land most affected by its proximity to the sea and that part of the ocean most affected by its proximity to the land*".

Mangroves are the only tall tree forests seen in the coastal zone and generally referred to as tidal forests or coastal woodlands (Kathiresan, 2010). Mangroves are woody plants that grow in tropical and sub-tropical latitudes along the land-sea interface, bays, estuaries, lagoons, backwaters and in the rivers, reaching upstream up to the point where the water still remains saline (Qasim, l998). Mangrove plants and their associated organisms (microbes, fungi, other plants and animals), constitute the 'mangrove forest community' or 'mangal' (Macnae, 1968). The mangal and its associated abiotic factors constitute the mangrove ecosystem. Mangroves are located in coasts of 123 tropical and subtropical countries approximately between 30° N and

30° S latitude with a total area of 15.2 million hectares. There are 73 species of true mangroves, which are found only in the intertidal zones of coasts, and are taxonomically isolated from terrestrial counterparts (Spalding *et al*., 2010).

This marginal environment lying at the interface between terrestrial and marine system is well adapted to withstand the extreme winds, salinity variations, tidal actions, anaerobic soil, lower pH and higher temperature. The unique morphological and physiological characteristics such as pneumatophores, stilt roots, buttress roots, salt-excreting leaves and viviparous propagules help them to adapt to the harsh environment and make them profusely rich in biodiversity compared to other coastal habitats.

Mangroves are the lifeline of the coastal zone conferring an array of services to the coastal communities and helps in sustaining their livelihood (Bijoy Nandan *et al*., 2015). They have vital role in functioning of coastal ecosystems through energy and material flux (Odum and Heald, 1975). In a broad sense, the importance of mangrove forest can be assessed by ecological sustainability (pollutant detoxification, sediment control, organic carbon flux, nutrient cycling), environmental security (climate mitigation, natural calamity mitigation), and economic prosperity (fishery and other goods, honey, firewood, medicines) (Sandilyan and Kathiresan, 2012). Socio-ecologically, mangroves offer the full range of ecosystem services. Mangroves can provide natural defences against extreme weather events and disasters, protecting the coastal communities from devastating natural calamities, develop specialised structures for flood protection and act as effective buffer against coastal erosion. They are stabilisers of coast by trapping sediments within their complex root structures with each retreating tide thus supporting soil consolidation and sedimentation. Mangrove forest support coastal fisheries by serving as an intermediate nursery habitat for juveniles of fishes, shrimps, molluscs and provide ideal place for completing their life cycles due to nutrient rich organic matter and highly sheltering roots. Mangroves have exceptionally high carbon stocks (UNEP, 2014) and their carbon sequestration potential is 50 times greater than other tropical forests due to higher levels of below ground biomass and rich deposit of organic carbon in mangrove sediment (Sandilyan and Kathiresan, 2012). Furthermore mangrove habitats serve as a sink of carbon and reduce greenhouse gas concentration in the atmosphere. Thus, mangrove forests offer a unique and highly efficient approach to climate change mitigation and adaptation. Mangroves are one of the largest annual primary producers in our biosphere (Donato *et al*., 2011), and organic matter degradation and mineralization provide a source of organic carbon and inorganic nutrients essential for the productivity of mangroves and the adjacent coastal waters (Bouillon *et al*., 2008; Alongi, 2014) and are comparable to highly productive terrestrial forests (Alongi, 2009). The habitat diversity and genetic diversity offered by the mangroves are immeasurable. Habitat heterogeneity ranging from core-forests, litter-forest floors, mudflats, complex roots, pneumatophores have diverse of animals and plants adapted to the environmental conditions of highly saline, frequently inundated, soft bottomed anaerobic mud. The ecological services provided by mangroves are listed in Figure 1.1.

However, despite such diverse roles of mangroves, they are considered as the most undervalued and trivialized ecosystems in the world (Lugo and Snedaker, 1974). Mangroves are regarded as valueless wastelands due to the perception that these environments are hostile, foul-smelling and muddy (Dittmar *et al*., 2006). The most alarming problem of mangrove destruction and deforestation is due to increased population pressure in coastal areas. Human impact on mangroves were sustainable in earlier periods where people depended on them for food, fodder, grazing of livestock etc., but due to the increasing demands, intense pressure for developments has resulted in unsustainable exploitation of mangrove resources for aquaculture, agricultural development, urban area expansion, industrial development and coastal tourism.

The introduction of pollutants such as heavy metals, oils, herbicides, sewage and acids is a severe cause of destruction of mangrove and depletion of sediment quality and stress to biotic dependents. Such negligence toward mangrove leads to a faster rate of destruction to the world's richest storehouses of biological and genetic diversity all over the world.

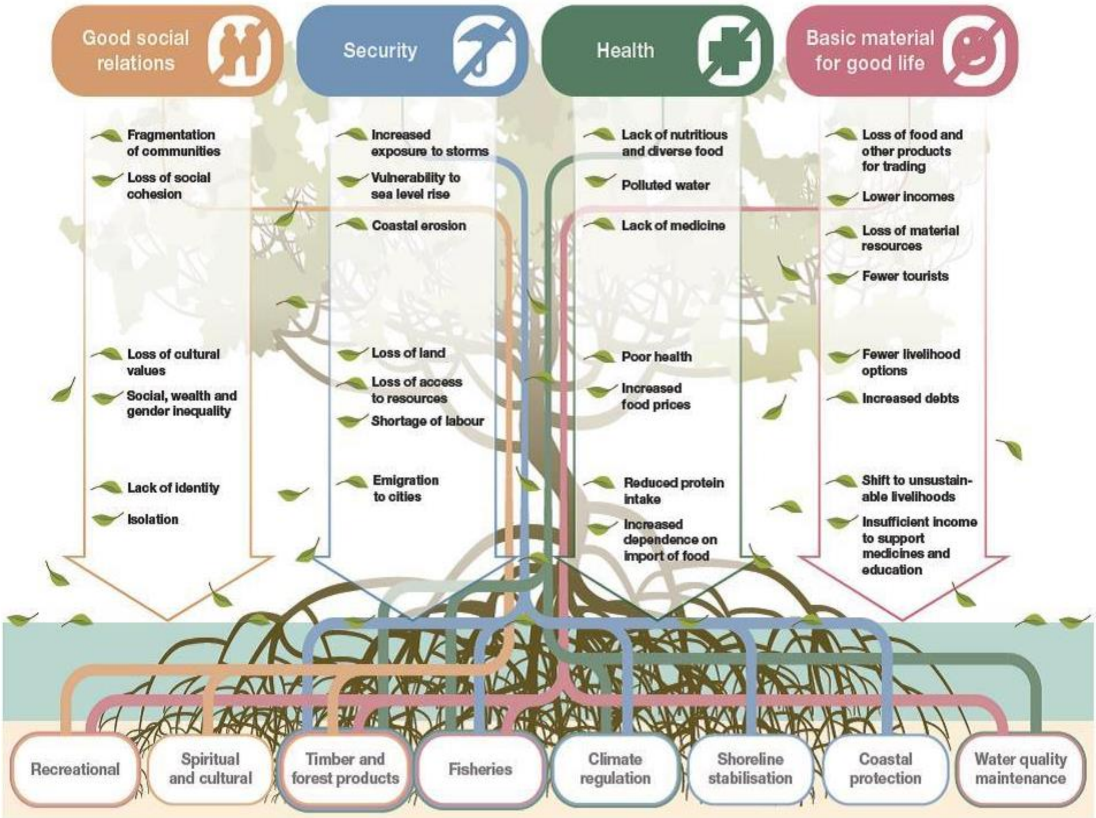


Figure 1.1 The ecological services provided by mangroves and impact of the unregulated management of mangrove ecosystem to human well-being (Source: UNEP, 2014)

Mangrove forests are often naturally disturbed by cyclones and other storms, lightning, tsunami and floods, and often take decades to recover (Smith *et al*., 1994). Mangroves become more susceptible to diseases and pests when stressed by changes in salinity, tidal inundation, sedimentation and soil physico-chemistry. In addition, climate change poses a threat to mangrove ecosystems (Gilman *et al*., 2008). The continuing degradation and depletion of this vital resource will reduce not only terrestrial and aquatic production but more importantly, the environmental stability of coastal zone will be hampered (Dittmar *et al*., 2006). Mangrove loss will also decrease coastal water quality, reduce biodiversity, eliminate fish and crustacean nursery habitat, adversely affect adjacent coastal habitats and human communities that rely on mangroves for numerous products and services (Nagelkerken *et al*., 2008).

1.1 Indian Mangroves

India ranks one among the 12 mega biodiversity countries of the world and enjoys warm tropical climatic conditions suitable for flourishing of mangrove vegetation. Indian mangrove forest harbours 38 true mangrove species (Bijoy Nandan *et al*., 2015) out of total 73 species of the world (Spalding *et al*., 2010). Mangroves in India are spread over an area of about 4921 sq.km, that account for about 3.3 % of the world's mangrove vegetation, 8 % of the Asian mangrove area and 0.15 % of the country's land area (India State of Forest Report, 2017). There has been a net increase in mangrove cover of 181 sq. km as compared to 2015 assessment (India State of Forest Report, 2017). This increase was due to the plantation and natural regeneration efforts in the states of Andhra Pradesh (37 sq.km), Gujarat (33 sq.km), Maharashtra (82 sq.km), West Bengal (8 sq.km) Odisha (12 sq.km), Karnataka (7 sq.km) and Tamil Nadu (2 sq.km). About 57.14 % of the total mangrove area is recorded on the east coast of India (Bay of Bengal region) and 30.3 % on the west coast (Arabian Sea region) and rest of 12.5 % in Bay islands (Andaman and Nicobar). The nutrient-rich alluvial soil formed by the major rivers and a continuous supply of freshwater along the deltaic coast facilitates colonization of mangroves on the east coast of India. The major mangrove areas in east coast include Sundarbans in Gangetic delta of West Bengal, Bhitarkanika in Mahanadhi delta of Orissa, Coringa in Godavari delta of Andhra Pradesh and Pichavaram in Cauvery delta of Tamil Nadu. Sunderbans is the only mangrove forest of the world having among its residents, the famous Royal Bengal Tiger (*Panthera tigris*). Bhitarkanika, the genetic paradise of India ranks first in hosting the largest number of true mangrove plants.

The west coast is characterised by backwater estuarine type of mangroves experiencing intense upwelling associated with south-west monsoon. Mangroves of west coast is distributed in five states, Gujarat with Gulf of Kachchh and Gulf of Khambhat mangroves, Maharashtra with Thane creek mangroves, Goa with Mandovi and Zuari estuarine mangroves, Karnataka with Karwar mangroves, Kerala with Kannur and Cochin mangroves. Andaman and Nicobar islands located in the northeast Indian Ocean, floats on Bay of Bengal, harbours 617 sq.km of dense and diverse mangrove cover (India State of Forest Report, 2017) along many neritic islets, tidal estuaries, lagoons and small rivers (Gopal and Krishnamurthy, 1993).

Indian mangroves support rich faunal resources (Rao, 1987). Among invertebrates, more than 500 species of insects, 229 species of crustaceans, 212 species of molluscs, 50 species of nematodes, and 150 species of planktonic and benthic organisms are known from Indian mangroves while vertebrate fauna is represented by 300 species of fishes, 177 species of birds and 36 species of mammals (Gopal and Krishnamurthy, 1993). Kathiresan and Qasim (2005) reported 3,091 mangrove-inhabiting faunal species in India. This includes 55 species of prawns, 138 species of crabs, 305 species of molluscs, 745 species of other invertebrates, 546 species of fishes, 7 species of fish parasites, 707 species of insects, 84 species of reptiles, 13 species of amphibians and 68 species of mammals. However, in Indian mangrove systems, 100% of mangrove species, 92% of other flowering plants, 60.8% of seaweeds, 23.8% of marine invertebrates and 21.2% of marine fish are threatened (ENVIS, 2002).

1.2 Benthic biocoenosis in mangroves–*ecological services and challenges*

Mangrove ecosystem, the ecotone between terrestrial and aquatic system is the most biodiversity rich coastal habitat. Habitat heterogeneity provided by mangroves attracted most of the species to this dynamic ecosystem. Benthos (bottom dwellers) is the only resident fauna that spend their lifespan entirely in mangroves. Other fauna which are either aquatic visitor such as fishes, zooplankters depends on tidal flux to visit mangroves or few are terrestrial visitors especially birds, reptiles and mammals. The resident benthic fauna in mangroves can be classified into three functional groups based on their habitat preferences as infauna, epifauna and hyperfauna. Benthic infauna are those living within the soft muddy substratum in crevices or by making burrows, especially the polychaetes, oligochaetes and insect larvae. The epifauna lives either on the surface of sediment or on litter floors, aerial roots, pnuematophores and mainly consists of gastropods, crabs, amphipods and isopods. The hyper-fauna includes certain gastropods, insects, barnacles that occupies the tree trunks, foliage of mangrove leaves etc. Another arbitrary classification of benthos is based on the size as macrofauna, meiofauna and microfauna. Macrofauna are organisms larger than 0.5 mm, which are visible by naked eye, mainly invertebrate animals such as polychaetes, crustaceans, molluscs, echinoderms etc. Meiofauna between 0.5 mm and 0.063 mm size consists mainly of nematodes, harpacticoid copepods, foraminiferans, polychaetes, kinorhynchs, tardigrades and some of the invertebrate species living within the sediment grains temporarily as a part of their life cycles. The microfauna are unicellular organisms less than 0.063 mm that include bacteria, fungi, protozoans and blue-green algae.

Karl Mobius, in 1877 coined the term “biocoenosis” that describes the interacting organisms living together in a habitat (biotope). The benthic biocoenosis in mangrove biotope is a key factor in ecological stability and sustainability of this coastal wetland. Mangrove litter-fall provides sufficient food for the benthic fauna forming the trophic basis for many food webs (Camilleri, 1992). In addition to their trophic contribution, the structural complexity and habitat heterogeneity offered by mangrove microhabitats (pneumatophores or prop roots) help them to withstand the unfavourable and harsh environmental conditions and provide excellent shelter to fauna from predators (Primavera, 1997; Macia *et al*., 2003)

The benthic invertebrates within mangrove habitats inturn help in shaping the mangrove forests and ecological processes through their feeding, burrowing and ventilatory activities. Bioturbation (sediment reworking) by benthos can change porosity, permeability, grain-size, water-content, organic-content and erosion-threshold of sediments (Austen *et al*., 1999; Tolhurst *et al*., 2003).They also recycle the various carbon fractions among the autotrophic and heterotrophic components maintaining the energy requirements and reserves in these zones. Burrowing macrofauna greatly modifies pore water flow, increase the surface area of the sediment-air/water interface, and intensify O_2 diffusion affecting the redox equilibrium and biogeochemical processes of redox sensitive elements (sulphur and iron) (Aschenbroich *et al*., 2017). The reduced concentration of sulphide, iron and ammonium in sediments positively affects the mangrove productivity (Smith *et al*., 2009). Sediment reworking by benthos can also assist in flushing of toxic substances (Phytotoxins) and accumulated salts.

Benthic fauna can promote natural regeneration of mangrove plants by reducing competition among propagules by propagule predation especially by crabs. Benthic invertebrates such as molluscs and sesarmid crabs are the main shredders and consumers of nutritionally poor mangrove leaf litter enhancing litter turnover rates in mangrove systems and enrich the primary production (Lee, 2008). They cycle and conserve nutrients in the system including the consumption of microphyto-benthic individuals, plant debris and detritus deposited in the sediment, thus incorporating organic matter in their biomass (Koch and Wolff, 2002). Benthic fauna maintain the food chain in mangrove ecosystem and act as a food source for the fishes, shrimps etc. They also support the commercial fishery resources (crabs, shellfishes) for local population.

Benthic polychaetes, amphipods and molluscs are advantages as biological indicators of environmental change. They respond to environmental change (pollution, water quality, substrate specificity) by mortality of sensitive fauna and dominance of tolerant fauna and help to access the health of the system. They bio-accumulate the chemicals in their tissues and helps in detoxification of sediment. Nutrient enrichment (eutrophication) in a system can be scaled by change in community structure of benthos in particular of meiofauna by unusual abundance of nematodes, juvenile polychaetes whereas kinorhynchs, ostracods, harpacticoids and juvenile bivalves decrease (Widbom and Elmgren, 1988).

Benthos aid in benthic-pelagic coupling linking the bed sediments with the water column by nutrient cycling (Coull, 1999; Cummins *et al*., 2004). The flux of dissolved inorganic (mainly DIN) and organic material (mainly DOM) re-mineralised by benthic fauna enhance the pelagic primary production [Figure 1.2].

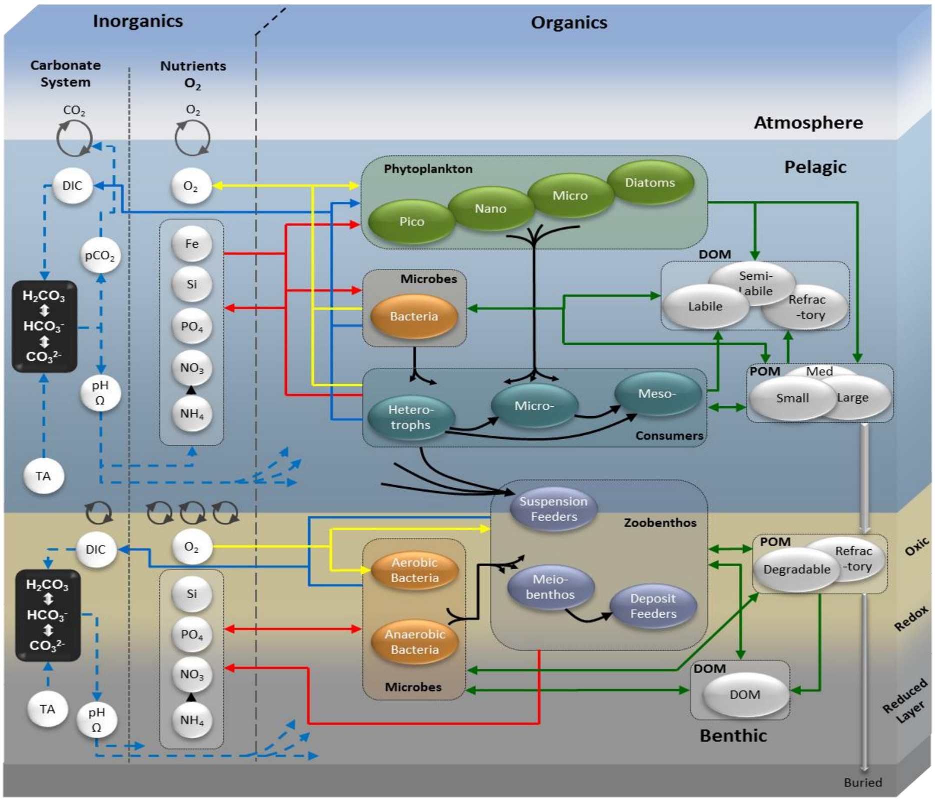


Figure 1.2 Benthic – pelagic coupling in an aquatic ecosystem linking benthic and pelagic biotope (source: http://www.enveast.ac.uk)

The active bioturbation, bio-irrigation, feeding, water pumping brought about by benthic macro, meio and microfauna increase water and sediment mixing, and thus flux of energy and matter to pelagic realm. According to Hargrave (1973) and Rowe *et al.* (1975) benthic secondary production or biomass was correlated to surface water primary production. Benthic nutrient regeneration supplied 50 to over 200 % of essential nutrients such as nitrogen and phosphorus for phytoplankton production. Sediment mixing activities also enhance the re-oxidation of reduced substances and facilitate removal of fixed nitrogen, thereby counteracting eutrophication.

The mutual interaction between benthic fauna and mangrove ecosystem has a positive influence on coastal ecosystems and human communities. But the functional efficacies of benthic biodiversity resources are not properly documented and interpreted due to difficulties in characterisation and sampling. Some methodological challenges, such as the generally high spatial heterogeneity and complexity of the mangrove habitat also evidently reduce sampling schemes. Macrobenthic and meiobenthic understanding of assemblage structure and the role of these animals in ecosystem function have ever since stagnated for a few decades.The ecological services provided by benthic fauna is summarised in the Figure 1.3.

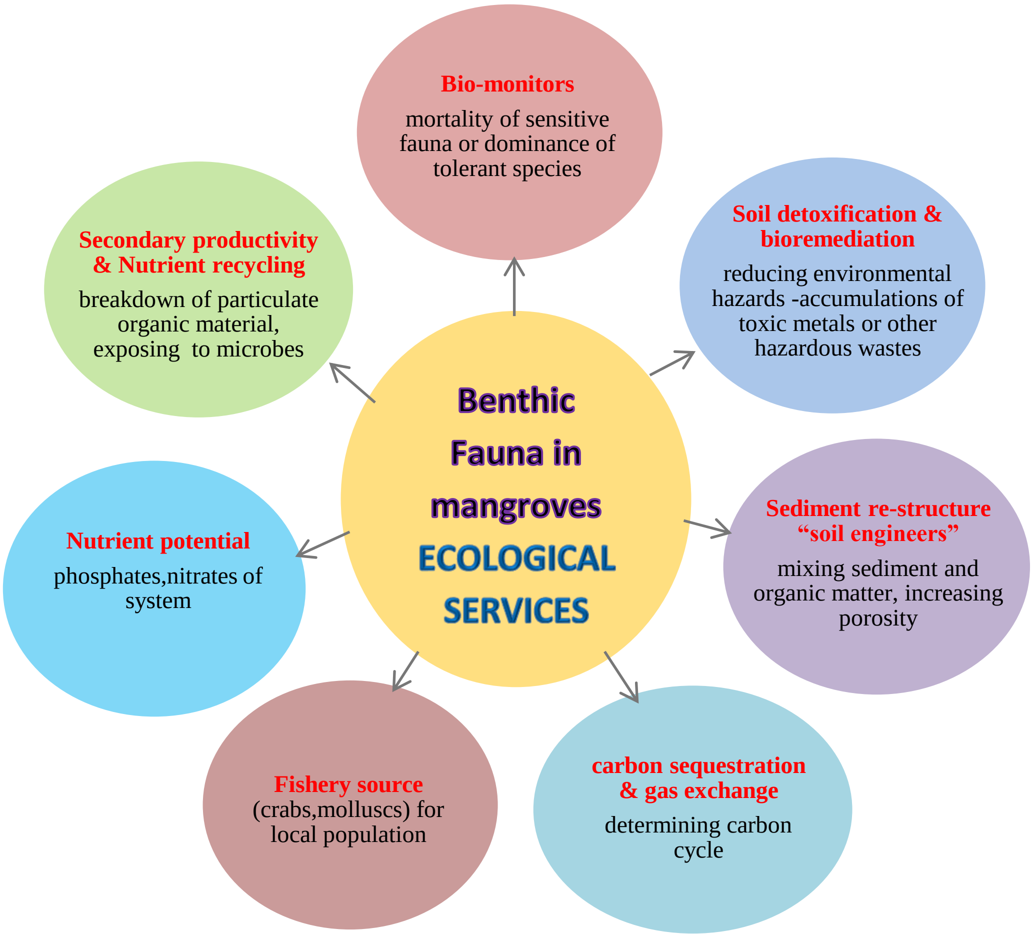


Figure 1.3 The ecological services provided by benthic fauna in mangrove forests

Even though benthic fauna provides ample of services, due to their relatively sedentary nature they cannot avoid deteriorating conditions within the water and sediment columns, instead have to face various challenges for their survival in mangrove habitat. The major challenges includes human-induced and natural disturbances such as predation, competition for resources, trophic limitation, abiotic stress including thermal stress, soil acidification, hyper salinity, hypoxia, organic pollution, human activities such as dredging and fish trawling, along with natural events such as storms and tidal fury (McLusky and Elliot, 2004). Habitat modification and changes to the structural complexity would significantly affect the diversity and abundance of benthic organisms in a mangrove system (Skilleter and Warren, 2000). The macrofaunal distribution and diversity are also susceptible to a variety of pollutants and impacts, such as metals, pesticides, hydrocarbons, sewage and altered nutrient loads (Cannicci *et al*., 2009). Although these factors have been the major contributors to the faunal changes observed over time, the severe effects of heavy metals and other chemicals are of great concern due to their bioaccumulation in faunal tissues and probable trophic transfer in higher organisms and thus cause ecosystem level perturbations.

1.3 Significance and objectives

Mangroves are considered as one of the most threatened ecosystems on the planet. The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) have warned that human infringement of mangrove habitat destruction by exploitation of land for urbanization, agriculture, aquaculture and pollution resulted in economic damages of up to $42 billion annually thus exposing ecosystems and coastal habitats to an increased risk of devastation from climate change (UNEP, 2014; Farnsworth and Ellison, 1997). The escalating destruction and degradation of mangroves have destroyed quarter of the earth's mangrove cover and even 50–80% losses in some regions (UNEP, 2014; Wolanski *et al*., 2000). The predictions on mangrove loss is alarming that, 30–40 % of coastal wetlands and 100% of mangrove forests may be lost in the next 100 years, if the present rate of loss continues (Duke *et al*., 2007). Indian mangroves are in par with other tropical countries in mangrove destruction and even 40% of Indian mangroves are reclaimed for aquaculture and agriculture alone (Upadhyay, 2002) and other losses due to tourism and coastal developments are even not predictable.

In a broad sense, mangrove loss means the loss of their ecological services, cultural services, provisional services, regulating and supporting services, culminating in the imbalance of coastal zone and loss of life supporting services. The imbalance in mangrove habitat also reflects the functionality of biotic organisms thriving in mangroves especially the resident benthic forms, the macro, meio and micro fauna. These benthic epifauna and infauna occupies all the major and minor niches in the mangrove environment residing among the stilt roots, pnuematophores, barks, soft and hard substratum, as grazers, tube dwellers, nestlers, deposit feeders, shredders, scavengers, and predators. They stabilise the mangrove sediment by maintaining the porosity, permeability, grain-size, water-content, organic-content and erosion-threshold by their bioturbation, productivity and carbon dynamics in the mangrove habitat. Benthic functional efficacies not only restrict to mangrove habitats alone, instead have profound influence on other associated coastal ecosystems (seagrass, estuaries, mudflats, coral reefs) by energy transfer through nutrient out welling, benthic–pelagic coupling, as indicators of pollution and sediment quality, trophic support and also to coastal communities as a major source of income (prawns, crabs) and livelihood support. Even though, the benthic fauna offers these multitude of functions they are neglected due to our ignorance on their community ecology and taxonomic strength from the habitats of Kerala.

The Kerala mangroves are also not different for the reasons cited above especially on the benthic fauna. These habits have also reported a sharp loss in the area from 700 Km^2 to 9 Km^2 (India State of Forest report, 2017) over the last three decades with many of the life forms getting endangered or threatened due to reclamation and various anthropogenic interventions. They have also been polluted by organic and inorganic contaminates from industrial and other activities grossly affecting the fauna and flora of the pristine habitats that easily undergoes trophic transfer from one level to another. There is also a serious lacuna in our knowledge on the status of the mangroves of the state and their ecological conditions. In this backdrop, a major research project funded by the Directorate of Environment and Climate Change (DOECC), Govt. of Kerala was implemented by Prof. (Dr.) S. Bijoy Nandan as Principal investigator on the mangrove ecosystems of south-west coast of India in the context of sustainable livelihood objectives.

The Ph.D topic entitled 'Benthic biocoenosis in the tropical mangrove stands of Kerala' has emanated from the DOECC research project to critically evolve and establish the ecology and taxonomy of the macro and meio benthic fauna from mangrove habitats of Kerala. It also provides insights on the heavy metal contamination in the mangrove sediments and bioaccumulation in macrobenthos from industrial and other anthropogenic activity in the Cochin region. The objectives of the study are thus outlined below.

- **Explore the standing stock and community organization of benthic fauna from selected mangrove stands of Kerala.**
- **Trace the environmental influence on faunal abundance and standing stock.**
- **Establish the species structure and morpho-taxonomy of amphipod crustaceans from the habitats.**
- **Determine heavy metal distribution and enrichment in mangrove sediment *vis a vis* their bioaccumulation in macrofauna**
- **Propose guidelines for the management and conservation of benthic fauna in mangrove stands of Kerala**.

Chapter 2

STUDY AREA AND GENERAL METHODS

2.1 Introduction

The Indian state of Kerala is environmentally unique as it is bordering one of the sensitive ecosystems in the world, the Arabian Sea to the west and the Western Ghats to the east between latitudes 8°.17'.30" N and 12°.47'.40" N and longitudes 74°.27'47" E and 77°.37'.12" E. Kerala's coastal belt is approximately 590 km, with an interconnected system of brackish water lakes, rivers and estuaries. Kerala experience a humid tropical climate influenced by the south-west monsoonal rain. The entry of tidal waters regularly from the sea, enrichment of estuaries and backwaters with the regular supply of fresh water flowing from the 44 perennial rivers creates a peculiar ecological environment leading to the development of unique mangrove vegetation on the fringes of the backwaters, estuaries, and creeks. Of the 14 districts in Kerala, mangroves are spread over in 10 Districts. Kannur has highest area under mangroves (755 ha), followed by Kozhikode (293 ha) and Ernakulum (260 ha) (Muraleedharan *et al*., 2009). According to one estimate, Kerala once supported about 700 km^2 of mangroves along its coast (Ramachandran *et al*., 1986). Now, the area under mangrove has dwindled significantly. According to the estimate of the Kerala Forest Department, the area under mangrove constitutes approximately 17 km^2 spread over the coastlines of 10 Districts in tiny patches. Recently Forest survey of India reported 9 km^2 of mangroves in Kerala covering districts of Kannur, Ernakulam and Kasargod (India State of Forest Report, 2017).

Cochin (Kochi), the most populous metropolitan area in Kerala is located on the southwest coast of India at 9°58′N 76°13′E, with a coastline of 48 km. Cochin is the part of Ernakulam district that grades second in extent of mangroves after Kannur district and first in maximum extent of mangrove destruction in the state. In Cochin, 600 ha of mangrove cover are seen along the Cochin coast and along Vembanad Lake (Vidyasagaran and Madhusoodanan, 2014). The mangrove islands along the Cochin coast are increasingly threatened by population pressure, aquaculture operations and mangrove environment conversion to shrimp pond. Further more industrial pollution, oil spills, storms, dredging for landfills and building ports, industrial estates and housing estates for human habitation have destroyed mangroves in Cochin with an alarming rate of 40% (Satheesh Kumar *et al*., 2011; Blasco *et al*., 2001).

2.2 Study area and Sampling design

The study is based on field collections and analysis for which monthly sampling was conducted from six selected sites in Cochin mangroves for 24 months from 2010 to 2012 for the collection of macrobenthic fauna along with the environmental parameters, whereas the sediment and benthic fauna for heavy metal analysis were collected on a bimonthly basis during 2010-2012 period. At the same time meiobenthic collections and analysis were conducted on a seasonal basis for 2011-12 periods [Figure 2.1]. One time field collections of benthic fauna from selected mangrove areas of 10 coastal districts from Kasaragod to Thiruvananthapuram were also accomplished during 2012-2013 period.

The location of each study sites were selected based on accessibility and mangrove floral diversity. The geographic positions were fixed using Global Positioning System (GPS- Magellan ® Triton 200/300) and necessary statistical calibrations. Based on prevailing meteorological conditions, three seasons were distinguished, the pre-monsoon (Prm) (February – May), monsoon (Mon) (June – September) and post-monsoon (Pom) (October –January) period.

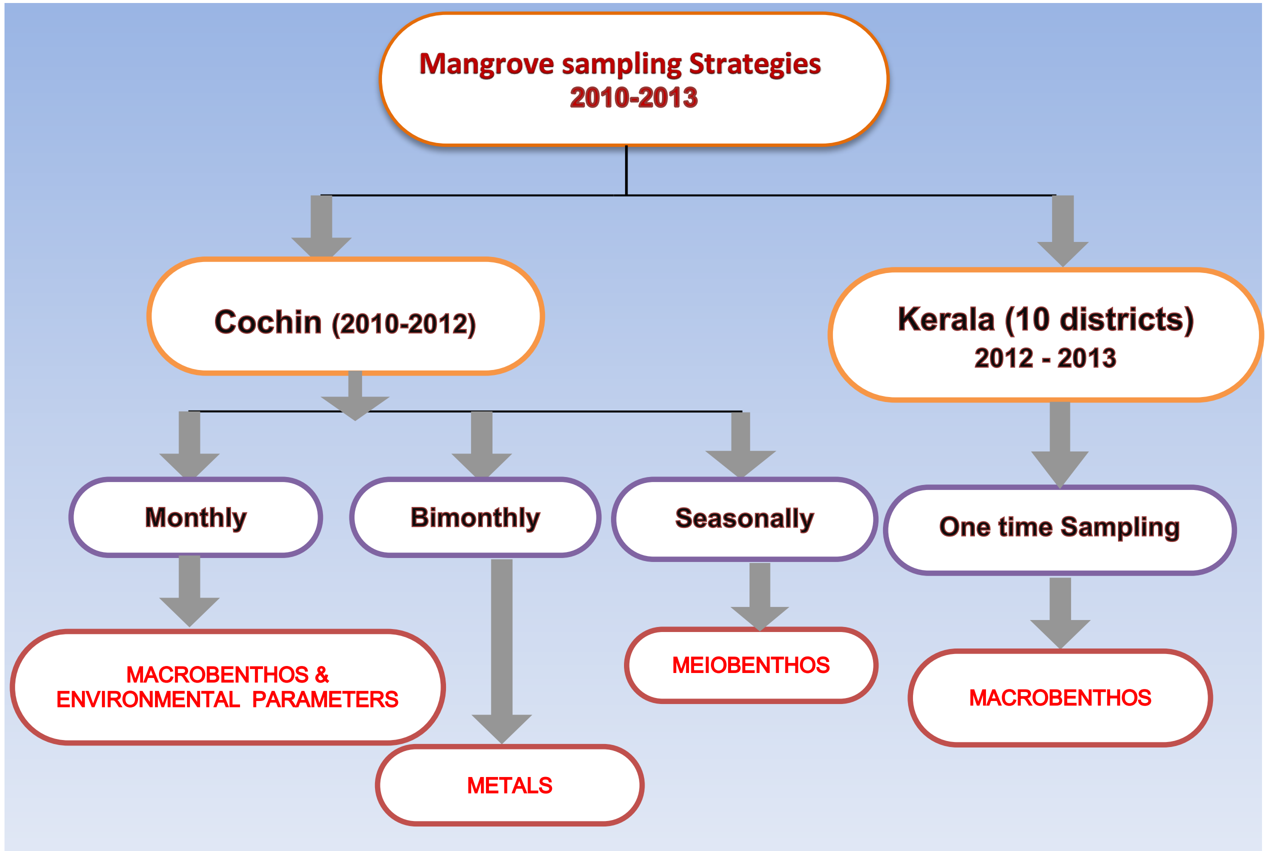


Figure 2.1 Sampling strategies of various parameters in mangroves of Kerala and Cochin

2.2.1 Mangrove study sites in Kerala

Macrobenthic samples were collected from 10 districts of Kerala [Figure 2.2] extending from Manjeswaram (12º 42' 44" N, 74º 53'14" E) in Kasargod district in the north to Akkulam (8°31'N 76°53'E) in Thiruvananthapuram district in the south [Table 2.1].

Figure 2.2 Map of mangrove sampling sites from different districts of Kerala during 2012-2013 period.

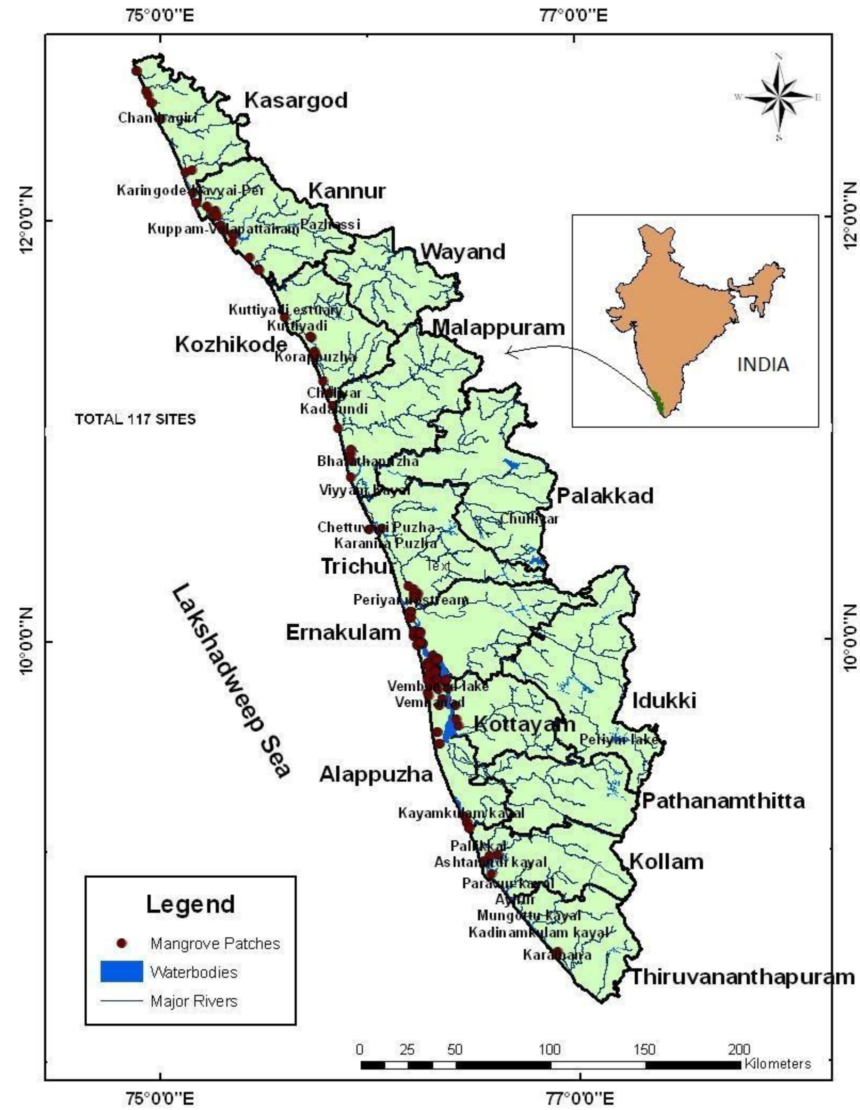


Table 2.1 Macrobenthic sampling locations from different mangrove sites of coastal districts of Kerala.

Districts	Sampling sites	Position(GPS)
Kasargod	Manjeswaram	12°42’N 75°53’E
	Kumbala	12°36’N 74°56’E
	Mogral Puthur	12°33’N 74°57’E
Kannur	Pazhayangadi	12°1’N 75°16’E
	Thavam	11°57’N 75°18’E
	Ezhome	12°1’N 75°16’E
Kozhikode	Kallai	11°45’N 75°45’E
	Kadalundi	11°7’N 75°49’E
Malappuram	Tanur	11°0’N 75°51’E
Ernakulam	Puthuvype	9°35’N 76°8’E
	Valanthakad	9°55’N 76°19’E
	Malippuram	10°0’N 76°7’E
Kottayam	Nerekadavu	9°46’N 76°22’E
Alappuzha	Poochackal	9°48’N 76°21’E
	Aroor	9°52’N 76°19’E
	Ezhupunna	9°50’N 76°17’E
Kollam	Munrothuruth	8°59’N 76°36’E
Thiruvananthapuram	Akkulam	8°31’N 76°53’E

2.2.2 Mangrove study sites in Cochin

Six stations were selected for sampling environmental, benthic and heavy metals from Cochin mangroves [Figure 2.3 and Figure 2.4].The station 1 (S1) is in Aroor region (9°52’N,76°18’E) which is a shallow zone with depth not more than 0.8-1m. This is a closed mangrove zone surrounded by few settlements and is dotted with small patches of mangroves which have rich biodiversity. Tidal inundation directly influences the zone. Several seafood industries, boat construction yards are major source of pollutants.

The station 2 (S2) (9°56’N, 76°31E) was 500m away from station 1 Aroor. This zone has an average depth of 0.75-1m.This station has a narrow channel of running water. Construction of road severely impacted the area and destroyed many mangroves.

The station 3 (S3) is at Puthuvype region (9°35’N, 76°13E), a part of Vypin island. This is a dense and open mangrove zone which has direct connection with the nearby sea. Fishing activities are common in this area. This zone is very closer to LNG terminal and has an average depth of 3-4m. These mangroves are under extreme pressure of urbanisation and industrialisation, which has led to mass deterioration of the area.

Station 4 (S4) is Malippuram (10°1’N,76°12E), a moderately dense mangrove zone adjoining the Arabian Sea with an average depth of 0.5-1m. The area is utilised for aquaculture and recreational activities. A part of this mangrove stretch was also converted to a mangrove park and has become a tourist spot of Vypin Island.

Station 5 (S5) is Valanthakad (Arkathadam) (9°55’N,76°19E) which is an island mangrove site that has direct connection with Vembanad lake and has an average depth of 1-1.5 m. The site is away from Cochin city and sampling was carried out mainly by using small boats (Vallam).This area is noted for aquaculture practices such as fish farming, mussel culture and an attractive site for migratory birds.

Station 6 (S6) is also a part of Valanthakad (Magranazhi) island (9°56’N,76°14E) which is half a kilometre away and have similar ecology as station 5. This zone has diverse mangrove vegetation and was found to be most undisturbed mangroves with dominance of *Acanthus ilicifolius*. This site has an average depth of 1-1.5m.

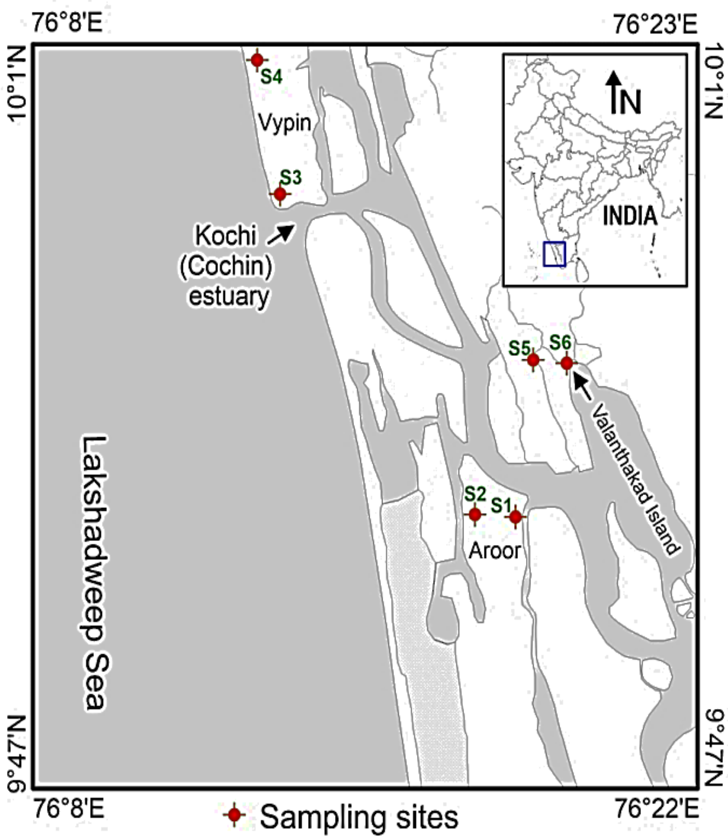


Figure 2.3 Map showing the stations selected for study various parameters from Cochin mangrove region during 2010-2012 period.

Station 1 (S1) **Aroor south**	**Station 2 (S2)** **Aroor north**
	

Station 3 (S2)
Puthuvype

Station 4 (S4)
Malippuram

Station 5 (S5)
Valanthakad-Arkathadam

Station 6 (S6)
Valanthakad-Magranazhi

Figure 2.4 Mangrove stations in Cochin selected for study during 2010-2012 period.

2.3 Analytical methods

2.3.1 Mangrove density

Mangrove plant density (ind.ha^{-1}) in each site was taken using quadrat method suggested by Cintron and Novelli (1984). Five quadrats of the size 5mx5m ($25m^2$) were laid on each site considering the representativeness, importance and accessibility. The plant species in the quadrat were identified based on Tomlinson (1986) and counted to obtain the quantitative data. Density of mangrove species is calculated as:

Density = Number of individuals of a species / Total area sampled

2.3.2 Hydrographic parameters

Rainfall data was obtained from India Meteorological Department (IMD) (www.imd.gov.in). Water samples were collected 10 cm below the surface water from the sampling stations using pre-cleaned plastic containers (500 mL) and BOD bottles forenoon during high tide (Satheeshkumar and Khan,2012; Gupta,2009). The water temperature was measured in-situ, using a 0–50°C precision thermometer. The pH of water samples were determined with a water analyser (Systronics model no. 371; accuracy ± 0.01), having a glass electrode and a calomel electrode as reference.

Salinity was measured by Mohr-Knudsen method (Strickland and Parsons, 1972). The halides present in the water samples were treated with standard silver nitrate solution and potassium chromate as indicator. The values were recorded as Practical Salinity Units (PSU). The samples for dissolved oxygen (DO) was taken in a 125 ml stoppered glass containers taking care that no air bubbles has trapped in the sample. The samples for dissolved oxygen were fixed immediately with manganous chloride solution (Winkler A) followed by alkaline potassium iodide (Winkler B) solution and estimated by the modified Winkler method (APHA, 2005). The results were expressed in the unit, milligrams per litre (mg/L). Turbidity was measured using Nephelo–Turbidity meter. Systronics model no: 132 (APHA, 2005). 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).

2.3.3 Sediment parameters

Sediment samples were collected at monthly intervals by standard van-Veen grab having mouth area of 0.04 m^2. **Sediment temperature** was recorded by a alcohol glass thermometer (0 - 100 ± 0.01 °C) immediately after the collection of sediment samples in the grab. **Sediment pH** was measured in the field by portable pH meter (Systronics model no. 371; accuracy ± 0.01) and having a glass electrode and a calomel electrode as a reference. The **redox potential (Eh)** was measured on the field using a portable Eh meter (Systronics model no.318) relative to a standard hydrogen electrode with a saturated calomel electrode as reference and expressed in mV. After onsite examination, soil samples were brought to the laboratory in clean polythene bags, air dried and stored for further analysis. The **sediment particle size** and composition of sand, silt, clay in the sediment samples were determined by Pipette method after removing the inorganic carbonates using HCl and the organic matter using H_2O_2 (Folk, 1974).

Another portion was dried to a constant weight around 60 °C utilised for estimation of **organic carbon,** by modified wet oxidation method (El-Wakeel and Riley, 1957; Nelson and Sommers, 1982; Trivedy and Goel, 1986). **Organic matter** content of sediment was calculated by multiplying organic carbon values by Van Bemmelen factor of 1.724 (Trask, 1939). Organic matter and organic carbon expressed as g kg^{-1}.**Total phosphorus** and **total sulphur** in sediment samples were determined using Inductively coupled plasma-atomic emission spectrometer (ICP-AES, Thermo Electron IRIS INTREPID II XSP DUO) (Liu et al.,2015).

2.3.4 Benthic fauna – collection, preservation and identification

a. Macrobenthic fauna

Macrofauna was collected from selected mangrove sites by using standard benthic grabs. For macrofauna, monthly duplicate samples were taken from each site by using standard van Veen grab of size 0.04 m^2 and the sediment samples were sieved onsite through a 0.5 mm mesh sieve. The sieved macrobenthos with residual sediment samples were then preserved in 4 - 7 % neutral buffered formaldehyde containing Rose Bengal, which facilitate sorting of the organisms from other components of the soil in the laboratory (Holme and McIntyre, 1984; Eleftheriou and McIntyre, 2005). The sieved samples were then labelled and stored for further examination. For qualitative enumeration, each sample was examined under a binocular microscope (Leica DM model 500). The organisms were separated into different taxonomic groups (malacostracans, polychaetes, molluscs, and other groups) and preserved in 5 % neutral buffered formaldehyde for further analysis. Later each specimen was subjected to detailed identification up to the lowest possible taxonomic level. The number of each organism was enumerated. The numerical abundance was expressed in individuals per meter square ($Ind.m^{-2}$), the live organisms were only considered for the numerical count of individuals in the sample. Many of the bivalves and gastropods were cut open to confirm staining of biological tissue. Numerous taxonomic references were used for identification of macrofaunal species (Barnard, 1935; Fauvel, 1953; Fauchald, 1977; Bradbury and Williams, 1999; Day, 1967; Chapman, 2007; Chilton, 1921; Subramanian and Sivaramakrishnan, 2007).

Taxonomically important parts were dissected out and mounted on glass slides and observed under higher magnifications. Diagrams were drawn using drawing tube fitted to Olympus CX2li bright field compound microscope and measurements were taken with a calibrated ocular micrometer. Photographs of organisms were taken in Leica 200 Phase contrast epiflourescence microscope. For Scanning Electron Microscopy, material was dehydrated in ethanol series (30%, 50%, 70%, 90%, 100%), fixed in glutaraldehyde, coated with gold and observed in Jeol SEM (JSM-6390 LV). The taxonomic status of species was corroborated according to World Register of Marine Species (WoRMS) website (www.marinespecies.org) or specialized literature (WoRMS, 2019). Macrofaunal biomass was estimated by the wet weight method using a high precision electronic balance (Sartorius AG–ME215P, Germany with a precision of 0.01 mg) and was expressed in g/m^2. The shells of molluscs and the tubes of the tube dwelling polychaetes were removed prior to weighing. Those organisms possessing wet weight more than 0.5 g were not extrapolated into 1 m^2 instead, taken as such to avoid a biased picture, but larger specimens (> 3 g) were not included when considering mean values.

b. Meiobenthic fauna

After successful extraction of the van Veen grab sampler from water column, the meiobenthic sub-samples was collected with a hand held graduated glass corer of 2.5 cm x 30 cm length from the topmost layer (5 cm) of sediment in the grab hauls (Eleftherioo and Mc Intyre, 2005; Giere, 2009). Duplicate core samples were taken at each sampling station from separate grab hauls. All collected sediment fractions were then immediately transferred into separately labelled plastic containers containing 8% of $MgCl_2$ and 4% of neutral formalin (Giere, 2009). It is then stained with Rose Bengal in 70% molecular grade ethanol (Merck, Germany) preservative before sieving for ease of identification of transparent organisms as it is known to adsorb onto proteins resulting in an intensively pink colored cytoplasm (Walton, 1952), then sieved through two layers of sieves, in the top one with a mesh size of 500 µm and the bottom one with 63-µm mesh size. The filtrate retained in the 63 µm mesh was then transferred into petridishes containing water. The animals were classified and enumerated using a binocular microscope (Leica DM model 500) to possible taxonomic levels and preserved in 4 % neutral buffered formaldehyde (Giere, 2009). The numerical abundance of organisms has been extrapolated into individual/10cm^2 (ind.10 cm^{-2}).The meiofaunal organisms were identified only up to group level.

2.3.5 Marine biotic indices

Ecological status of the mangrove habitat was assessed using the benthic macrofauna based on biotic indices such as AZTI's Marine Biotic Index (AMBI) and BENTIX. These indices are used in this study to assess the healthy status of Cochin mangrove habitat and also determine the tolerant and sensitive macrobenthic fauna to heavy metals and other pollutants.

a. AZTI-Marine Biotic Index (AMBI)

The biotic index AMBI was calculated using the software packages AMBI v5.0 freely available on the AZTI's website (http://www.azti.es), and it is developed based on the proportion of five ecological groups in the benthic community. The five ecological groups (EG) were assigned based on the sensitivity of each species to an increasing gradient of stress or disturbance in the benthic environment (Borja *et al*., 2000; Borja *et al*., 2007). They were EG1 (species highly sensitive to organic matter enrichment), EG2 (species indifferent to enrichment and found in low densities), EG3 (species tolerant to high organic matter enrichment), EG4 (second-order opportunistic species favoured by excess organic matter enrichment) and EG5 (first-order opportunistic species). Since some of the species identified from the estuary have not been included in the species list of AZTI, the procedure described by Borja *et al*. (2007) has been followed when assigning new species. The AMBI index was calculated using following formula:

AMBI = 0EG1 + 1.5EG2 + 3EG3 + 4.5EG4 + 6EG5

The AMBI index can vary from zero (high ecological status) to seven (bad ecological status). The values between 0 to 1.2 represent the undisturbed condition and that for the slightly disturbed situation was 1.2 to 3.3, moderately disturbed ranged from 3.3 to 5, heavily disturbed was between 5 to 6 and extremely disturbed conditions denote value between 6 to 7 in AMBI index (Borja *et al*., 2000).

b. BENTIX

The BENTIX index has been designed for the assessment of the impact caused by general stress factors and does not discriminate amongst natural and anthropogenic disturbances (Simboura and Zenetos, 2002). To calculate the BENTIX index, the same ecological groups were used with some proportional difference, EG1 and EG2 were placed in GI, and EG3, EG4, and EG5 were in G2 (Simboura and Zenetos, 2002).The BENTIX was calculated using following formula:

BENTIX = 6GI+2GII

Where, GI = EG1 + EG2 and GII = EG3 + EG4 + EG5. The results for the BENTIX index can vary from zero (bad ecological status) to six (high ecological status). The value less than 2 indicate the bad ecological condition of an ecosystem while between 2 to 2.5 poor and that for moderate condition ranged between 2.5 to 3.5 while good condition among 3.5 to 4.5 and normal or pristine environment indicated by the value between 4.5 to 6 in the soft bottom macrobenthic communities (Simboura and Zenetos, 2002).

2.3.6 Heavy metal analysis in the sediment

Sediment samples for the analysis of heavy metals such as aluminium (Al), iron (Fe), chromium (Cr), Zinc (Zn), Nickel (Ni), cadmium (Cd), mercury (Hg), lithium (Li), strontium (Sr), silver (Ag), arsenic (As), cobalt (Co), lead (Pb), copper (Cu), boron (B), barium (Ba), manganese (Mn) were collected from upper 10 cm using van-Veen grab of 0.04 m^2 and kept in clean plastic bags and brought to the lab and oven dried to a constant weight at 60°c and then crushed using mortar and pestle and sieved through 2mm sieve. For metal analysis, approximately 0.5g of homogenised dry sediment samples were accurately weighed and digested using nitric acid and perchloric acid in 5:1 ratio in KEL PLUS digestion unit (model KES 04L). The resultant sample was filtered using 42 mm filter paper then made up the volume to 50 ml using Milli-Q water (AOAC, 1995). Six blanks were also run to qualify the digestion procedures. The digested samples were analysed for heavy metals in Inductively Coupled Plasma-Atomic Emission Spectrometer (Thermo Electron IRIS INTREPID II XSP DUO) at DST-SAIF, Sophisticated Test and Instrumentation Centre, CUSAT. Working standards of 0.1 ppm, 0.2 ppm, 0.5 ppm, 1ppm, 2 ppm, 5 ppm, 10 ppm were prepared for calibration and analysis using Merck ICP single/multi element 1000 ppm standard.

Sediment quality analysis was carried out using Sediment Guidance Value (SGV) and by various pollution indices. The most commonly used indices were background enrichment indices or Enrichment factor, *EF* (Abrahim and Parker, 2008), Geoaccumulation index, I_{geo} (Muller, 1979), Contamination Factor, *CF* (Hakanson, 1980) and Pollution Load Index, *PLI* (Tomlinson *et al*., 1980).

a. Sediment Quality Guidelines (SQG)

Ecological risk and toxicity of the metals were analysed by comparing the metal concentration with reference values that were developed by the U.S. National Oceanic and Atmospheric Administration (NOAA). NOAA Screening Quick

Reference Tables (SQuiRTs) uses two screening standards, Effect Range Low (ERL) and Effect range Medium (ERM) that consider all adverse biological effects associated with elevated metal concentrations (Long *et al*., 1995; MacDonald *et al*., 1996). The concentrations below the ERL value represent a minimal effects range, concentrations equal to and above the ERL but below the ERM represent a possible effects range within which adverse biological effects would occasionally occur, concentrations equivalent to and above the ERM value represent adverse biological effects would frequently occur (Buchman, 2008).The ERL and ERM values of selected metals were given in Table 2.2

Table 2.2. Sediment quality guidelines of selected metals (mg/kg) by NOAA (SQuiRTs) (Buchman, 2008).

SQG	As	Cr	Cd	Cu	Pb	Hg	Ni	Ag	Zn
ERL	8.2	81	1.2	34	46.7	0.15	20.9	1.0	150
ERM	70	370	9.6	270	218	0.71	51.6	3.7	410

b. Enrichment factor (EF)

Enrichment factor helps to analyse the magnitude of anthropogenic contributions of metals (Chaudhuri *et al*., 2014). EF value ranging from 0.5–1.5 suggests the lithospheric or crustal origin of metals in sediment and values above 1.5 (EF>1.5) is said to have an anthropogenic origin (Abrahim and Parker, 2008; Zhang and Liu, 2002). The enrichment factor is calculated by equation

$$EF = (M_s/Al_s) / (M_b/Al_b)$$

Where M_s is the content of the metal in the sample, M_b is the world shale average of the metal, Al_s is the content of Al in the sample, and Al_b is the world shale average of Al.

The EF values were interpreted as described by Chen *et al*. (2007) where EF<1 indicates no enrichment, EF<3 is minor enrichment, EF=3-5 is moderate enrichment, EF=5-10 is moderately severe enrichment, EF=10-25 is severe enrichment, EF=25-50 is very severe enrichment and EF>50 is extremely severe enrichment.

c. Geoaccumulation index (I_{geo})

I_{geo} index derived by Muller (1979) is one of the reliable index to calculate the pollution status of a system. It can be calculated using the equation

$$I_{geo} = log_2 (C_n /1.5B_n)$$

Where in, C_n the concentration of the metal in the sample and *Bn* is the background metal concentration in average shale (Turekian and Wedepohl, 1961). The factor 1.5 is the background matrix correction factor to minimise variation due to lithogenic effects. Muller (1979) distinguished 7 classes based on the I_{geo} value as: < 0 = practically unpolluted, 0–1 = unpolluted to moderately polluted, 1–2 = moderately polluted, 2–3 = moderately to strongly polluted, 3–4 = strongly polluted, 4–5 = strongly to extremely polluted, and >5= extremely polluted.

d. Contamination factor (CF)

The metal contamination of sediment is often expressed in terms of a contamination factor (Hakanson, 1980). It gives a quantitative value of contamination by pollutants in an ecological system. It is represented as,

Contamination Factor, $CF = Cn/Bn$

Where, *Cn* is the concentration of the metal in the sample and *Bn* is the background metal concentration in average shale (Turekian and Wedepohl, 1961). CF is widely used to compute the extent and degree of metal pollution (Cevik *et al*., 2009). CF values were interpreted as $CF < 1$ = low contamination, $1 \leq CF \geq 3$ = moderate contamination, $3 \leq CF \geq 6$ = considerable contamination and $CF > 6$ indicates very high contamination (Hakanson, 1980).

e. Pollution Load Index (PLI)

PLI proposed by Tomlinson *et al*. (1980) is a widely used index to access overall pollution loadings of heavy metals and its contamination level (Ray *et al*., 2006), which is the geometric mean of the contamination factor of each metal present in the study area. It is represented as

$$PLI = CF_1 \times CF_2 \times CF_3 \times \ldots\ldots CF_n)^{1/n}$$

Where n represents the number of metals and CF represents the contamination factor for the respective metals. According to Tomlinson *et al*. (1980), PLI = 0 indicates unpolluted state, PLI=1 lower pollution due to the presence of contaminants, PLI > 1 polluted sediment.

2.3.7 Heavy metal analysis in macrofauna

Macrobenthic fauna was collected using van-Veen grab of $0.04m^2$, sieved and sorted into taxonomic groups such as polychaetes, amphipods, tanaids, bivalves, penaeids etc. Bivalve tissues were separated from shells and oven dried along with other macrofauna at 60^oc to a constant weight. Then 0.2 g of dried sample were digested using nitric acid and perchloric acid in 5:1 ratio in KEL PLUS digestion unit (model KES 04L). The resultant sample was filtered to make up the volume to 25 ml using Milli-Q water (AOAC, 1995). The mineralised samples were then analysed for metals (Cd, Pb, Zn, Li, Cr, Ag) using Inductively Coupled Plasma-Optical Emission Spectrometer (Perkin Elmer Inc. USA, Optima: 2000DV (APHA, 2012) at Central Institute of Fishery Technology (CIFT), Kochi. **Bioaccumulation factor** (BAF) was calculated according to Klavinš *et al*. (1998) as

BAF = M tissue / M sediment

where, M tissue is metal concentration in soft tissue;

M sediment is metal concentration in sediment.

2.3.8 Statistical Analysis

The statistical analysis was performed by SPSS *v*.16 (Statistical Programme for Social Sciences) software for ANOVA, Pearson correlation and Principal component analysis (varimax rotated). The PRIMER *v* 6.1 (Plymouth Routines in Multivariate Ecological Research, version), was employed for univariate analysis (Shannon diversity, Margalef richness, Pielou's evenness, Simpson dominance index and taxonomic diversity / taxonomic distinctness index) and multivariate analysis

(Bray-Curtis similarity matrix, similarity profile test (SIMPROF), ANOSIM, *k*-dominance plot, Abundance Biomass Comparison (ABC) curve, similarity percentages (SIMPER), Species accumulation plots and Principal Component Analysis (PCA). RDA (Redundancy Analysis) was performed using CANOCO *v*.4.5. Plotting of data was done using Origin *v*.8, Microsoft Excel *v*.2010, SPSS *v*.16 and PRIMER *v*. 6.

a. Univariate methods of diversity indices

The **Shannon diversity index** (H’) was calculated from log transformed data on benthic assemblages in the mangrove site which explains both abundance and evenness of species present in the community (Shannon and Weaver, 1949). The index value will be high in samples that have large numbers of unique species or have greater species evenness. The species richness was tested by **Margalef’s index** (d), and it measures the number of species present for a given number of individuals (Margalef, 1958). While species equitability was tested by **Pielou’s index** (J’), species equitability or evenness shows how evenly the individuals have been distributed among the different species, and species dominance shows the dominance of particular species among a given number of individuals (Pielou, 1966). The **Simpson's index** (λ’) is a measure of both the richness and proportion (percentage) of each species (Simpson, 1949).

b. TAXDTEST analysis

Taxonomic diversity and distinctness are measures of taxonomic relatedness of individuals or species in a sample (Clarke and Warwick, 2001; Warwick and Clarke, 1998). This concept of taxonomic relatedness is totally independent of the numbers of species present (species richness) but on taxonomic spread. Average taxonomic distinctness index (Δ +) and variation in taxonomic distinctness (Λ+) were used to construct funnel plots to test for any significant variation of species from the expectation (Clarke and Warwick, 2001). These are unique ways to evaluate biological diversity where unimpacted assemblages of species have a wider taxonomic spread and the species belong to many different genera, families, orders, classes and phyla, however in impacted assemblages taxonomic spread is minimised. Warwick and Clarke (1998) reported that chronically disturbed locations would exhibit greater variation and reduced taxonomic distinctness.

c. Species accumulation plot

The number of species or species richness in a species assemblage is a significant measure of biodiversity. The species accumulation curve is the graphical representation of the sampling process, that measure the rate of accumulation of different species (expected number of species) as the area sampled is increased (Sanders, 1968; Palmer, 1990). Species accumulation curves have also been used by ecologists to perform quantitative comparison among species assemblages. The species accumulation plot for the macrofaunal grab samples from the mangrove was prepared using PRIMER *v*6, which helps to determine if the species collected during the survey adequately describe the actual species composition of the study area.

d. Species Estimator

In order to estimate the species richness of macrobenthic fauna, various species estimators such as Chao 1 (Chao's estimator based on number of rare species) Chao 2 (Chao's estimator using presence-absence data), Jacknife 1 (based on species that only occur in one sample) Jacknife 2 (Second order jacknife estimator), Bootstrap (based on proportion of quadrats containing each specie s), UGE (Calculated species accumulation curve (Ugland *et al.*, 2003), SOBS (Curve of observed species counts) and MM (Michaelis-Menton Curve fitted to observed S curve) were done in PRIMERv.6.

e. *k*-dominance plot

The *k*-dominance curve is a powerful tool for measuring dominance and abundance trends in communities over time. *k*-dominance curves are the cumulative ranked abundance against a log species rank (Jennings *et al.*, 2001). The logic behind the use of these curves as indicators is that only the subset of species that can tolerate perturbation will thrive and the rest will decline or disappear. Thus, the steepest and most elevated curve shows the lowest diversity and the most perturbed system state (Rice, 2000). This metric has wide application for measuring changes in species assemblages and pollution effects on macrobenthos (Clarke, 1990).The curve of J shaped representing the dominance of opportunistic species (disturbed condition) whereas S shaped curve indicate occurrence of conservative species (undisturbed condition).

f. Abundance Biomass Comparison curve (ABC plot)

The plot is used to evaluate the disturbances based on the trend of ABC curve at the particular site without any reference site (Warwick, 1986). Uniformity in the distribution of abundance and biomass values represents the level of stress in the community. In undisturbed communities the biomass curve lies above the curve for abundance. Under moderate pollution (or disturbance), the biomass and abundance curves are closely coincident and may cross each other one or more times. In polluted condition, abundance curve lies above the biomass curve throughout its length. The W- value (Warwick value) were used to statistically define the relationship between curves and quantify the level of stress that a community experiences. When the biomass curve is above the abundance curve the W-value will be positive and will be negative when the abundance curve is above the biomass curve, with intermediate cases tending toward zero.

g. Bray-Curtis similarity index

Bray-Curtis similarity analysis was carried out to find out the similarities between benthic groups after suitable transformation (square root) for the species-abundance data to group the samples with similar community composition following the procedure described by Clarke and Warwick (1994). Hierarchical clustering methods are commonly used and the similarity percentage was used to determine the degree of similarity. The dendrogram with the X-axis representing the full set of samples and the Y-axis defining the similarity level at which the samples or groups are fused.

h. Similarity Profile Analysis (SIMPROF)

SIMPROF test was carried out for detecting statistically significant cluster (Clarke and Gorley, 2006). It conducts a series of permutation tests to determine if clusters in the dendrogram have statistically significant structure.

i. Analysis of Similarity (ANOSIM)

It is a non-parametric statistical test operates on a ranked dissimilarity matrix. ANOSIM significance test was performed in order to test for significant differences between two or more groups of sampling units. Here, the significance level was calculated by referring the observed value of R to its permutation distribution (Clarke and Warwick, 2001). R value varied between -1 to +1. When R value close to zero, denote the clear distinction between samples (Clarke *et al*., 2006).

j. Similarity Percentages Routine (SIMPER)

This analysis assesses the average percentage contribution of individual variables to the dissimilarity between objects in a Bray-Curtis dissimilarity matrix. This allows observing the variables that are important in contributing any similarity/difference between groups detected by methods such as ANOSIM.

k. Principal component analysis (PCA)

Principal component analysis (PCA) was also conducted on environmental data to detect trends of variation of ecological characteristics across the study area (Jolliffe, 2002). This analysis also uses an ordination plot to project the points of higher similarities closer together while samples more dissimilar are further apart. Unlike biological data, environmental data have mixed estimation scales, and similarity methods, such as normalised Euclidean distance is used in PCA (Clarke and Gorley, 2006). A useful exercise before performing PCA is to examine the environmental data in a Draftsman's scatter plot to ascertain whether there are variables that is highly correlated with one another, which may then be omitted from the PCA. In this study, significant environmental variables measured have been included for the PCA.

All the above mentioned analysis was performed using **PRIMER *v*.6 program** (Clarke and Gorley, 2006).

l. ANOVA (Analysis of variance)

It was computed by using SPSS *v*.16 to test statistically significant spatio-temporal variation between the selected parameters. Homogenity test and normality test were carried out before doing ANOVA. For non-homogenous data non-parametric test were carried out. The Tukey HSD (Honest Significant Difference) was used for post-hoc analysis to determine the groups which differ in a sample.

m. Factor analysis or Principal Component Analysis (Varimax rotated)

Principal component analysis (PCA) was performed using SPSS *v*.16 to establish possible factors that contribute towards the metal concentrations and their probable source. The number of significant principal components (PC) was selected on the basis of Varimax orthogonal rotation with Kaiser normalisation. Varimax orthogonal rotation was applied in order to identify the variables that are more significant for each factor based on the significance of their correlations that are expressed as factor loadings (Buckley *et al*., 1995 and Davis, 2002) with eigenvalue greater than 1. The rotated component matrix, sometimes referred to as the loadings, is the key output of principal components analysis (Kaiser, 1958). PCA is a standard approach to explore the variability in multivariate data by converting the observations of possibly correlated variables into a set of linearly independent variables, namely principal components (PCs), and has been frequently used to investigate environmental pollution with respect to different factors, including major pollutants, influential factors, or possible sources (Harrison *et al*., 1996). By transforming the original variables into a number of PCs, the first principal component (PC1) has the largest possible variance to account for as much of the variability in the observations as possible, while the succeeding component (e.g., PC2, the second principal component) has the largest variance uncorrelated with those of the previous components. The loading value was used to represent the correlation between the observation and component. Loading values larger than 0.7, between 0.5 and 0.7, and less than 0.5 indicate strong, medium, and weak correlations, respectively.

n. Pearson correlation analysis

Correlation is the test statistics that measures the statistical relationship, or association, between two continuous variables using SPSS *v*.16 software. It is known as the best method of measuring the association between variables of interest because it is based on the method of covariance. It gives information about the magnitude of the association, or correlation, as well as the direction of the relationship. A Pearson correlation is a number between -1 and 1 that indicates the extent to which two variables are linearly related. If the value is near ± 1, then it is said to be a perfect correlation: as one variable increases, the other variable tends to also increase (if positive) or decrease (if negative). If the coefficient value lies between ± 0.50 and ± 1, then it is said to be a strong correlation. If the value lies between ± 0.30 and ± 0.49, then it is said to be a medium correlation. When the value lies below ±.29, then it is said to be a small correlation. When the value is zero, then there is no correlation.

o. Redundancy analysis

Redundancy analysis (RDA) is the canonical version of principal component analysis (PCA) performed using CANOCO *v*.4.5. RDA is a direct gradient analysis technique and a constraint ordination which summarises the linear relationships of both the species and the environmental matrices and attempt to explain variability in species composition between sites by differences in measured environmental variables. In RDA triplot, vectors pointing in the same direction indicate a positive correlation while those in the opposite direction indicate a negative correlation. The vectors pointing in a perpendicular direction indicate no correlation between the parameters.

Chapter 3

FLORAL DIVERSITY AND PHYSICO-CHEMICAL CHARACTERISTICS OF SELECTED MANGROVE HABITATS

3.1 Introduction

Biocoenosis of benthic fauna in mangrove habitats invariably dependent on the abiotic components including hydrological, meterological and sedimentological parameters and the biotic counterpart, the mangrove flora. The physical, chemical and biological processes operating in mangrove ecosystems sustain the mangroves productivity by wide range of interactions among different structural components such as soil, water, flora and fauna of the ecosystem.

3.1.1 Mangrove floral diversity

Mangrove vegetation is critical in determining the coastal community structure, diversity of fauna providing various microhabitats and also as the nutrient sources driving the productivity of mangrove and other coastal ecosystems (Camilleri, 1992). They are significant not only in detrital and nutrient near shore production but also as filters for land runoff, protection from coastal storms, sediment traps, and sediment stabilizers (Fenchel, 1977; Adam, 1990). Mangrove vegetation has lower diversity compared to other tropical ecosystems (Duke *et al*., 1998). In spite of their lower diversity their functionality was higher to make up a completely interacting self-dependent ecosystem. Floristic diversity equates structural and functional diversity and are repository of biodiversity (Duke, 1992; Duke *et al*., 1998). The structural diversity provide habitat, and functional diversity provide food sources that links the dependent fauna. The diversity and distribution of mangroves are constrained by various physical, environmental, climatic and biological factors (Smith, 1992; Chapman, 1976; Hutchings and Saenger, 1987;

Duke, 1992). The factors which limit species presence and growth, will also limit the functions and benefits of mangroves [Figure 3.1].

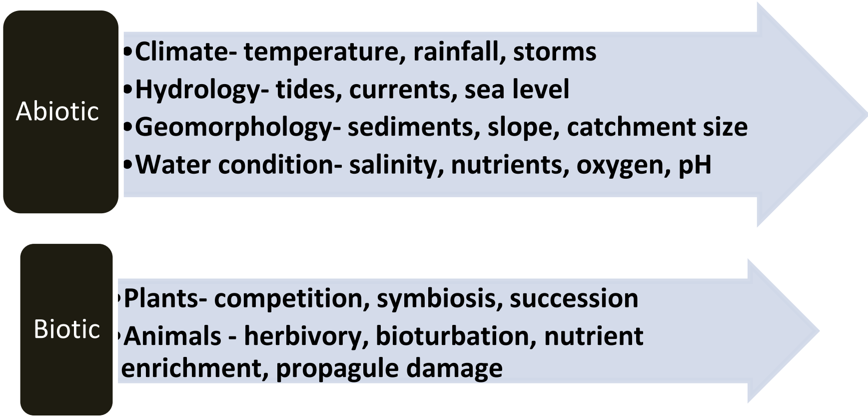


Figure 3.1 Factors influencing the floristic diversity of mangroves (Duke *et al*., 1998).

Earlier study has reported 90 species of mangroves in the world (Chapman, 1976) later, Saenger *et al*. (1983) recorded 83 species whereas UNDP/UNESCO (1986) reported only 65 species. According to Tomlinson (1986), a total of 54 mangrove species in 20 genera and 16 families were recorded while Duke (1992) recorded 69 mangrove species belonging to 26 genera in 20 families. Kathiresan and Bingham (2001), tabulated 65 mangrove species in 22 genera and 16 families, but the recent classification by Spalding *et al*. (2010) accounted 73 species as true mangrove and rest as associates of which many of them are in endangered list of IUCN (Polidora, 2010). Recent classification by Duke (2011) listed 77 true mangrove species in the world. Indian mangroves have a rich floral mangrove diversity (Blasco, 1975). Untawale (1984) reported 59 species of mangrove from India; however Kathiresan and Qasim (2005) reported 79 species of mangroves, later Kathiresan (2010) reviewed the diversity to 39 mangroves and 86 mangrove associates. Bijoy Nandan *et al.* (2015) reported 38 true mangroves in India.

The deltaic Sundarbans mangroves in Ganges delta of West Bengal is the earth's most extensive mangrove ecosystem named after the governing mangrove species, *Heritiera fomes*, locally known as ‘Sundari’. About 34 true mangroves have been reported from Sunderbans dominated by *Heritiera fomes, Avicennia* sp., *Xylocarpus granatum, Sonneratia apetala, Bruguiera gymnorrhiza, Ceriops decandra, Aegiceras corniculatum, Rhizophora mucronata* and *Nypa fruticans* (Chaudhuri and Choudhury, 1994). Bhitarkanika mangroves in Orissa have the second single largest block of mangrove formations in India. There are about 62-67 species of mangroves in this region, of these 32 are true mangroves and ranks first among the Indian state with highest number of true mangrove species (Bijoy Nandan *et al.*, 2015). In Bhitarkanika, *Heritiera fomes* exhibited highest density followed by *Excoecaria agallocha* and *C. ramiflora* and these three species together accounted for 77 % of the total mangrove plants (Misra *et al*., 2005). Coringa mangroves of Andhra pradesh is home to as many as 35 species of mangroves, of which 16 are true mangroves, the rest being associated species. The three communities of mangroves making up the Coringa mangrove forest are *Excoecaria-Avicennia, Avicennia-Sonneratia* and *Avicennia* community. A rare mangrove species, *Scyphiphora hydrophyllacea* (Rubiaceae) was reported from Andhra Pradesh (Venkanna, 1991). The major mangrove zones of Tamil Nadu include Pichavaram, Muthupet and Gulf of Mannar. Pichavaram mangroves represents 14 true mangrove species with predominance of *Rhizophora* sp., *Avicennia marina, Excoecaria agallocha, Bruguiera cylindrica, Lumnitzera racemosa, Ceriops decandra* and *Aegiceras corniculatum* (Kathiresan, 2000). However Muthupet mangroves have only 8 true mangrove species and *Avicennia marina* is the conqueror of the forest. Gulf of Mannar have only 9 true mangrove species of which *Pemphis acidula*, a true mangrove is endemic to these islands. Pondicherry mangroves, a minor mangrove zone in Tamil Nadu have 7 true mangrove species. The Andaman and Nicobar Islands, floats on Bay of Bengal endowed with 10 true mangrove species with dominance of *Rhizophora mucronata, Bruguiera gymnorrhiza, Avicennia* sp., *Ceriops tagal* etc (Kannan, 1990). Gujarat is having the largest mangrove patch on the west coast confined to the Gulf of Kachchh and the Gulf of Khambat region. Gujarat has 14 species of mangroves (Sahu *et al*., 2015).The mangrove species *Avicennia officinalis* and *Rhizophora mucronata* dominate on the Gulf of Kachchh and *Avicennia marina* as a single dense species in Gulf of Khambhat, *Sonneratia apetala* has dispersed and sparse distribution Goa has low diversity of mangroves represented by 12 true species dominated by *Acanthus ilicifolius* and *Kandelia kandel* followed by *Avicennia officinalis* and *Sonneratia caseolaris*. The mangrove forest of Karnataka includes 14 species of mangroves belonging to 9 genera and the dominant mangrove flora includes *Acanthus ilicifolius*, *Rhizophora mucronata* and *Excoecaria agallocha*. Mangroves of Maharashtra existed largely in the Thane creek, Mahim, Versova, Gorai and Ghodbunder with 20 true mangrove species. Kerala eventhough have less stretch of mangroves have higher diversity with 18 species of true mangroves and 38 species of associate forms (Bijoy Nandan *et al*., 2015 ; Sreelekshmi *et al*., 2018). *Acanthus ilicifolius* ranks first in its density followed by *Avicennia officinalis* and other major mangroves include *Rhizophora mucronata*, *Bruguiera cylindrica* and *B.gymnorrhiza.* Mangrove species such as *Sonneratia alba*, *Avicennia alba*, and *Ceriops tagal* were found to be rare whereas *Bruguiera parviflora* was extinct in the State (Sreelekshmi *et al*., 2018).

3.1.2 Physico-chemical parameters in relation to benthic fauna

Inorder to understand the linkage between benthic dynamics and ecosystem functioning, spatial and temporal changes in the physico-chemical parameters have to be considered as they control the secondary productivity in mangroves (Edgar and Barrett, 2002; Rodrigues *et al*., 2006). Furthermore sediment grain size, organic matter quality and quantity, plant cover, and disturbance are the net factors that reflect spatial heterogeneity of macrofaunal assemblages (Bissoli and Bernardino, 2018).

Chollett and Bone (2007) observed temporal variation in benthic community due to heavy rainfall. Hylleberg and Nateewathana (1991) observed reductions in density and species richness of polychaetes in Phuket Island, India due to heavy rains and the consequent increase of stress caused by a salinity drop. Salinity have been found to be the most important environmental variables controlling the diversity and distributional patterns of macrofauna (Sunil Kumar,1993; Lui *et al*.,2002) and in

Sunderban mangroves salinity seems to affect the biodiversity (Gopal and Chauhan, 2006). Hoq *et al*. (2006) have clearly demonstrated the influence of salinity and temperature on the seasonal abundance and distribution of molluscs in the Bangladesh Sundarban. Temperature is another important factor that determines mangrove floristic structure and the associated fauna (Tomlinson, 1986). Since mangroves are tropical in nature, temperature is critical for mangroves. Increase in temperature are likely to result in faster growth, reproduction, photosynthesis and respiration, changes in community composition, diversity, and a poleward expansion of latitudinal limits in mangroves (Cavanaugh *et al*., 2014; Saintilan *et al*., 2014). Benthic fauna in mangroves prefer mangrove shade to avoid excess transpiration and worst effects of temperature in open waters. Temperature even have influence on decomposition of organic matter that forms the major food source for benthic fauna in mangroves (Alongi *et al.*, 2000).The pH variations in water as well as sediment column significantly affects the bottom fauna (Jayachandran *et al*.,2012; Bijoy Nandan and Abdul Azis, 1995a). Mangrove pH seems to be alkaline in nature (Tam and Wong, 1998; Tam and Wong, 1995b; Meera and Bijoy Nandan, 2010) but Sasekumar (1974) observed acidic trend in Malayan mangroves. Studies have shown that dissolved oxygen in water helps to meet the respiratory needs of aquatic fauna and its reduced rate may leads to physiological stress due to hypoxia (Breitburg *et al*., 2009). The lower levels of DO in water may be associated with pollutants or due to decomposition of organic waste and oxidation of inorganic waste (Bijoy Nandan and Abdul Azis, 1995b; Ordoñez *et al*., 2015). In mangrove sediments with high carbon loading and high respiration rates, dissolved oxygen (DO) dynamics was influenced by range of factors such as tidal height, amount of sunlight, tidal phase, and distance from the outer edge of the mangrove forest (Mattone and Sheaves, 2017). Dissolved oxygen concentration below 2 mg/L are considered lethal to aquatic life (mortality), while concentrations above 2 mg/L but below 4-5 mg/L may support aquatic life may affect metabolism, but prolonged periods of exposure to below optimum conditions may be stressful (Gray *et al*.,2002).

Sedimentation in mangroves depends on the autochthonous litter and allochthonous inputs from natural and anthropogenic sources (Lee, 1990). Sediment particle size was the most important parameter shaping the benthic community structure and species richness in mangroves and influences the distribution and settlement of different forms of benthic life (Ansari and Purulekar, 1998; Harriague *et al*., 2012; Sanders, 1958). As the sediment size decreases (less than 3 mm) and sediment mud content increases, a declining trend in diversity and abundance of benthos can be seen (Thrush *et al*., 2003; Ellis *et al*., 2004; Lohrer *et al*., 2004). The sediment particle size also determines the organic matter in mangroves together with mangrove litter. The organic matter content in the mangrove sediments is often higher than that of estuarine sediments due to the inherent biological productivity within the mangrove systems. Decomposition of the mangrove foliage and other vegetative remains and their re-suspension contribute substantially to the organic matter content in the mangrove sediments. Organic carbon serves as a food sources for benthic organisms and determines assemblage and density in sediments (Coull, 1973). The redox potential (Eh) is a quantitative measure of reducing power indicating the degree of anaerobiosis or anoxia (Patrick and Delaune, 1977). Since mangrove soils are typically clayey and anaerobic, decomposition of litter by microbes is driven by a series of oxygen-reduction (redox) processes. The anoxic sediments have redox potentials below -200 mV, while oxic soils have potentials of above +300 mV. Nutrient also seems to control the growth, reproduction and metabolic activities of biotic components (Saravanakumar *et al*., 2008). Mangrove nutrition is the interactive effects between different nutrients and environmental factors such as salinity, soil type and texture, and frequency of tidal inundation. In mangroves the spatial distribution of nutrients are driven by the external loadings and internal loadings, vertical distribution by benthic and microbial activity (Prasad and Ramanathan, 2008). However an apparent paradox is that mangroves are highly productive and rich in carbon while nutrient-poor (Alongi, 2018). Total phosphorus, sulphur and potassium are sediment nutrients essential for benthic metabolism.

Moreover the nutrient-rich sediments create a breeding and fishing ground for various ecologically and economically important species (Ramanathan *et al*., 2010).

Cochin mangroves adjoining the Cochin estuarine system are always facing the brunt of ecological variations, not only due to climatic conditions but also due the faster rate of deforestation and pollution as part of coastal development. This has severely affected the physico-chemical nature of mangrove habitat with further impact on their resident fauna. The hydrological factors such as salinity, temperature, pH and dissolved oxygen and sediment parameters such as sediment texture, organic carbon, organic matter, redox potential, nutrients were studied to analyse the spatio-temporal variation in benthic fauna in Cochin mangroves. This study would highlight the interaction of mangrove vegetation, benthic fauna and environmental factors of Cochin mangrove ecosystem.

3.2 Results

3.2.1 Mangrove floral diversity and spatio-temporal variation in Cochin

Cochin mangroves harbour 13 species belonging to 6 families and 8 genera of true mangroves out of the total 18 species in Kerala. The most represented family was Rhizophoraceae with 6 species including *Rhizophora apiculata* Bl., *Rhizophora mucronata* Poir., *Kandelia candel* (L.) Druce., *Bruguiera cylindrica* (L.) Bl., *Bruguiera gymnorrhiza* (L.) Lamk., *Bruguiera sexangula* (L.) Bl., followed by Acanthaceae with *Avicennia officinalis* L., *Avicennia marina* (Forssk.) Vierh., *Acanthus ilicifolius* L., Lythraceae family with *Sonneratia caseolaris* (L). Engler. and *Sonneratia alba* Griff., Euphorbiaceae with *Excoecaria agallocha* L., Pteridaceae with *Acrostichum aureum* L.

In Cochin mangroves, density of mangroves [Figure 3.2] ranged from 7840 to 68400 ind.ha^{-1} with an overall density of 141497 ind.ha^{-1} of which *Acanthus ilicifolius, Excoecaria agallocha, Acrostichum aureum* were the densest species. In selected mangrove stations of Cochin, station 6 represented maximum density of

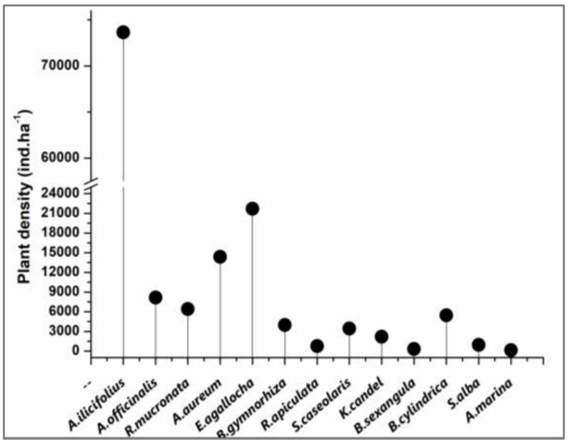


Figure 3.2 Mean density and diversity of mangrove vegetation in Cochin mangroves during 2010-2012 period.

68400 ind.ha^{-1} followed by station 5 (31100 ind.ha^{-1}) followed by station 2 (14531 ind.ha^{-1}) and station 4 (11760 ind.ha^{-1}) while station 3 (7866 ind.ha^{-1}) and station 1 (7840 ind.ha^{-1}) represented least density. Eventhough station 1 has lowest density, species diversity was maximum with 11 species of which *Avicennia officinalis* was the dominant vegetation with a density of 2080 ind.ha^{-1} followed by *Acanthus ilicifolius* (1680 ind.ha^{-1}), *Rhizophora mucronata* (1440 ind.ha^{-1}) *Sonneratia caseolaris* (880 ind.ha^{-1}) while *Bruguiera cylindrica* (80 ind.ha^{-1}) and *Rhizophora apiculata* (80 ind.ha^{-1}) with lower density. Station 2 consists of 10 species with highest density of *Acanthus ilicifolius* (9066 ind.ha^{-1}), *Avicennia officinalis* (1600 ind.ha^{-1}) and *Rhizophora mucronata* (1200 ind.ha^{-1}) and least density of *Bruguiera gymnorrhiza* (133 ind.ha^{-1}) and *Rhizophora apiculata* (133 ind.ha^{-1}). Station 3 and 4 have only seven species of mangroves, of which station 3 is unique in having *Avicennia marina* and *Sonneratia alba* in Cochin and most densest species was *Bruguiera cylindrica* (3467 ind.ha^{-1}) and *Avicennia officinalis* (1200 ind.ha^{-1}), however in station 4 *Excoecaria agallocha* was predominant in terms of density (6400 ind.ha^{-1}). Station 5 and station 6 have 9 and 10 species of true mangroves respectively, both having the dominant mangrove species *Acanthus ilicifolius* with a density of 12500 ind.ha^{-1}, and 50000 ind.ha^{-1} respectively. In station 6, *Bruguiera sexangula* was least represented with a density of 80 ind.ha^{-1}. *B.sexangula* was present only in station 6 and station 1. *Avicennia officinalis*, *Rhizophora mucronata*, *Excoecaria agallocha* and *Bruguiera gymnorrhiza* were common to all stations [Figure 3.3].

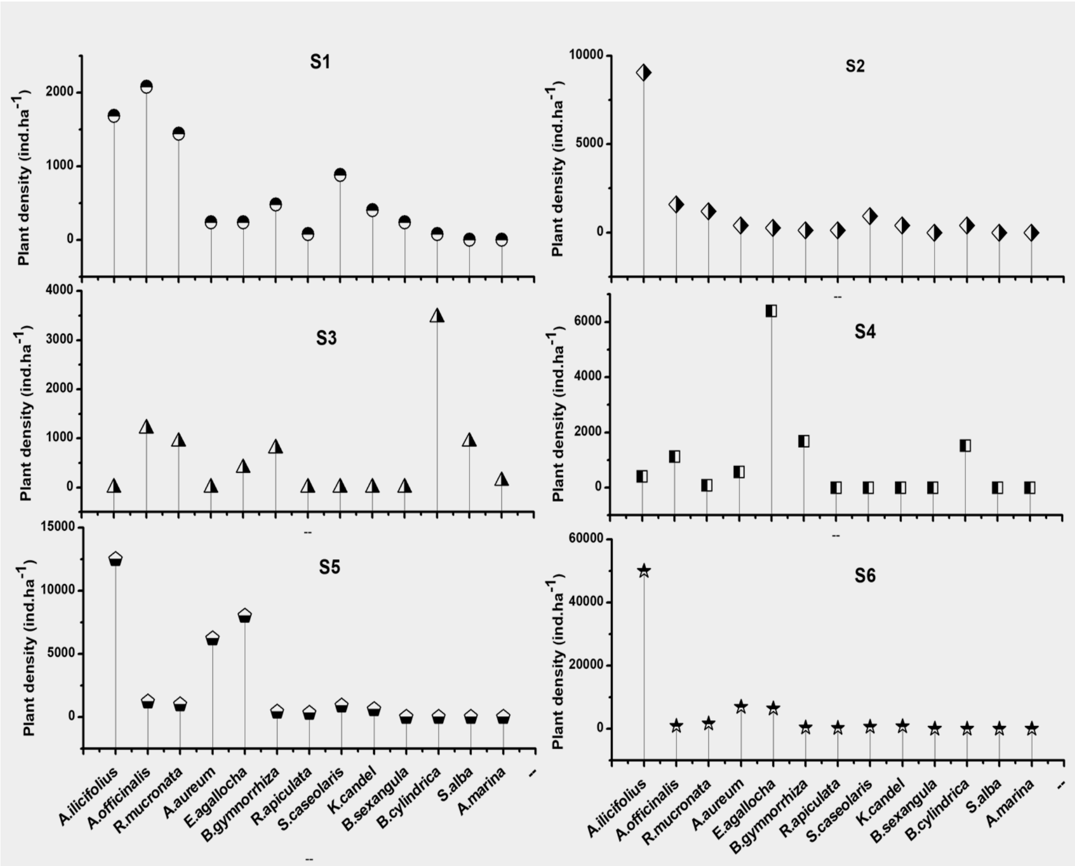


Figure 3.3 Spatial variation in plant density in Cochin mangroves during 2010-2012 period.

3.2.2 Physico-chemical parameters structuring mangrove ecosystem

Environmental parameters were collected on monthly basis from six mangrove stations in Cochin for two year period during 2010-2012.

a. Rainfall

The mean rainfall in mangrove ecosystem was 213 ± 159 mm during the entire study period (2010-2012).Annual precipitation was highest (2775.9 mm) during the first year (2010-2011) period as compared to the second year (2011-2012) period (2341.7 mm). Seasonally, significant difference has recorded in rainfall (ANOVA F (5,144) = 25.59, p =0.000). Monsoon season of both years showed peak rainfall, and it was 1554.3 mm in first-year period and 1314.2 mm in second year, followed by post-monsoon of first year 797.4 mm, and second year 510.9 mm and lower in pre-monsoon, 424.1 mm in first year and 516.5 mm in second year respectively [Figure 3.4].

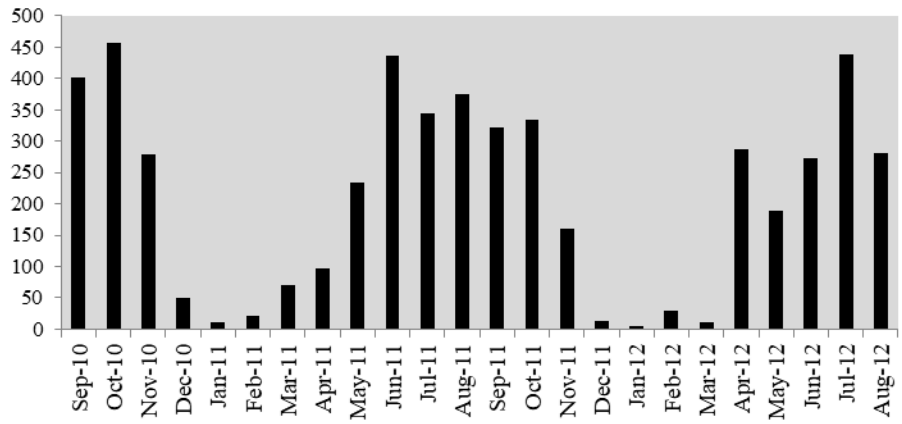


Figure 3.4 Mean monthly rainfall (mm) in Cochin mangroves during 2010-2012 period.

b. Temperature

Water temperature in mangrove ecosystem usually ranged between 25°C to 35°C .The mean water temperature during the entire study was 29.4 ± 2 °C and that for the first year was 29.3 ± 1.7 °C and 29.5 ± 2.3 °C in the second year period. In the mangrove stations, temperature has of no significant variation and has a mean value of 29 °C in all stations [Figure 3.5a]. Significant variation in temperature was observed between seasons (ANOVA F (5,144) = 20.27, p =0.000) [Figure 3.5b] and was higher during pre-monsoon periods both during the first year (30.3 ± 1.8 °C) and second year (31.6 ± 2.2°C). The mean lowest seasonal value was recorded in post-monsoon seasons of first (28.3 ±1.6) and second year (27.5± 1.3°C). Monsoon season gave a mean value of 29.5 °C in both the years.

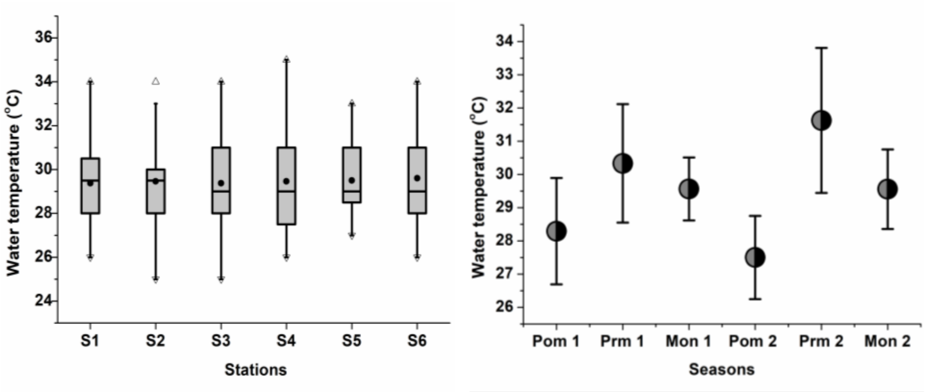


Figure 3.5: a) Spatial variation and **b)** seasonal variation in water temperature (°C) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

c. pH

pH in mangrove water column usually ranged between 4.6 to 8.9.The mean pH for the two year study period was 7.2 ± 0.53, and annual variation was not significant and the mean value was 7.2 both in first and second year.

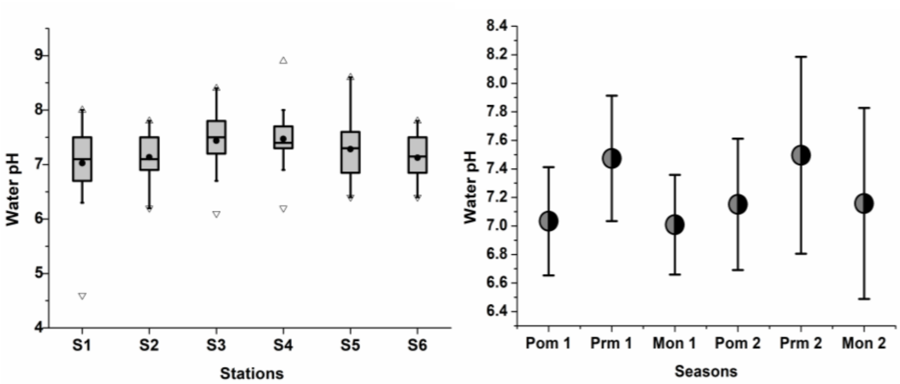


Figure 3.6 a) Spatial variation and **b)** seasonal variation in water pH of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

Spatially, station 4 (7.5 ± 0.5) and station 3 (7.4 ± 0.6) exhibited slightly alkaline pH values, while acidic pH was observed during different periods of sampling in station 1 (7±0.7) and station 2 (7.1±0.4) but the mean value approaches to a neutral state. Station 5 and station 6 exhibited a neutral to alkaline condition in most of the sampling months with a mean value of (7.3±0.6) and (7.1±0.4) respectively. Significant variation in water column pH exist between mangrove sites (ANOVA *F* (5,144) = 3.05, *p* = 0.012) [Figure 3.6a]. pH values found to vary significantly between seasons (ANOVA *F* (5,144) = 3.69, *p* = 0.004) [Figure 3.6b]. Seasonally, highest value of 7.5 ± 0.7 was recorded during post-monsoon of the second year and also in first year (7.5± 0.4). Monsoon and post monsoon season exhibited neutral value of 7 ± 0.4 in first year whereas it was slightly alkaline (7.1) in the second year.

d. Salinity

In mangrove sites salinity ranged between 0.12 to 35.9 PSU with an annual mean value of 8.17 ± 7.19 PSU. Annual variation in salinity was significant (ANOVA *F* (1,144) = 19.58, *p* = 0.000) with a higher mean salinity in second year (10.8 ± 5.3 PSU) than first year (5.6 ± 6.2 PSU). Salinity also varied significantly between stations (ANOVA *F* (5,144) = 4.53, *p* = 0.001) and highest mean salinity was recorded in station 3 (14.17± 10.9 PSU) followed by station 4 (8.1±4.9 PSU) and lowest in station 2 (6.06±5.2 PSU). Station 6, station 5 and station 1 exhibited a mean salinity of 7.96±9.36 PSU, 6.26±7.2 PSU, 6.43±5.5 PSU respectively [Figure 3.7 a].

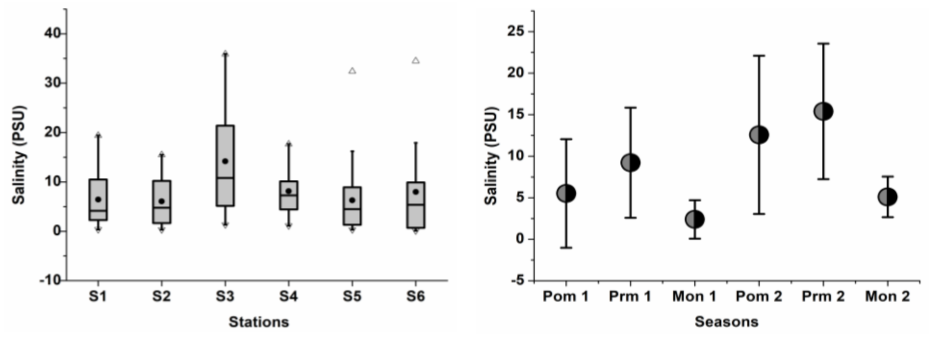
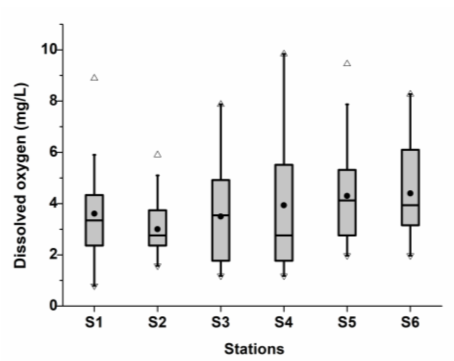


Figure 3.7 a) Spatial variation and **b)** seasonal variation in salinity (PSU) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

Seasonal salinity regime also vary significantly (ANOVA *F* (5,144) = 17.36, *p* = 0.000) and was higher in pre-monsoon followed by post-monsoon seasons and lowest in monsoon [Figure 3.7b]. Pre-monsoon (15.2±8.1 PSU) of second year recorded highest salinity followed by post monsoon (12.5±9.5) of same year. Similar trend was also followed in first year pre-monsoon (9.2±6.6) and postmonsoon (5.5±6.5 PSU). Monsoon (2.4±2.3 PSU) of first year and second year (5.1±2.4 PSU) recorded least salinity during entire study period.

e. Dissolved oxygen

Dissolved oxygen in mangrove ecosystem varies and ranged as 0.79 to 9.84 mg/l with an overall mean value of 3.8 ± 1.2 mg/L for two year period (2010-12).There was no significant variation in annual and spatial values and was 4 mg/L both in first and second year. Spatially DO exhibited a mean value that ranged between 3-5 mg/L of which S5 and S6 exhibited a higher DO of 4.3 ± 1.2 and 4.4 ± 1.8 mg/L respectively. However it was 3.9 ± 2.9 mg/L in station 4 , 3.6 ± 2.6 mg/L in station 1 and 3.5 ± 2.3 mg/L in station 3 and lowest in station 2 with a mean value of 3.0 ± 0.9 mg/L [Figure 3.8a]. Seasonal variation was significant (ANOVA F (5,144) = 2.55, p = 0.030) with higher dissolved oxygen in monsoon (second year) and pre-monsoon (both first and second year) with a mean value of 4.2 mg/L and it was lowest in post-monsoon of first year (2.8±1.2 mg/L) [Figure 3.8b]. In other seasons it was between 3-4 mg/L.



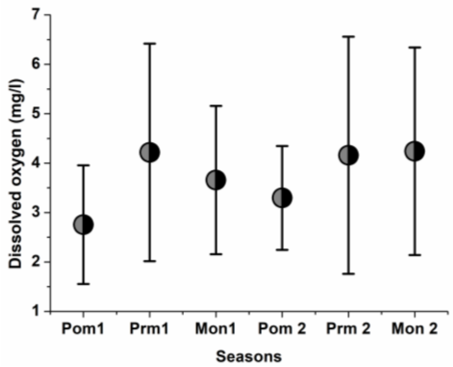


Figure 3.8 a) Spatial variation and **b)** seasonal variation in dissolved oxygen (mg/L) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

f. Turbidity

The turbidity in mangrove ecosystem ranged from zero to 39 NTU. The two year mean turbidity value was 4.5 ± 5.7 NTU, and no differences were observed between first year (4.5 ± 4.5 NTU) and second year (4.5 ± 6.7 NTU). Station-wise data depicted higher values in station 1 (8.0 ± 9.8NTU), station 3 (5.6 ± 6.6 NTU) and station 2 (4.3 ± 4.3 NTU) and station 4 (4.1 ± 2.7 NTU). However, comparatively lower values were recorded at station 5 (2.4 ± 1.9 NTU) and station 6 (2.5 ± 2.7 NTU) [Figure 3.9a]. The significant variation between stations were proved using one way ANOVA (F (5,144) = 3.94, p =0.002).Seasonal variation in turbidity was significant (ANOVA F (5,144) = 3.88, p = 0.003) with highest mean values observed during monsoon season (7.8 ± 5.9 NTU) of the first year and pre-monsoon of second year (6.9 ± 10.0 NTU) [Figure 3.9b]. Similarly monsoon of second year and pre-monsoon of first year showed lowest values of 2.1 ± 1.5 NTU and 2.1± 1.7 NTU respectively. Post-monsoon season gives a moderate value both in first (4.0± 3.8) and second year (3.1± 2.8).

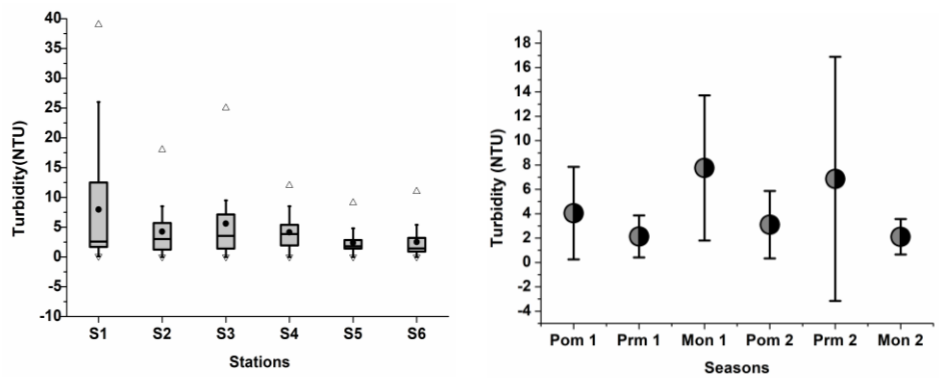


Figure 3.9 a) Spatial variation and **b)** seasonal variation in turbidity (NTU) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

g. Sediment temperature

Sediment temperature ranged between 26 to 35°C. The mean sediment temperature for the entire study period was 30.2 ± 1.8°C, and that was 30.1 ± 1.3 °C in the first year and 30.3 ± 1.9 °C for the second year. Spatially no much variation was observed in sediment temperature and mean value lie in the range of 30°C, but comparatively station 2 recorded higher value (30.5± 1.2°C) and station 4 (30± 2.2°C) recorded lower value [Figure 3.10a]. Significant variation was observed in sediment temperature between seasons (ANOVA F (5,144) = 20.69, p = 0.000) [Figure 3.10b] and pre-monsoon depicted maximum value, 31.1 ± 1.5 °C in the first year and 32.2 ± 1.7 °C in the second year followed by monsoon first year (30.5± 1.1°C) and second year (29.6±0.8°C) and lowest in post-monsoon of the first (28.8± 1.2°C) and second year (29 ± 1.7°C).

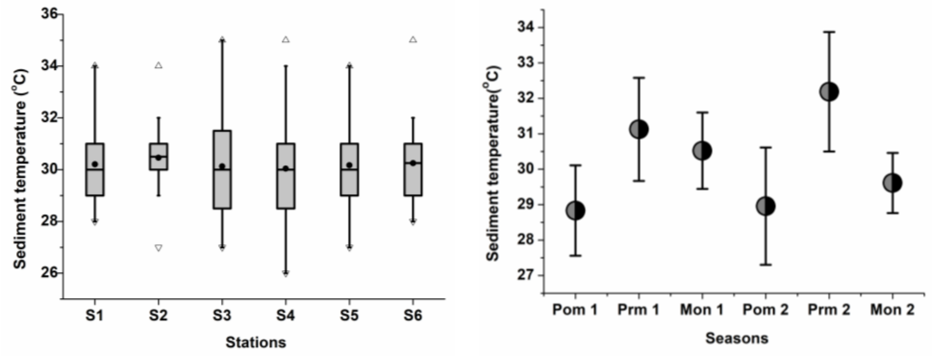


Figure 3.10 a) Spatial variation and **b)** seasonal variation in sediment temperature (°C) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean)

h. Sediment pH

Sediment pH in mangrove sediments of Cochin ranged between 4.6 to 9.1 with inter-annual mean value of 7.3 ± 0.5 during 2010-2012. Sediment pH was almost neutral to alkaline side for first (7.3±0.3) and second year (7.2±0.5) with least variability. Spatio-temporal variation was significant for pH of sediment (season: ANOVA F (5,144) = 4.64, p = 0.001, station: ANOVA F (5,144) = 2.54, p = 0.031). Spatially higher mean pH with an alkaline trend was observed in station 3 (7.6±0.4) and in station 4 (7.5±0.3). Similarly station 2 (7.2±0.5), station 5 (7.2±0.5 and station 6 (7.1±0.3) experience higher pH. Lowest pH was observed in station 1 with mean value of 6.9± 0.7 [Figure 3.11a]. Seasonally monsoon of first year, postmonsoon and premonsoon of second year exhibit similar mean pH of 7.3 with a standard deviation of 0.3, 0.2 and 0.7 respectively [Figure 3.11b]. Similarly post-monsoon and pre-monsoon of first year have mean pH of 7.2. Lowest pH was recorded during monsoon of second year with a mean value of 7.0 ± 0.5.

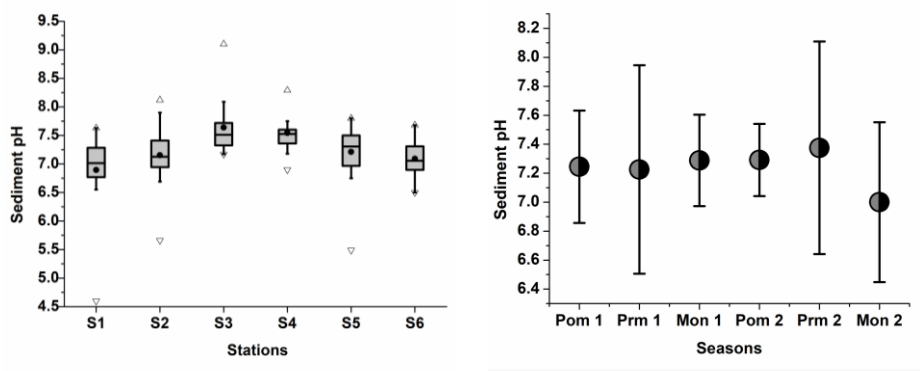


Figure 3.11 a) Spatial variation and **b)** seasonal variation in sediment pH of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean)

i. Sediment Eh

The sediment redox potential (Eh) values showed a reducing trend in all stations with a mean value for the entire study area of -108.7 ±137.8 mV and it ranged from -555 to 127. Eh values showed significant annual variation (ANOVA F (1,144) = 28.63, p = 0.000) with a highly reduced condition in second year (-163.9 ± 137.7mV) than first year (53.5±114.4 mV).

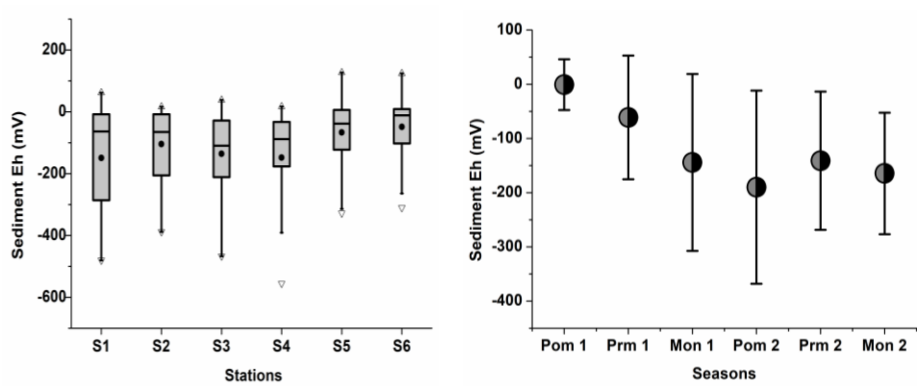


Figure 3.12 a) Spatial variation and **b)** seasonal variation in sediment Eh (mV) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

Spatially, remarkable variation in sediment Eh with highly reduced condition is seen in station1 (-149.0 ± 169.2), station 4 (-148.2 ±167.4), station 3 (-135.4 ± 128.4) and station 2 (-104.4 ± 111.7). However, station 5 (-66.9 ± 110.2) and station 6 (-48.5±102.6mV) depicted a comparatively oxidised condition [Figure 3.12a]. Eh values also showed significant variation seasonally (ANOVA F (5,144) = 7.78, p = 0.000) and spatially (ANOVA F (5,144) = 2.43, p = 0.038). Seasonally post monsoon (-189.9±178.1 mV) of second year showed highly reduced state followed by monsoon in both first (-144.4±163.1mV) and second year (164.4± 112 mV) and pre-monsoon (-141±127.5mV) of second year [Figure 3.12b]. Comparatively oxidised condition was noticed in the post-monsoon period (-0.75 ± 46.7mV) and pre-monsoon period (-61.1±114 mV) of first year (2010-2011).

j. Sediment Texture

Mangrove habitats are characterised by varying composition of sediment particles with higher composition of sand particles followed by silt and then clay [Figure 3.13a]. Sand content of sediment ranged between 9.73 to 96.34% with overall mean of 75.10 ± 23.03 % during the study and that for the first year was 75.68 ± 22.93 % while 76.54 ± 23.29 % in the second year

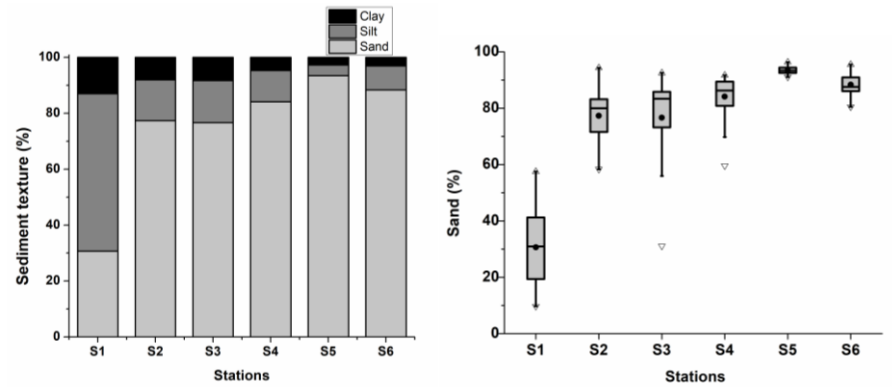


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Figure 3.13 Spatial variation in **a)** sediment texture (%) and **b)** sand (%) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean)

Significant difference in sand content was noted between stations (ANOVA F (5,144) = 118.98, p = 0.000). Station 5 (93.45± 1.49 %), station 6 (88.33 ± 3.51%), station 4 (84.13 ± 7.58 %) exhibited comparatively higher sand fraction than station 2 (77.35 ± 9.5 %) and station 3 (76.68 ± 16.2 %), however station 1 (30.67 ± 13.60 %) recorded least sand content [Figure 3.13b]. Seasonal variation does not show significant differences in sand content [Figure 3.15]. The postmonsoon and monsoon season for both years exhibited highest sand fraction in sediments that ranged from 75 to 77% and was lower during pre-monsoon season (73 %).

Silt fraction of sediment ranged between 0.36 to 74.08 % with an average value of 18.24 ± 19.46% for the entire period and that was 19.86 ± 19.21% in the first year while 18.79± 19.72 % in the second year. Significant difference in silt content was noted between stations (ANOVA F (5,144) = 115.08, p = 0.000) and observed highest at station 1(56.28 ± 12.84) however moderate at station 2 (14.60 ± 8.66), station 3 (14.99 ± 11.55) and station 4 (11.15 ± 8.42) and least silt composition was seen in station 5 (3.80±1.45) and station 6 (8.59±2.73) [Figure 3.14a]. Seasonally, the pre-monsoon season of the first year (19.20 ± 18.85 %) and second year (20.12 ± 18.20 %), post-monsoon of first year (18.19 ± 16.84%) depicted comparatively high silt content in sediment [Figure 3.15]. While Monsoon of first (17.25± 22.67 %) and second year (16.85 ± 23.56 %) and post monsoon (16.09 ± 18.53 %) of the second year showed least silt fraction.

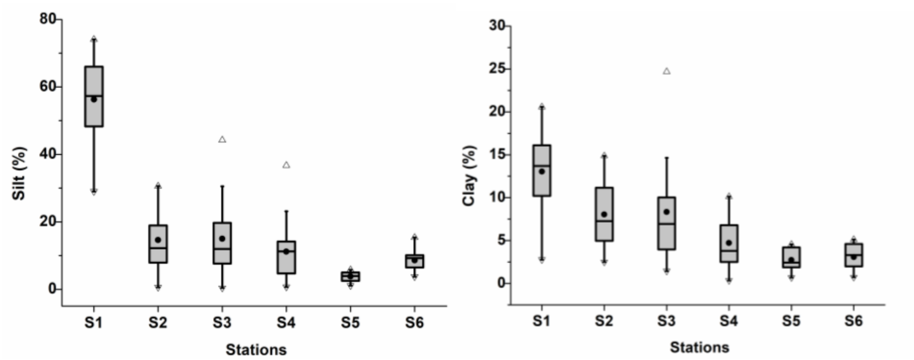

Figure 3.14 Spatial variation in **a)** silt (%) and **b)** clay (%) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean)

However, clay fraction of sediment ranged between 0.35 to 24.68% with an average value of 6.66 ± 5.08% in mangrove sites. It was 8.60 ± 4.72 % in the first year and that for the second year was 7.65 ± 5.25 %. In spatial scale, significant differences observed in the clay fractions of sediment between the stations (ANOVA F (5,144) = 27.60, p =0.000). Station 1(13.05± 4.39 %), station 2 (8.05 ± 3.76 %) and station 3 (8.32 ± 6%) depicted comparatively higher percentage of clay whereas, station 4 (4.72 ± 2.56 %), station 5 (2.74 ± 1.25 %) and station 6 (3.08± 1.44%) recorded very low fractions of clay in sediment [Figure 3.14b].Seasonally no much variation in clay content, but comparatively higher values in monsoon of first (7.27± 4.76%) and second year (7.43 ± 4.39 %) compared to all other seasons [Figure 3.15]. Pre-monsoon and post-monsoon represent almost similar average clay content of 6% in both years.

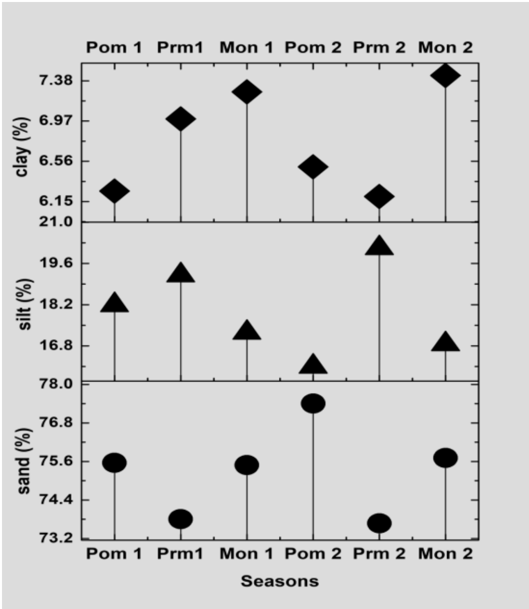

Figure 3.15 Seasonal variation in sand, silt and clay (%) of Cochin mangroves during 2010-2012 period.

k. Organic matter

Mangrove sediment usually exhibited a higher organic matter and in Cochin it ranged between 1.34 to 93.5 g/kg with an average value of 31.82 ± 23.09 g/kg during two year (2010-2012) study period. Annually there was no much variation in organic matter and was 31.2 ± 21.4 g/kg during the first year and 32.5 ± 24.8 g/kg for the second year. Significant differences were observed in organic matter content of sediments between stations (ANOVA F (5,144) = 44.48, p = 0.000). Spatially, station 1 (67.3 ± 15.2 g/kg) stands separate from other station with highest and noticeable range of organic matter]. Station 3 (35.8 ± 19.3 g/kg), station 4 (33± 18.1 g/kg) and station 2 (27.1 ± 15.8 g/kg) also exhibited higher values. However station 5 (10.7 ± 4.5 g/kg and station 6 (16.9± 7.7 g/kg) recorded least organic matter [Figure 3.16a]. Seasonally, no significant variation was observed in organic matter and mean value was between 29 to 33 g/kg, however pre-monsoon season (32.90 ± 24.4 g/kg in first year and 33.50± 23 g/kg in second year) exhibited a higher value compared to other seasons and monsoon of the second year (32.9± 25 g/kg) exhibited higher organic matter in sediment. However post-monsoon of first (30.50± 20.9 g/kg) and second year (31.2± 27.9 g/kg) and monsoon of first year (29.10 ± 20.4 g/kg) recorded comparatively lower organic matter [Figure 3.16b].

l. Organic carbon

Organic carbon in mangrove ecosystem of Cochin ranged between 0.78 to 54.21 with an average of 18.5 ± 13.4 g/kg. Annually it exhibited mean value of 18.1 ± 12.4 g/kg in first year and that for the second year was 18.9 ± 14.4 g/kg. In spatial scale, highly significant variation was observed (ANOVA F (5,144) = 43.45, p = 0.000) and station 1 recorded highest organic carbon (39.04 ± 8.83 g/kg) [Figure 3.16a]. Similarly station 3 (20.78± 11.19 g/kg) station 4 (19.12 ± 10.51 g/kg) and station 2 (15.73 ± 9.18 g/kg) also have higher average value for organic carbon. However organic carbon content was lowest in station 5 (6.22± 2.65 g/kg) and station 6 (9.84± 4.51 g/kg) as that of organic matter. Seasonally, the organic carbon does not vary significantly and was between 17 to 19 g/kg, however pre-monsoon season of the first year (19.09 ± 14.13 g/kg) and second year (19.45± 13.34 g/kg), and monsoon of the second year (19.09 14.19 g/kg) depicted the highest concentration of 19 g/kg. However, post-monsoon of first (17.66± 12.13 g/kg) and second (18.10 ± 16.16 g/kg) year and monsoon of the first year (16.87 ± 11.81 g/kg) depicted lowest values [Figure 3.16b].

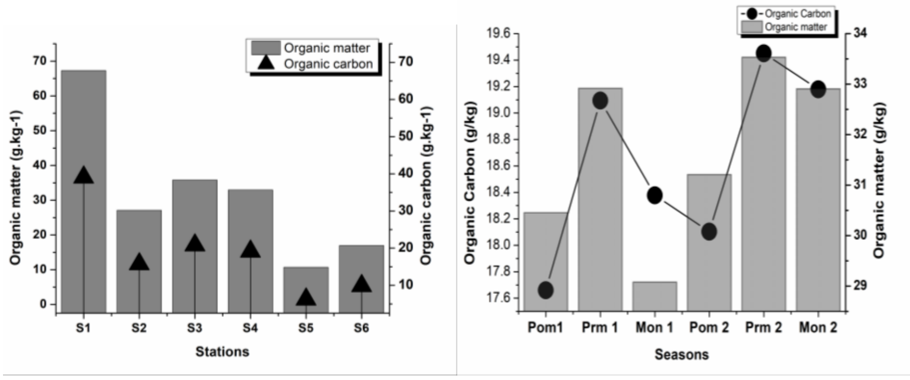

Figure 3.16 a) Spatial variation and **b)** seasonal variation in organic matter and organic carbon (g/kg) of Cochin mangroves during 2010-2012 period.

m. Total Sulphur

Total sulphur in mangrove sediments ranged between 533.1 to 23539 mg/kg. The mean value for the entire period of study was 6502.47 ± 5187.62 mg/kg and significant differences (ANOVA F (1,144 = 4.52, p = 0.035) were observed between first (6034 ± 4452 mg/kg) and second year (6970 ±5825 mg/kg).

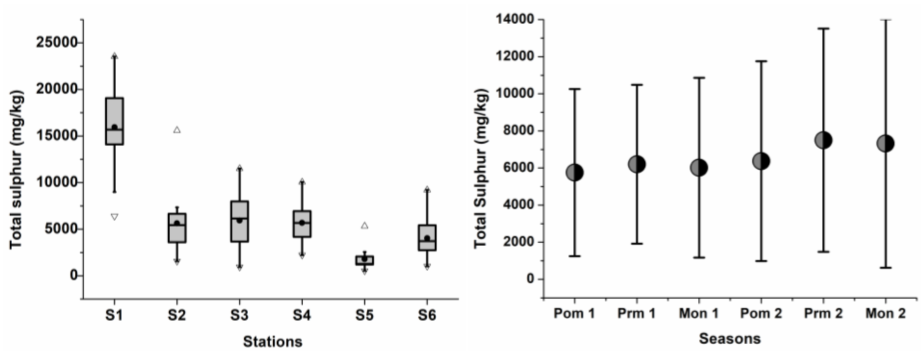

Figure 3.17 a) Spatial variation and **b)** seasonal variation in total sulphur (mg/kg) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

Spatially significant differences were observed in sulphur content of sediment (ANOVA F (5,144) = 81.11, p = 0.000) and highest values of sulphur was recorded mainly at station 1 (15940 ± 3796 mg/kg) while lower in station 3 (5938 ±2773 mg/kg), station 4 (5683 ± 2015 mg/kg), station 2 (5634 ± 3796 mg/kg) and station 6 (4032 ± 1950 mg/kg). Sulphur was lowest observed in station 5 (1784 ±1221 mg/kg)

[Figure 3.17a]. Seasonally highest value was observed during pre-monsoon (7496 ± 6014 mg/kg), monsoon (7322 ± 6702 mg/kg) and post-monsoon (6367 ± 5384 mg/kg) of second year, while moderate values in monsoon (6014 ± 4848 mg/kg) and pre-monsoon (6200 ± 4277 mg/kg) and lowest in post-monsoon (5750 ± 4506 mg/kg) of first year [Figure 3.17b].

n. Total phosphorus

Total phosphorus in mangrove sites ranged between 101 to 2192 mg/kg. The overall mean value for the entire period of study was 581.88 ± 387.40 mg/kg and that for first year was 571.07±412.45 mg/kg and second year was 592.68±363.21 mg/kg. Station wise variation was highly significant (ANOVA F (5,144) = 32.66, p = 0.000) and higher values of phosphorus was recorded in station 1(1020.45±189.46 mg/kg) and station 3 (835.70±420.0 mg/kg) while station 2 (519.19±258.9 mg/kg) and station 4 (616.65±296.56 mg/kg) have moderate values. Phosphorus values were lowest in station 5 (209.19±78.95 mg/kg) and station 6 (290.09±229.10 mg/kg) [Figure 3.18a]. Seasonally highest value was observed during, monsoon (722.75± 412.67 mg/kg) of second year and lowest in pre-monsoon (504.3±353.20 mg/kg) of first year. However phosphorus in sediment was moderate in pre-monsoon (604.26± 339.46 mg/kg) of second year and post-monsoon (625.03±429.57 mg/kg) and monsoon 586.74 ± 441.91 of first year [Figure 3.18b].

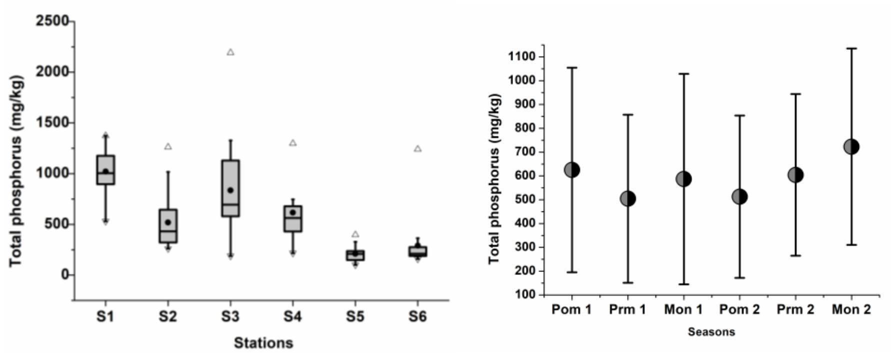

Figure 3.18 a) Spatial variation and **b)** seasonal variation in total phosphorus (mg/kg) of Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean)

Principal component analysis

Principal component analysis helps to determine the correlation of variables in relation to each other and also their pattern of variability in mangrove stations. The first five principal components accounted for 74.4 % of variability between stations. The first PC accounted for 34.1% variability with an eigen value of 5.12 and were determined by sediment parameters such as sediment texture, organic carbon, organic matter, total sulphur and total phosphorus. Here sand was positive determinant while other parameters exhibited negative correlation.The second PC accounted for 14 % of variability and was driven by sediment temperature. The third principal components were determined by water temperature, water pH and sediment pH while PC 4 by dissolved oxygen and sediment Eh and PC 5 by salinity and turbidity [Figure 3.19, Table 3.1].

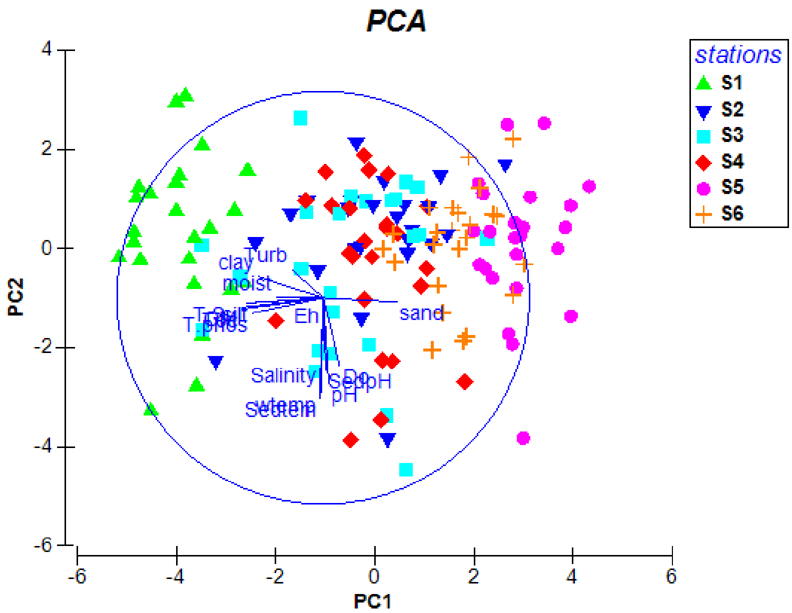

Figure 3.19 Two-dimensional principal component analysis (PCA) ordination of selected normalized environmental variables in Cochin mangroves on a spatial basis during 2010-2012 period.

Table 3.1 Two-dimensional principal component analysis (PCA) of environmental conditions at each sampling stations in Cochin mangroves.

PC	PC1	PC2	PC3	PC4	PC5
Eigen values	5.12	2.11	1.74	1.18	1.01
% Variation	34.1	14	11.6	7.9	6.8
Cum % Variation	34.1	48.2	59.7	67.6	74.4
Variable					
Water temperature	-0.018	-0.466	0.491	-0.028	0.050
Water pH	0.026	-0.411	-0.482	0.064	-0.171
Salinity	-0.013	-0.321	-0.249	-0.352	0.553
Dissolved oxygen	0.081	-0.331	0.076	0.461	-0.359
Turbidity	-0.152	0.135	0.070	-0.330	-0.461
Sediment temperature	-0.014	-0.486	0.449	-0.120	0.030
Sediment pH	0.011	-0.350	-0.425	-0.175	-0.356
Organic matter	-0.394	-0.046	-0.119	0.045	0.019
Sand	0.356	-0.019	-0.074	-0.104	0.193
Silt	-0.350	-0.023	0.014	0.117	-0.098
Clay	-0.317	0.103	0.145	0.005	-0.061
Sediment Eh	-0.001	-0.036	-0.116	0.678	0.302
Total Sulphur	-0.373	-0.025	-0.010	0.003	0.144
Total phosphorus	-0.344	-0.074	-0.058	-0.114	0.149
Total organic carbon	-0.392	-0.054	-0.117	0.069	0.042

3.3 Discussion

Mangrove communities are often characterised by distinct assemblage of species governed by the complexity of environmental factors (Joshi and Ghose, 2003) and mangrove vegetative structure (Mc kee, 1993). In Cochin uneven, aged mixed mangrove forest was observed (Rani *et al*., 2016a) and floristic diversity revealed 13 true mangrove species. Sreelekshmi *et al*. (2018) also reported presence of 13 true mangroves in Cochin, however studies by Sateeshkumar (2011) reported 12 species and Sunil Kumar and Antony (1994) reported 10 species of mangroves from Cochin estuarine region. Density of mangroves ranged between 7840 to 68400 ind.ha^{-1} in Cochin area was represented mainly by *Acanthus ilicifolius*, *Exoecaria agallocha* and *Acrostichum aureum*. Muralidharan and Rajagopalan (1993) also observed dominance of *Acanthus ilicifolius* in Cochin, however Satheeshkumar (2011) observed the dominance of *Avicennia officinalis* and *Rhizophora mucronata* but according to Sunil Kumar and Antony (1994), *Rhizophora mucronata* is the most dominant species, followed by *Avicennia officinalis* and *Acanthus ilicifolius*. This variability in mangrove vegetation might be due to geographical locations selected for the study. The higher abundance of shrub mangrove *Acanthus ilicifolius* is due to its tolerance to pH and salinity gradients hence can flourish in varying ecological conditions and preferred sites with regular tidal inundation (Joshi and Ghose,2003; Rani *et al*., 2016a). In Ashtamudi and Kayamkulam wetlands *Acanthus ilicifolius* was predominant with a density of 19386 ind.ha^{-1} (Sreelekshmi *et al*., 2017). *Exoecaria agallocha* seems to be present in low saline area (Cintron *et al*., 1978; Pal *et al*., 1996) but its presence were also observed in high saline condition and preferred sandy substratum (Rani *et al*., 2016a) as observed in the present study. *Exoecaria* is rich in diterpenoids, flavonoids, phenolic acids, sterols, tannins, and triterpenoids as these chemical constituents cause toxicity effects to microbial and other faunal components (Chan *et al*., 2018) as seen in station 4 where it is the dominant vegetation. *Avicennia* seems to be more tolerant to organic pollution (Sathe and Bhosale, 1991) and its higher density was observed in station 1 characterised by organic rich sediments with silty texture. *Acrostichum aureum* prefers the areas of low pH and salinity (Thomas and Fernandez, 1993). Eventhough mangrove areas are less in Cochin, mangrove density seems to be higher than those reported from Coringa mangroves (Satyanarayana *et al*., 2009), Bhitarkanika mangroves (Upadhyay and Mishra, 2014), Kachchh mangroves, Gujarat (Sawale and Thivakaran, 2013). The mangrove floral diversity and distribution largely determined by geographical locations, soil texture, salinity and environmental factors.

Structure of mangrove stands has a direct impact on the physical processes operating within the habitat (Wolanski *et al*., 1992). This mangrove vegetation together with physicochemical parameters determines the benthic community in a mangrove habitat.

Mangroves usually grow in tropical zone with higher rainfall and humidity (Macnae, 1966) and prefer annual rainfall between 1500 and 3000mm. Kerala experiences a typical tropical climate controlled by south-west monsoonal rains and three different seasons were classified based on rainfall and other environmental factors as pre-monsoon (February to May) with little rainfall and higher temperature and salinity, monsoon (June to September) with heavy rainfall, lower temperature and salinity and post-monsoon with lower rainfall but moderate salinity and temperature. Similar trend was observed in the present study in mangrove habitats of Cochin. Rainfall influences hydrography especially salinity and temperature which may create a stress to benthic fauna (Hylleberg and Nateewathana, 1991; Kim *et al.*, 2018) especially during monsoon season (r= -0.589), p<0.01) due to higher precipitation. It deteriorates the structure and functions of aquatic ecosystems (Meyer *et al.*, 1999; Poff *et al.*, 2002). Kim *et al.* (2018) observed species richness and abundance of the benthic macroinvertebrate communities apparently decrease with increasing rainfall (>200mm cumulative for three days) especially in Asian monsoon events during July-August months due to higher flow rate and relative higher disturbance.

Temperature is an important factor determining mangrove vegetation (Macnae,1968; Chapman, 1977). Temperature required for optimal growth of mangrove species varies between 18 and 26 ^{o}C and cannot flourish if annual average temperature is below 19 ^{o}C (Alongi, 2002; Alongi, 2008). In the present study water temperature ranged between 25 - 35 ^{o}C that influences the sediment temperature, 26-35 ^{o}C (r=0.809 p<0.01) due to shallow nature of mangrove area. The temperature range in the study corroborates with the values reported by Sunil Kumar (1993) in Cochin mangroves, Andamans mangroves (Damroy, 1995) and Tamil Nadu mangroves (Samidurai *et al.*, 2012) but lower than Kachchh mangroves (Saravanakumar *et al.*, 2007). Higher temperature was seen during pre-monsoon seasons due to lower precipitation, as in other wetlands of Kerala (Bijoy Nandan and Abdul Azis, 1995b; Jayachandran, 2017). Temporal variation in sediment temperature may influence species distribution patterns and also on migration, spawning, egg incubation, growth, and metabolism of aquatic organisms (Portner, 2001; Addy and Green, 1997). However spatially there were no much variation in temperature patterns (29 ^{o}C) and hence their influence in benthic species distribution in mangrove sites is minimal, but determines mangrove plants. Temperature also affects the dissolution of oxygen (r=0.220, p<0.01) in mangrove sediments.

In Cochin mangrove, pH showed an acidic to alkaline trend as reported in Cochin estuary, Vembanad backwaters and Kodungalloor Azhikode estuary (Jayachandran *et al*., 2013; Asha *et al*., 2016) which varies spatially and station 1 exhibited comparatively acidic trend than other sites. Higher sewage discharges and organic matter decomposition and sulphur oxidation strongly acidify the sediment (Marchand *et al*., 2004). Furthermore carbon dioxide arising from decomposition of organic matter and from animal respiration or the humic acid production in mangroves due to litter degradation also lowers pH values in the soil. However in station 3 and 4 closer to sea experiences a highly alkaline condition due to the influence of salinity. In other Indian mangrove forests, alkaline range of pH was observed (Pravinkumar *et al*., 2013; Samidurai *et al*., 2012). Seasonal variation in water pH(r=0.309, p<0.01) and sediment pH(r=261, p<0.05) may be due to the salinity fluctuations and was lower in monsoon due to heavy rainfall (r=-0.317, p<0.01). Lower pH in monsoon was also reported by Meera and Bijoy Nandan (2010) in Valanthakad mangroves due to tidal influence and land runoff. pH variation is also due to the oxidation of Fe SO_4 and Fe S to H_2SO_4 (Holmer *et al*.,1994). pH in sediment was directly influenced by water column pH (r=0.540, p<0.01).Since, mangroves are considered as wastelands, chemical and other industrial discharges, constructional wastes dumped into mangrove zone along with discharges from Cochin port activities, International container transhipment terminal, may also vary pH concentration in mangrove area and cause a severe stress in dependent fauna particularly benthic fauna and may impair their growth and metabolic activities.

Salinity is an important factor that determines the mangrove plant structure (Duke,1992; Kathiresan,1998; Rani *et al*.,2016a) and acts as a limiting factor in the distribution of living organisms, and its variation caused by dilution and evaporation is most likely to influence the fauna in the intertidal zone (Sunil Kumar,1995;1993).The salinity was higher in stations (Vypin) closer to Arabian sea due to ingress of saline water through barmouth (Asha et al., 2016) while lower in inland area due to fresh water inflow (Gopal and Chauhan, 2006) as in Aroor (S1 and S2) and Valanthakad (S5 and S6). One of the major factor that vary salinity is monsoonal rainfall (r=-589, p<0.01). The lower salinity in Valanthakad was also reported by Meera and Bijoy Nandan (2010) especially during monsoon where the region may be transformed into fresh water basin with minimum salinity stratification. However pre-monsoon is characterised by dry periods with higher evaporation, lower rainfall and higher temperature (r=0.170, p<0.05) that significantly increases salinity. The spatio-temporal variability in salinity have marked influence on the structural and functional responses of organisms to variations in total osmotic concentration, the relative proportion of solutes, coefficient of absorption and saturation of dissolved gases (Sakamoto *et al*., 2015). Influence of salinity on benthic assemblage structure and decapod larval dispersal (Diele and Simith, 2006) were reported in Hongkong mangroves (Lui *et al*., 2002), Cochin mangroves (Sunil Kumar, 1993) and Cochin estuary (Sheeba, 2000).

Dissolved oxygen in water column depicts the environmental quality and is a pre-requisite for supporting life in the whole aquatic system ranging from microbes to higher fishes and each organism have an optimum oxygen requirements. In mangroves the anoxic nature of the sediments likely influenced the dissolved oxygen (DO) dynamics of water. In Cochin mangroves, DO exhibited wide fluctuation spatially and temporally but mean value doesnot show any significant variation between the sites. Higher DO in monsoon is due to higher primary production, increased precipitation and fresh water influx, during which salinity and temperature will be lower (Qasim *et al*.,1969; Pravinkumar *et al*., 2013).The higher DO during monsoon were reported in estuarine and mangrove zones in Cochin (Sunil Kumar,1993; Sreedevi *et al*., 2017; Asha *et al*.,2016). Furthermore, the oxygen dissolution in a water body is affected by salinity, altitude, groundwater inflow, tidal height, time of the day, tidal phase and distance from the forest edge and water temperature (r=0.294, p<0.01) (Addy and Green,1997; Mattone, 2016). Dissolved oxygen enter water bodies through diffusion from atmosphere or by primary production by mangrove plants, algae etc. Generally in mangroves the dissolved oxygen will be lower due to shallowness of system, higher litter degradation and higher organic matter that severely impact the sedentary benthic fauna. However Mattone (2016) studied the tidal influence and found that diurnal tide may oversaturate the mangrove pools but tidal disconnection may convert mangrove forest anoxic, and low DO saturations are likely to affect nekton and benthic fauna.

Turbidity defines the loss of transparency of water due to suspended particles in water column. Turbidity increases as the depth of water column decreases due to the influence of sedimentation, terresetrial inputs and also the textural state of sediment. As the particle size decreases the turbidity increases and in mangrove sites higher turbidity was noted in station 1(Aroor) due to its higher silt content(r=0.318,p<0.01) and organic matter (r=0.289, p<0.01) as reported by Asha *et al*.,2016 and lowest in station 5 and 6 due to sandy texture(r=-0.329, p<0.01). In the present study turbidity correlates with all the sediment variables and also to rainfall (r=0.172, p<0.05) which might be a reason for higher turbidity during monsoon season. Asp *et al*. (2016) observed a turbidity maximum zone during rainy season in Brazilian mangroves with rich mud content. The sediment mixing, disturbance and flocculation will be maximum due to heavy rainfall in mangroves and further influx of terrigenious substances, agricultural runoff, sewage, and other particulate matters also increase the turbidity. The turbidity cause lower diversity and biomass of benthic fauna in intertidal zone as reported in west coast of India (Raghunathan *et al*., 2003).

Substrate specificity is one of the factors influencing the benthic biocoenosis. Sediment not only provide substratum to live but also for feeding and acts as a source or sink of nutrients (Krom and Berner 1980).Sediment also determines the hydrography of aquatic systems (Nair *et al*.,1993) and distribution of aquatic vegetation especially mangroves. Mangrove vegetation inturn have influenced the sediment type by their root structures, pnuematophores resulting in accretion of sediment in mangrove zone. Generally mangrove plants prefer fine texture for their growth which are hostile for infauna due to low oxygen penetration and high toxins (sulphide) (Lee, 2008). Moreover the contaminants such as heavy metals, pesticides and herbicides have a strong tendency to get adsorbed on to fine-grained sediments that make it unfavourable for benthic fauna. Furthermore the effects of mangrove felling as part of coastal urbanisation increased the rate of erosion due to flooding of construction projects for tourism amenities and residential requirement which ultimately end up in estuaries. Site specific variation was observed in sediment texture of Cochin mangroves, but majority of sites have silty sand and sandy texture, however station 1 Aroor experiences silty texture due to stagnant nature of mangrove habitat and subsequent retention of higher organic matter (Schrijvers *et al.*, 1995). Station 5 and 6 (Valanthakad), with 90 % of sand have higher species density (r=0.169, P<0.05), biomass (r=0.260, p<0.01) and diversity of benthic fauna, as sand provides more micro-habitats, good permeability, oxygen and food particles for permanent burrowers (infauna) and also for surface dwellers (epifauna) which can move freely in and on the sediment. In mud, however permeability is poor with an anoxic layer just below the surface and supports only epifauna (Horikoshi, 1970; Sanders, 1968). Seasonal variation was not significant in mangrove sites. Previous study in Cochin mangroves and other mangroves of world reported correlation of sediment texture with abundance of benthic fauna (Sunil Kumar, 2002; Gray, 1974; Snelgrove and Butman, 1994) and sandy biotope support more fauna than muddy biotope.

Krom and Berner (1980) have reported that the decomposition of organic matter consists of nutrients such as nitrogen and phosphorus, which play a vital role in the establishment of healthy mangroves. It is also a crucial factor than sediment particle size in determining the infaunal distribution (Snelgrove and Butman, 1994). However in the present study benthic faunal density (r=-0.293, p<0.01) and biomass (r=- 0.279, p<0.01) seems to be lower in organic rich mangrove sediments (Aroor,S1) where *Avicennia* plants dominated with higher litterfall rate (Rani *et al*.,2016 b). Unlike other organic sediments mangrove litter is rich in alkaloids, flavonoids, phenols, saponins, tannins, glycosides and terpenoids (Feng *et al.*, 2007) which is the major constituent of *Avicennia* plants. It is also observed that low or high values of organic matter may lead to decline in species richness, abundance and biomass (Harkantra, 1982). Higher organic matter may deplete oxygen and leads to anaerobic conditions and subsequent accumulation of metals and other chemical contaminants (Ganapathi and Raman, 1973).

The mangrove ecosystem serves as sink of carbon (Alongi, 1996; Alongi *et al*., 2001).The storage or burial of carbon in the sediments of mangroves depends on several factors like litterfall rate, sediment texture, crab burrowing activity and root structure. All these help in trapping or retaining the carbon within the ecosystem and long term carbon sequestration. Both organic matter and organic carbon(r=-0.778, p<0.01) in mangrove sediments decreases with increasing sand content and increases with silt (r=0.770, p<0.01) and clay (r=0.570, p<0.01).The spatial variation in organic carbon in the present study agrees with this concept as higher organic carbon (39.04 ± 8.83 g/kg) in station 1 with silty texture and lower in station 5 (6.22± 2.65 g/kg) and 6 (9.84 ± 4.51 g/kg) with sandy texture. Organic carbon derived from decaying mangrove leaves are primary food source in sustaining larval and juvenile stocks of benthos and other organisms (Dogiparti, 2014).The outwelling of mangrove carbon also serves as primary food for nearby estuarine and coastal food chain. Any disturbance of mangrove sediments due to mangrove felling for meeting human requirements, may release the stored carbon, increasingly known as coastal blue carbon in the form of greenhouse gases affecting the global climate.

Redox potential (Eh) in sediments is the direct measure of reducing power and indicates degree of anoxia (Fiedler *et al*., 2007). According to Kaurichev and Shishova (1967), oxic sediment have an Eh over + 400 mV; moderately reduced sediment between +100 and +400 mV; reduced sediment between −100 and +100 mV; and highly reduced soils between −100 and −300 mV. Mangrove sediments generally have a reduced condition (Lyimo and Mushi,2005) due to higher organic content, higher litter decomposition, associated with lower water movement and low particle size (Clay, r=-0.194,p<0.05) as observed in present study. Thus sediment may act as a trap for electron acceptors in the overlying water and resulting in oxygen depletion associated with sulphide reduction and formation of hydrogen sulphide. Extensive production of H_2S, lower Eh and sulfidic sediment is hostile to aerobic organisms, however mangrove plants can sustain in the sediment. Spatial variation in Eh depends directly on mangrove tree species, their root structure, pneumatophores which have differential oxidation properties (Nickerson and Thibodeau, 1985; Lacerda *et al*., 1993). In the present study Eh varies from -555 to 127 which was comparable to values in Cochin estuary (Asha *et al*.,2016; Geetha *et al*.,2010), and also in coconut husk retting zones (Bijoy Nandan and Abdul Azis.,1997), but highly reduced than that reported in mangroves of Tamil Nadu (Samidurai *et al*.,2012).

Phosphorus (P) is an essential macronutrient in mangrove which plays a key role in global biogeochemical cycles (Singh *et al*., 2015). The phosphorus dynamics in mangrove sediment is linked to the organic matter decomposition and further immobilisation of nutrients to be available to organisms in their bioavailable orthophosphate form (Alongi, 1991; 1994; Kristensen, 1998).In mangroves, autochthonous litter, canopy nutrient transfer, below ground biomass and allochthonous inputs from natural (soil mineralisation, weathering) and anthropogenic sources (agricultural, sewage, aquaculture) increase phosphorus loads in sediments. Physicochemical factors such as low redox potential and low pH also contribute to release of phosphate bound to matrix in mangrove sediments (Clough *et al*., 1983). In Cochin mangroves, phosphorus ranged between 101 to 2192 mg/kg which was higher than those reported from Sunderbans (Ramanathan *et al*., 2008), Bhitarkanika (Chauhan, 2008); Pichavaram (Ranjan *et al*.,2011). However studies by Joseph *et al*. (2011) have reported higher values of total phosphorus 2,226–28,665 mg/kg in Cochin mangroves. Phosphorus presence is very much correlated to organic matter (r=0.692, p<0.01) which might be the reason for spatial variation in this study. Seasonal changes in plant uptake and microbial growth, temperature, rainfall, oxygen availability and sediment type have a profound effect on concentration which seems to be higher during monsoon.

Sulphur is an essential nutrient for mangrove vegetation. Sulphur cycle in mangrove ecosystems is important because high inputs of organic matter into the mangrove soils, along with oxic surface and anoxic subsurface zones, potentially allow sulphur to play a critical role in the biogeochemistry of these wetlands (Rosily, 2002). Total sulphur includes both organic and inorganic sulphur. Spatio- temporal variation in mangrove sulphur is associated with organic sulphur component in organic matter (Casagrande *et al*., 1979; Altschuler *et al*., 1983) and is evident in the present study due to its higher values in organic rich sediment (r=0.810, p<0.01) of station 1 (Aroor). Total sulphur showed a gradual increase in concentrations with the depth which can be attributed to the precipitation of sulphide sulphur in the sediments due to prevailing reducing condition. Sulphur is an important redox element and sulphate reduction usually increases with the increasing load of particles with associated reactive organic matter to the sediment (Thamdrup and Canfield, 1996; Wijsman *et al*., 2001).Higher sulphur values were observed in Cochin mangroves that ranged between 533.1 to 23539 mg/kg which was comparable to that reported in Cochin estuary and Kerala coast reaching upto 26000 mg/kg (Beenamma,1993) and higher than mangrove-fringed coast in French Guiana where it reached upto 12000 mg/kg (Marchand *et al*.,2003). Sulphate reduction is therefore the major mineralization pathway in sediments of productive coastal marine systems, accounting for 10-90 % of the total organic matter degradation (Jorgensen, 1977; Kostka et al., 1999). Mangroves play a major role in the global cycle of nitrogen and sulphur and act as reservoirs in the assimilation of wastes (de La Cruz, 1979). The correlation between the environmental variables were represented in Table 3.2

In PCA analysis first five principal components accounted for 74.4 % of variability, however the first axis implies variability between mangrove sites is due to substratum linked to organic matter, organic carbon, sediment particle size, sediment nutrients between stations. It is clear that station 1 differentiate from other sites due to these sediment variables except sand. Station 2, 4, 5 and 6 are separated from other sites by presence of sandy biotope. However in station 3, salinity, pH and DO seems to be the major differentiating environmental variable. So, in the present investigation, the nature of the substratum is found to be an influencing factor in the occurrence and abundance of benthic organism.

Table 3.2 Pearson correlation analysis of environmental variables in Cochin mangroves during 2010-2012 period.

	Wtem	**WpH**	**Salinity**	**Do**	**Turb**	**S.temp**	**S.pH**	**OM**	**Sand**	**Silt**	**Clay**	**Eh**	**T.Sul**	**T.phos**	**TOC**	**rain**
W.tem	1															
W.pH	.016	1														
Salinity	.074	.309**	1													
Do	.294**	.316**	-.008	1												
Turb	.083	-.092	-.071	-.143	1											
S.tem	.809**	.057	.170*	.220**	.104	1										
S.pH	.048	.540**	.261**	.119	.074	.122	1									
OM	-.024	.084	.058	-.112	.289**	-.036	.025	1								
Sand	-.054	.109	.081	.091	-.329**	-.031	.045	-.778**	1							
Silt	.049	-.066	-.05	-.078	.318**	.03	-.018	.770**	-.985**	1						
Clay	.055	-.240**	-.173*	-.112	.272**	.027	-.138	.578**	-.756**	.633**	1					
Eh	-.084	.107	-.031	.045	-.185*	-.095	-.084	-0.115	0.125	-0.098	-.194*	1				
TS	.023	-.093	.018	-.118	.311**	.04	-.109	.810**	-.803**	.801**	.569**	-.146	1			
TP	.046	.054	.098	-.046	.228**	.064	.018	.692**	-.562**	.539**	.480**	-.162	.685**	1		
TOC	-.024	.084	.058	-.112	.289**	-.036	.025	1.00**	-.778**	.770**	.578**	-.115	.810**	.692**	1	
Rain	.027	-.317**	-.589**	.044	.172*	-.041	-.269**	-.079	.011	-.05	.142	-.170*	-.012	.006	-.079	1

Significant correlation at a level of $p < 0.01$ (**), $p<0.05$ (*)

Chapter 4

STANDING STOCK OF BENTHIC FAUNA IN MANGROVE HABITATS

4.1 Introduction

Healthy mangroves are the pre-requisite for all aspects of coastal protection (Spalding *et al*., 2014). World Bank *et al*. (2004) put forth their vows on mangrove management as "*The fundamental objective of mangrove management is to promote conservation, restoration or rehabilitation and sustainable use of mangrove ecosystems and their associated habitats, supported where necessary by ecological restoration and rehabilitation*". Structure of benthic assemblages and benthic production studies is a powerful tool in mangrove management. The benthic fauna, unlike any other biota, because of their ubiquitous distribution and sedentary nature has a strong ecological relationship with mangroves and is an efficient assemblage to check the healthy status of this tropical ecosystem. Furthermore, benthos have major role in productivity and shaping the structure and function of the system, as ecological engineers, by their bioturbation activities, nutrient recycling and out-welling to coastal habitats promoting benthic pelagic coupling and with a definite response to environmental change (bioindicators). Mangrove in turn offers range of microhabitats that include trunk, prop roots, pneumatophores and foliage of mangrove trees (hard substratum), biogenic structures and soft muddy sediment for the benthic fauna. Their assemblage and biomass depends not only on physico-chemical factors but also on mangrove tree density and their stand age (Alongi, 2002; Morrisey *et al*., 2003). Alongside substrate elevation, tidal regime, salinity, sediment particle size, organic enrichment, chemical pollutants are other important factors (Lee, 2008).

Macrobenthic fauna was classified as epifauna (surface dwellers) generally dominated by brachyuran crabs and gastropods and infauna (burrowers) dominated by polychaetes, oligochaetes and insect larvae. The governing macrobenthos in mangroves are polychaetes, crustaceans and molluscs that conquer the benthic realm and significantly contribute to secondary production. Mangrove macrobenthos especially oligochaetes are being referred to as 'trophic dead ends', most serve as important link between mangrove organic matter and estuarine secondary production (Lee, 2008; Schrijvers *et al*., 1998). Secondary production is the ultimate measure of the success of a benthic population in mangrove habitats because it integrates abundance, biomass, growth, reproduction, and survivorship and thus link macroinvertebrate communities to ecosystem function (Benke, 1993). It also helps in quantifying energy flow through aquatic consumers, and thus may provide insight into the trophic status and dynamics (Odum, 1983). Moreover production estimates allow for better characterization of macrobenthic community structure and function.

The study on benthic macrofauna in mangroves has a long history (Macnae, 1968; Walsh, 1967; Warner, 1969; Sasekumar, 1974; Day, 1975). Mangrove habitat and their benthic faunal interaction was studied worldwide (Lee, 2008; Nagelkerken, 2008; Alongi, 2002). The functional role of macrobenthic fauna in mangrove ecology (Robertson and Alongi, 1992; Schrijvers *et al*., 1995; Bouillon *et al*., 2002; Kathiresan and Qasim, 2005) and their spatial distribution and temporal variation was studied by Alfaro (2006) in New Zealand mangroves and Dittmann (2001) in Australian mangroves. The influence of mangrove vegetative structure on benthic production was detailed in studies by Skilleter and Warren (2000); Odum and Heald (1972), moreover, secondary production of macrobenthos in mangrove area was discussed by Zhou and Cai (2010), benthic food web in mangroves was studied by Herbon (2011) and Kon *et al*.(2007). Sediment benthic interaction and sediment biogeochemistry were discussed by Chapman and Tolhurst (2007) and Alfaro (2010). Mangrove removal and habitat loss (Alfaro, 2010; Levings *et al*., 1994) and the effects of habitat complexity on the biodiversity and abundance of mangrove-associated fauna (Hatcher *et al*., 1989) were also reported. Furthermore comparative studies on benthic realm of mangrove with estuarine habitats (Davis *et al*., 2001; Dittmar *et al*., 2001) revealed lower diversity but higher density in mangroves.

Out of various mangrove sites in India, Sunderbans ranks first in benthic abundance and diversity studies followed by Pichavaram mangroves in Tamil Nadu in east coast and reported higher benthic standing stock in these regions whereas lower diversity was observed in the west coast that pertains to less scientific studies. Detailed study of benthic realm was carried out on the distribution, composition and abundance of benthic fauna in Sunderbans mangroves (Bhunia and Choudhury, 1981; Choudhury *et al*., 1984; Dehadrai, 1994). Actiniarians, polychaetes, nemertines, bivalves, echiurids, decapods, isopods, amphipods and gobiids are the major macrobenthic residents with the dominance of sipunculids and gastropods. Earlier studies on marine borers (Molluscs) in mangrove ecosystem were carried out by Ganapati and Rao (1959) while the ecology and diversity of mangrove molluscs was studied by Radhakrishnan and Janakiram (1975); Ramanamurthy and Kondalarao (1993) in Godavari mangroves. Critical Habitat Information System for Coringa Mangroves (Andhra Pradesh) in 2001 reported 114 species of macrobenthos. Major benthic study in Pichavaram was on mangrove crabs and nematodes. Sediment suitability, effects of tidal flushing and mangrove vegetation were the possible factors that could influence zonation and abundance of the crabs. *Avicennia marina* zone support more crabs than *Rhizophora zone* (Raffi *et al*., 2002; Ravichandran *et al*., 2001, 2011). Sundaravarman *et al*. (2012) compared the macro-meiofaunal composition in mangrove site (lined with *Excoecaria agallocha and Avicennia marina*) with land ward and coastal area without mangroves and found maximum macrofaunal counts in the mangrove-lined lagoon and the minimum in the landward site. A detailed study of benthic fauna of Andaman and Nicobar islands was done by Das and Roy (1989).

In west coast, studies on benthic faunal assemblage (Sesh Serebiah, 2003) and brachyuran crabs (Saravanakumar et al., 2007, Shukla *et al*., 2013) were carried out in Kachchh mangroves. Untawale and Parulekar (1976) conducted extensive studies on ecological aspects of estuarine mangrove area of Goa. The penaeid prawn stock of mangrove fauna of the Mandovi and Zuari estuaries in Goa comprises 13 species with *Metapenaeus dobsoni* and *M. monoceros*, together accounting for 80% of the total harvest (Parulekar and Achuthankutty, 1993). Marakala *et al*. (2005) studied the ecology and biodiversity of macrofauna of Karnataka mangroves and observed higher diversity index in dense mangrove area while evenness was higher in riverine stretch. Gowda *et al*. (2008) found the dominance of polychaetes followed by molluscs and crustaceans, with higher species diversity at the upper surface and decreased with sediment depth. Boominathan *et al*. (2012) studied the molluscan fauna of mangroves of India with special reference to Karnataka mangroves. Macrobenthos from the mudflats of Thane Creek, Mumbai includes polychaetes, gastropods, bivalves and sea anemones inhabiting the mangrove systems (Athalye and Gokhale, 1998). Padmakumar (1984) investigated the benthos of mangroves in Mumbai with reference to sewage pollution. Diversity of bivalve and gastropod molluscs from mangrove habitat, rocky substrata, sandy beach, and muddy habitat was compared by Khade and Mane (2012).

Benthic studies are scanty in mangrove ecosystem of Kerala. Kurian (1984) studied the benthic fauna in Cochin Mangroves. Community structure and distribution of macrobenthic fauna in mangrove sediments has been studied extensively (Sunil Kumar, 1993; 1995a, b; 1997, 1998) and compared the mangrove macrobenthic fauna with estuarine fauna of Vembanad estuary (Sunil kumar, 2002). Studies on environmental and sediment influence in diversity and distribution of polychaete fauna has been extensively studied from Cochin Mangroves (Sunil Kumar & Antony, 1993, 1994 a). Benthic diversity in mangrove ecosystems of India is depicted in Figure 4.1

Meiobenthic fauna, the metazoan component in the benthic ecosystem occur in all aquatic biotopes ranging from polar ice to alpine lakes, from hadal troughs to mangrove swamps (Giere, 2009). In the area of systematics, diversity and distribution, meiobenthic fauna hold key positions in metazoan phylogeny, linking various invertebrate lines. Nematodes form the most dominant meiobenthos in mangroves, along with foraminiferans and harpacticoid copepods. Structural complexity of mangrove vegetation provides diverse niche and mosaic of habitats for flourishing of these microscopic metazoans. However the density and diversity was lower in this detritus based mangrove ecosystem (Alongi 1987; Alongi and Sasekumar 1992; Chinnadurai and Fernando, 2007b) due to intrinsic stress factors. One such factor is the bioturbation and sediment reworking by macrobenthos. It has both negative and positive effects, negative impacts is through disturbance and destabilization on sediment for colonisation while positive ones involves higher oxygen and organic matter and helps in deeper vertical distribution in burrows as niche (Thistle *et al*., 1999; Koller *et al*., 2006).

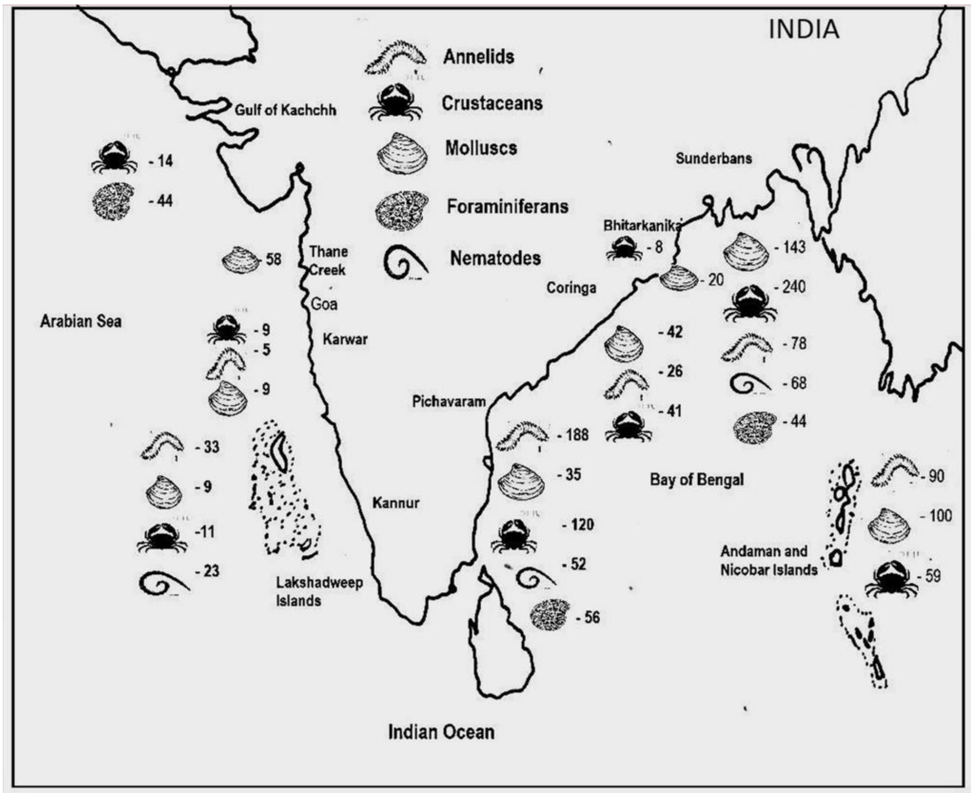

Figure 4.1 Benthic faunal diversity in mangrove ecosystems of India (Source: Philomina *et al*., 2018)

They have considerable ecological value in trophic cycle as a food source for higher organisms (Coull, 1999) as well as aiding in the recycling of organic matter

(Murray *et al.*, 2002). Compared to macrofauna, meiofauna is highly useful in environmental impact assessment and ecosystem health monitoring in view of its higher species richness, shorter life-cycles and lack of larval stages (Ansari *et al.*, 2014).

The term “meiobenthos” was first coined by Molly F. Mare in 1942 to define an assemblage of benthic metazoans that can be distinguished from macrobenthos by their small size. Their taxonomy seems to be much difficult due to their microscopic size and diversity. Hence the meiofaunal studies were limited world-wide (Armenteros *et al.*, 2011; Dye, 2006; Pinto *et al.*, 2013; Netto & Gallucci, 2003). Alongi (1987) recorded 1600 turbellarian flatworms, 200 nematodes, 9 harpactoid copepods and numerous ciliate protozoans, formaniferans, bivalve molluscs, oligochaetes, polychaetes, hydrozoans, archiannelids, kinorhynchs, amphipods, cumaceans, tardigrades and gastrotrichs from the mangroves of Australia. Sasekumar (1994) observed predominance of free-living nematodes, harpacticoid copepods, oligochaetes and kinorhynchs in Malaysian mangroves where density was maximum at Avicennia station followed by Rhizophora station and least in Bruguiera station. He could also found their abundance is linked to tidal action and areas where recurrent tides occur will have higher meiofauna due to frequent flushing of mangrove litters rich in tannin and sites were infrequent tidal inundation occur will have higher litter content, higher tannin concentration which have negative influence on meiobenthos (Alongi, 1987).

In Indian scenario, Rao and Misra (1983) studied meiofaunal abundance in Sagar Island, Sunderbans with predominance of nematodes followed by copepoda, polychaeta, ostracoda. Meiofaunal study showed 11 major faunal taxa, of which nematodes are dominant in Bhitarkanika mangrove sediments (Sarma and Wilsanand, 1994). About 28 meiofaunal taxa were recorded from Coringa mangroves with the predominance of nematodes followed by foraminiferans and harpacticoid copepods (Kondala Rao and Ramanamurty, 1988). Ali *et al.* (1998); Chinnadurai and Fernando (2006a, 2007a) studied the meiobenthic composition, and observed 37 species of nematodes from Pichavaram and 14 from Vellar mangroves (Chinnadurai and Fernando, 2006b). Meiofauna population density and assemblage of nematodes were higher in areas with *Avicennia marina* compared to *Rhizophora apiculata* cover (Chinnadurai and Fernando, 2007b; Ansari *et al*., 2014). 106 species of meiofauna identified from Muthupet and Sethukuda mangrove with predominance of foraminifera (Suresh *et al*., 2014; Thilagavathi *et al*., 2011). Rao (1986) recorded nematodes, copepods, gastrotrichs, kinorhynchs, archiannelids, polychaetes and ostracods from South Andaman of these nematode contributed 80% of the total fauna followed by copepods (12%). Higher carbonate and moderate organic carbon was essential for density and distribution of meiofauna (Mohan *et al*., 2012). In west coast, Ansari *et al*., (1993) studied the meiobenthic fauna of mangroves of Goa and reported that the nematodes, turbellarians and harpacticoids were reduced due to vertical gradients such as redox potential, organic matter in the environment and was positively correlated with interstitial water of the sediment and also to the microbial density in mangrove mudflats. Studies on the meiobenthos of intertidal zone of mangrove mudflats of Maharashtra revealed dominance of nematodes (Goldin *et al*., 1996). Chinnadurai and Fernando, (2006c) studied meiofauna of Cochin mangroves, and observed 7 major taxa represented by nematodes, copepods, foraminifera, polychaetes, oligochaetes, ostracods and turbellarians. Nematodes was abundant with 23 species belonging to 16 genus. with *Daptonema oxycerca* was the most common species that existed in all the stations due to high mud concentration in the sediments. He also determined the inter-relationship between the meiofauna and mangrove vegetation and found higher abundance of nematodes under *Avicennia marina* (48.2 %) and *Sonneratia caseolaris* (30.3 %) stand. Thilagavathi *et al*. (2011) reported that *Avicennia* determines the particles size of the sediment as pneumatophores are especially effective in trapping sediments and characterised by higher silt and clay for inhabitation of meiofauna.

These studies pertaining to the distribution of macrofauna and meiofauna are found deficient in the west coast particularly in Kerala mangroves. Moreover mangrove degradation rate was alarming in Kerala. Hence, the present investigation attempted to gain an insight into standing stock, assemblage structure and density of the mangrove-associated macrofauna and meiofauna of Kerala with due reference to the spatial and temporal scales of variation. It would also help us to gain a holistic view of the mangrove ecosystem.

4.2 Results

4.2.1 Macrofauna in mangrove stands of Kerala

Macrobenthic fauna was collected from mangrove ecosystems in different districts of Kerala during 2012-13 periods. Benthic fauna was grouped based on taxonomic class into Polychaeta, Malacostraca, Mollusca and Others. The ‘others’ were the infrequent representatives that include two taxa such as oligochaetes and pisces. The mean numerical density of macrobenthic fauna in mangrove ecosystem of Kerala was 279±300 ind.m^{-2} where crustaceans dominated with 48% (32% of amphipods, 9% decapods and 7% tanaids) followed by polychaetes with 27%, molluscs 22% (bivalves 18% and gastropods 4%) and ‘others’ 3% (2% oligochaetes and 1% benthic fishes). Macrobenthic density in different districts of Kerala are depicted in Figure 4.2.

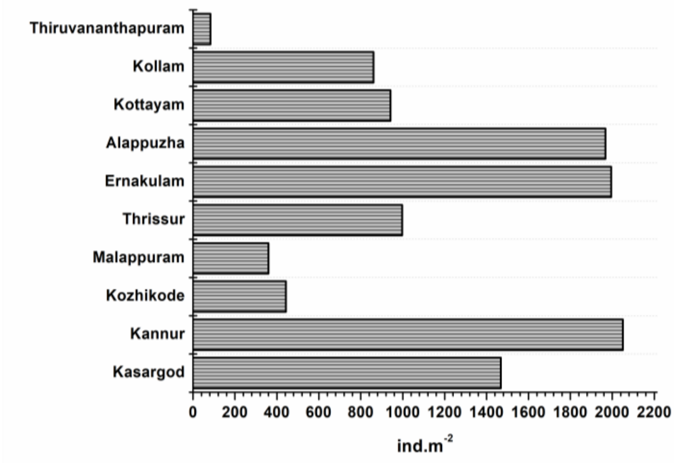

Figure 4.2 Macrobenthic density (ind.m^{-2}) in mangrove stands of different districts of Kerala during 2012-2013 period.

Mean numerical density ranged from 21 ± 27 ind.m^{-2} in Thiruvananthapuram to 512 ± 364 ind.m^{-2} in Kannur, where dense healthy mangroves were observed. Other districts such as Alappuzha 492±409 ind.m^{-2}, Ernakulam 499±405 ind.m^{-2}, Kasargod 367±380 ind.m^{-2} also exhibited higher density, while Thrissur (249±196 ind.m^{-2}), Kottayam (235±236 ind.m^{-2}) and Kollam (215± 246 ind.m^{-2}) have moderate density. Lower density was observed in Malappuram 90±83 ind.m^{-2} and Kozhikode 111±88 ind.m^{-2} districts.

Crustaceans, were the principal fauna in mangrove ecosystem with a mean density of 537±392 ind.m^{-2} and its predominance were seen in districts such as Ernakulam (1080 ind.m^{-2}), Alappuzha (997 ind.m^{-2}), Kannur (859 ind.m^{-2}) and Kasargod (859 ind.m^{-2}). Among crustaceans, amphipods were the major group in every station except at Kasargod where decapods were predominant. Polychaetes were the second dominant fauna in mangrove ecosystem of Kerala with an overall mean density of 302±218 ind.m^{-2}, however it was the predominant fauna of Kottayam district forming 60% of total fauna with a density of 554 ind.m^{-2} and also of Kozhikode (50%) with a density of 222 ind.m^{-2}. Its density ranged from 28 ind.m^{-2} in Thiruvananthapuram to 690 ind.m^{-2} in Kannur. Lower abundance were also noted in Malappuram (55 ind.m^{-2}) and Kollam (55 ind.m^{-2}). Molluscs exhibited a mean density of 244 ± 206 ind.m^{-2} in mangrove ecosystems. Its dominance was observed in Malappuram district forming 54% of macrofauna with a numerical abundance of 194 ind.m^{-2}. Its density ranged between zero (Thiruvanathapuram) to 582 ind.m^{-2} (Kannur). Spatial variation in relative density(ind.m^{-2}) of macrobenthic fauna in different districts of Kerala is plotted in Figure 4.3

Bivalves exhibited a universal distribution while gastropods were limited to Kasargod, Kannur, Ernakulum, Alappuzha and Kollam. The “other” groups such as oligochaetes, fishes exhibited a mean density of 33±52 ind.m^{-2} whereas fishes were observed in few numbers in Kasargod, Ernakulum and Kollam having a density of 28 ind.m^{-2} and oligochaetes in Kozhikode (55 ind.m^{-2}), Ernakulum (111 ind.m^{-2}) and Kollam (83 ind.m^{-2}).

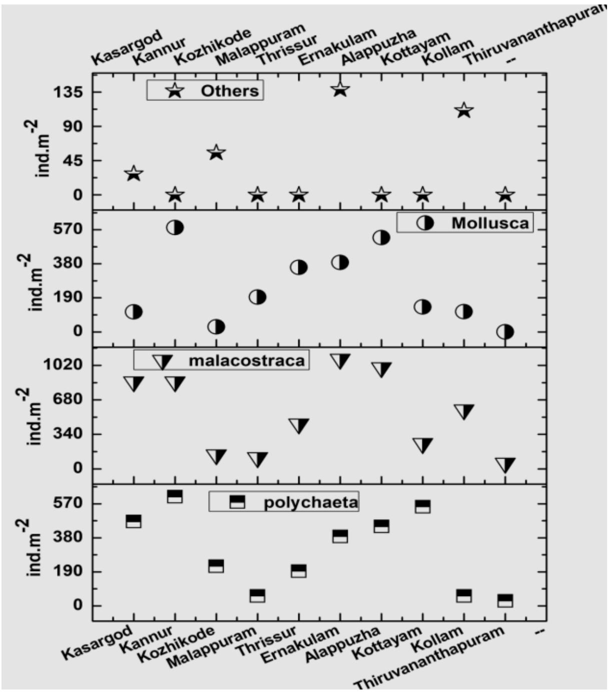

Figure 4.3 Spatial variation in relative density (ind.m^{-2}) of macrobenthic fauna in mangrove stands in different districts of Kerala during 2012-2013 period.

4.2.2 Macrobenthic standing stock in mangrove stands of Cochin

Cochin mangrove habitats were extensively studied for benthic standing stock of macrobenthos on a monthly basis for a two year period (September 2010-August 2012). About eleven diverse taxonomic groups (class) of macrofauna were encountered during the study period. The numerical density of macrofauna in study area varied between zero to 11223 ind.m^{-2} with an overall density of 234381 ind.m^{-2} and mean of 1628 ± 2283 ind.m^{-2}. Out of the total 8437 organisms collected in the grab samples, 4629 (55 %) were malacostracan crustaceans, the dominant group during the entire study, 1955 (23 %) polychaetes, 1085 (13 %) molluscs and 768 (9%) 'others' [Figure 4.4]. The infrequent representatives were grouped together as 'others' including oligochaetes, insects, collembolans, platyhelminthes, nemerteans, nematodes and benthic fishes.

Biomass of macrofauna was estimated on a wet weight basis, after sorting them into four major groups such as malacostracan crustaceans, polychaetes, molluscs (bivalves & gastropods) and 'others'(platyhelminthes, nematodes, insects, oligochaetes, nemerteans and benthic fishes). During the entire study, biomass varied between 0.22 to 72.11 g.m^{-2} with a total biomass of 3003.15 g.m^{-2} and a mean of 20.85 ± 44.70 g.m^{-2}. The dominant groups that contributed to benthic biomass were molluscs (64 %), then polychaetes (19%), malacostracan crustaceans (15 %) and 'others' (2%) [Figure 4.4]

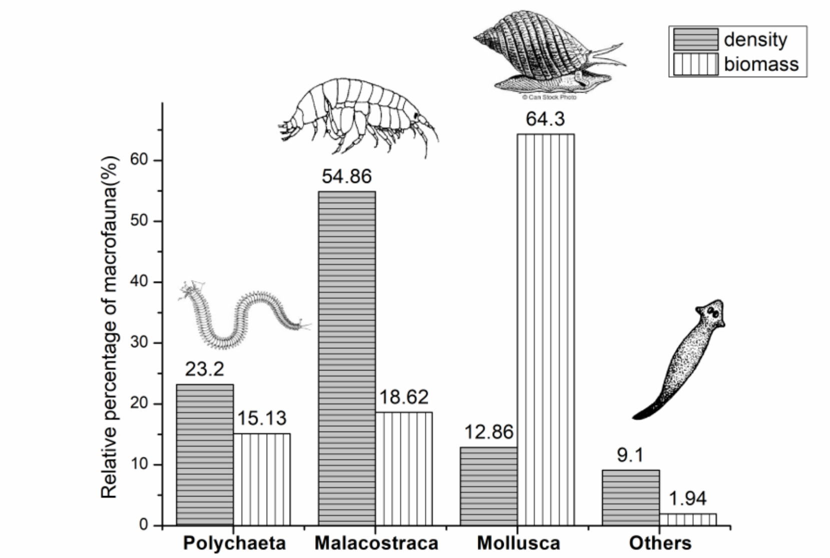

Figure 4.4 Mean percentage contribution of macrobenthic faunal density and biomass (%) in mangrove stands of Cochin during 2010-2012 period.

4.2.2.1 Spatio-temporal variation in macrobenthic fauna in Cochin

Significant spatial and temporal variations were observed in the numerical density and biomass of macrofauna during two year study period (2010-2012). one-way ANOVA was performed to test the significant variability in density and biomass of macrofauna on a spatio-temporal scale.

a. Macrobenthic Density

Macrofaunal density exhibited annual, seasonal and spatial variations.

Significant variations were observed between two years of benthic samples ANOVA F (1,144) = 3.947, p = 0.049) (Figure 4. 5a). During first year numerical density was 95785 ind.m^{-2} that ranged between zero (Station 4) to 11223 ind.m^{-2} (Station 1) with an overall mean value of 1330 ± 2102 ind.m^{-2}. Maximum mean density was observed in month of November 2010 (3551 ± 4154 ind.m^{-2}) and minimum in March 2011 (380 ± 300 ind.m^{-2}) during first year (2010-2011). However in second year numerical density was 138594 ind.m^{-2} that ranged between zero (Station 4) to 8806 ind.m^{-2} (Station 5) with an overall mean value of 1925 ± 2428 ind.m^{-2}. Maximum density was observed in November 2011 (3408 ± 3539 ind.m^{-2}) and minimum in September 2011(537 ± 773 ind.m^{-2}) during second year (2011-2012). Both in first and second year malacostracan crustaceans were dominant.

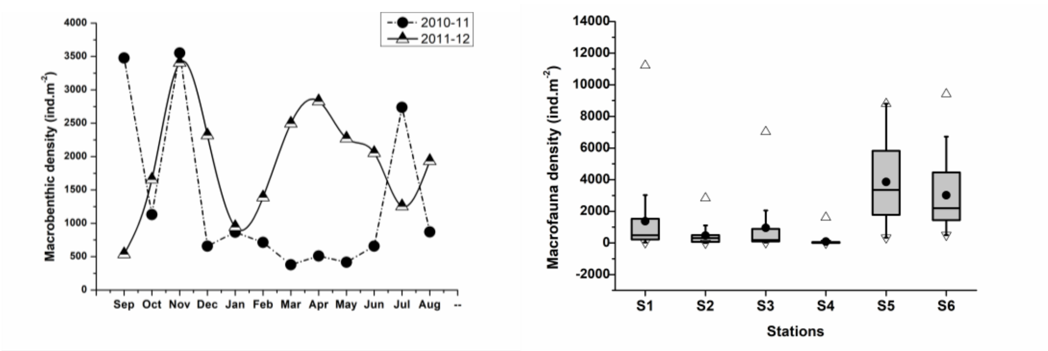

Figure 4.5 Macrobenthic density (ind.m^{-2}) a) annual variation b) spatial variation in Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

Significant spatial variation was observed in benthic samples collected from mangroves of Cochin (ANOVA F (5,144) = 16.54, p = 0.000). Open mangrove zones of Valanthakad island including station 5 (3861 ± 2453 ind.m^{-2}) and station 6 (3015 ± 2265 ind.m^{-2}) recorded highest density, contributing to 40% and 31% respectively. Mean density of other stations were intermediate as in station 1(1375±2408 ind.m^{-2}), station 2 (471±663 ind.m^{-2}) and station 3 (957±1810 ind.m^{-2}). Station 4 (86 ± 326 ind.m^{-2}) documented lowest mean density contributing to less than 1 % [Figure 4.5 b]

Similarly, significant differences were observed between seasons (ANOVA F (5,144) = 2.94, p = 0.015). Seasonally highest mean numerical density was observed in post-monsoon season (7267±7848 ind.m^{-2}) followed by monsoon (6762±6557 ind.m^{-2}) and pre-monsoon (5503±5584 ind.m^{-2}) during two year study period (2010-12). Pre-monsoon and post-monsoon of second year exhibited maximum mean density of 8987 ± 9323 ind.m^{-2} and 8329 ± 10149 ind.m^{-2} respectively, however pre-monsoon of first year (2019±1805 ind.m^{-2}) recorded least density [Table 4.1].

Table 4.1. Seasonal variation in macrobenthic density (ind.m^{-2}) in mangrove stands of Cochin during 2010-2012 period.

Seasons	Polychaeta	Malacostraca	Mollusca	Others	Total
Pom 10-11	792 ±960	3079 ± 3374	204 ± 163	2130 ± 4023	6204±5546
Prm 10-11	273 ± 285	1426 ± 1329	153 ± 311	167 ± 178	2019±1805
Mon 10-11	2463 ± 2858	3473 ± 3271	1245 ± 2199	560 ± 408	7741±6385
Pom 11-12	2681 ± 4441	5065 ± 5525	375 ± 521	208 ± 163	8329 ±10149
Prm 11-12	1269 ± 1913	5815 ±5570	1708 ± 2533	194 ± 200	8987±9363
Mon 11-12	1574 ± 2415	2574 ± 2154	1338 ± 2430	296 ± 319	5783±6729

b. Macrobenthic biomass

Macrofaunal biomass doesn’t exhibited significant differences annually In the first year the mean biomass was 16.34 ±42.25 g.m^{-2} and that of second year was 25.36±46.88 g.m^{-2}. The highest mean monthly biomass was observed in October 2010 (39.12 ± 84.10 g.m^{-2}) during first year and in April 2012 (58.28 ± 84.37 g.m^{-2}) during second year while lowest recorded in February of first (1.54 ± 1.84 g.m^{-2}) and second year (5.91± 8.17 g.m^{-2}) respectively [Figure 4.6a]. Molluscs were dominant in both years in terms of biomass. Spatial variability was significant (ANOVA F (5,144) =15.240, p=0.000) with the highest mean of 72.11 ± 71.90 g.m^{-2} recorded at station 5 contributing to 58% and station 6 (39.76 ± 50.94 g.m^{-2}) to 32 %. In other mangrove stations, comparatively lower values were noticed particularly at station 1(7.28 ± 12.67 g.m^{-2}), station 2 (3.02 ± 7.20 g.m^{-2}) and station 3 (2.70± 4.45 g.m^{-2}) and the least value in station 4 (0.22 ± 0.78 g.m^{-2}) [Figure 4.6b].

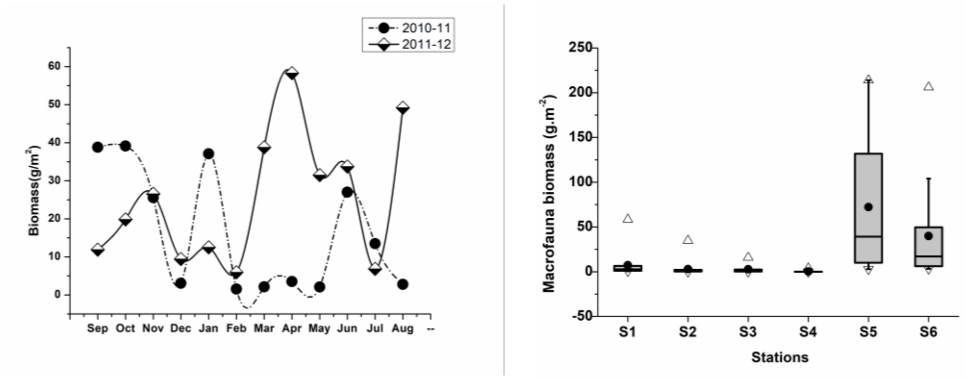

Figure 4.6 Macrobenthic biomass (g.m^{-2}) a) annual variation b) spatial variation in Cochin mangroves during 2010-2012 period (whisker: range, box: interquartile range, circle: mean).

On a seasonal scale, no significant differences were observed. The seasonal mean biomass was in a decreasing order of monsoon (91.8 ± 133.6)> post-monsoon (86.5 ± 126.1)> pre-monsoon (71.8± 94.3) in mangroves. The pre-monsoon of the second year (134.4 ±193.5 g.m^{-2}) depicted higher biomass however pre-monsoon of the first year (9.25 ± 10.6 g.m^{-2}) with lowest mean biomass [Table 4.2]

Table 4.2. Seasonal variation in macrofaunal biomass (g.m^{-2}) in mangroves of Cochin during 2010-2012 period

Seasons	Polychaeta	Malacostraca	Mollusca	Others	Total
Pom 10-11	9.9 ± 14.9	8.7 ± 9.09	79.2 ± 126.2	6.8 ± 13.3	104.8 ± 163.6
Prm 10-11	4.56 ± 6.8	4.3 ± 3.2	0.18 ± 0.36	0.15 ± 0.16	9.25 ± 10.6
Mon 10-11	13.9 ± 17.3	17.6 ± 24.08	49.1± 116.5	1.38 ± 1.46	82.1 ± 159.4
Pom 11-12	25.9 ± 44.7	13.4 ± 11.1	28.6 ± 69.17	0.19 ± 0.18	68.2 ± 125.2
Prm 11-12	25.5 ± 38.04	22.8 ± 21.2	85.4 ± 133.6	0.55 ± 0.61	134.4 ± 193.5
Mon 11-12	13.2 ± 20.6	8.5 ± 6.7	79.2 ± 126.9	0.58 ± 0.73	101.6 ± 155.1

4.2.2.2 Macrofaunal communities

a. Malacostraca

Malacostracan crustaceans were the most dominant fauna having ubiquitous distribution in the unique mangrove system. They were largely represented by the amphipods and tanaids, with significant representation from decapods and isopods. Amphipods were the prime representative of malacostracans with a numerical density of 87507 ind.m^{-2} (68.03%), then tanaids 39364 ind.m^{-2} (30.61%), together contributing to 99% of crustaceans in mangrove ecosystem. Whereas isopods (611.16 ind.m^{-2}) and decapods (1138.98 ind.m^{-2}) were the minor represented members less than 1% in abundance and their annual variation is depicted in Figure 4.7a.

Mean crustacean density was 893 ± 1271 ind.m^{-2} adding to 55% of total macrofauna during the entire study period. Mean density for first year (665 ± 962 ind.m^{-2}) significantly varied (ANOVA F (1,144) =7.106, p=0.009), from that of the second year (1121 ± 1491 ind.m^{-2}). Crustacean density varied significantly between stations (ANOVA F (5,144) = 15.036, p =0.000) and seasons (ANOVA F (5,144) = 3.965, p =0.002). In a spatial scale, crustacean density was highest at Valanthakad region (S5 and S6) contributing to 70% of density. The mean density was highest in station 5 (2046 ± 1346 ind.m^{-2}) and in station 6 (1696±1400 ind.m^{-2}) while least density in station 4 (25 ± 74 ind.m^{-2}) [Figure 4.7b]. Crustaceans were dominant among other benthic representatives in all stations except at station 4. The relative abundance of this group compared to other macrofauna was 61.95% at station 1, 53.07% at station 2, 51.03 % for station 3, 29.73 % for station 4, 53% for station 5, 56.24% for station 6. Seasonally, the mean density was highest during pre-monsoon (5815 ± 5570 ind.m^{-2}) and post-monsoon season (5065±5525 ind.m^{-2}) of the second year period and lowest during pre-monsoon season of the first year (1426 ± 1329 ind.m^{-2}) [Table 4.1].

Mean crustacean biomass was 18.93 ± 17.86 g.m^{-2} contributing to 15% of benthic biomass during the entire period of study. Annual and temporal variation in biomass was not significant however, the mean biomass was higher in second year (22.47±12.71 g.m^{-2}) compared to first year (15.40±21.86 g.m^{-2}). Temporally pre-monsoon of second year accounted for higher biomass (22.8 ± 21.2 g.m^{-2}) [Table 4.2]. Spatial variation in benthic biomass of crustaceans were significant (ANOVA F (5,144) = 4.369, p =0.001) with highest value in station 1 (6.77±12.72) and in station 6 (4.80±4.97) and least biomass observed in station 4 (0.07±0.18)[Figure 4.7b].

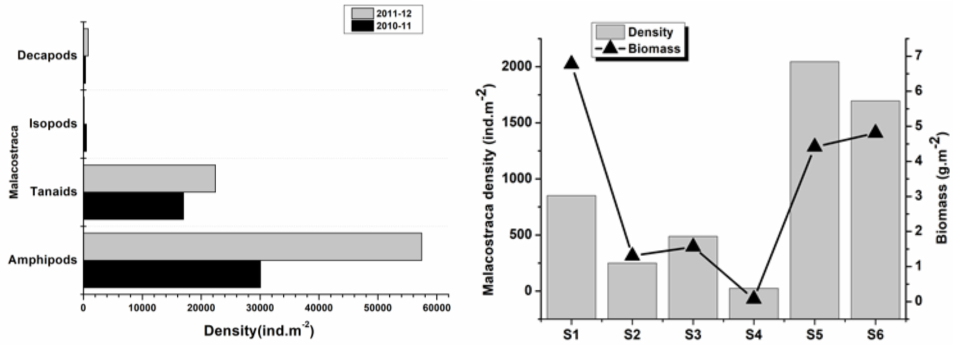

Figure 4.7 Malacostracan crustaceans a) annual variation in density b) spatial variation in density and biomass in Cochin mangroves during 2010-2012 period.

b. Polychaeta

Polychaetes were the second most dominant fauna representing 23 % of all benthic groups in mangrove ecosystem. Mean density of polychaetes during the entire study period (2010-2012) was 377 ± 976 ind.m^{-2} and that for the first year period was 294 ± 967 ind.m^{-2} and 460 ± 985 ind.m^{-2} for the second year. Annual and temporal variation in polychaete abundance was not significant however, significant differences were observed between stations (ANOVA F (5,144) = 6.773, p =0.000). The mean density was highest at station 5 (1158 ± 1490 ind.m^{-2}) and lowest at station 4 (1 ± 6 ind.m^{-2}) and station 1(8±25 ind.m^{-2}) [Figure 4.8a].The relative abundance of this group was 0.59 % for station 1, 8.6%, for station 2, 38.57 % for station 3, 1.35 % for station 4, 29.9 % for station 5, 22.76 % for station 6. Seasonally, mean density of polychaetes observed to be highest during the post-monsoon season of the second year (2681 ± 4441 ind.m^{-2}) and monsoon of first year (2463±2858 ind.m^{-2}). However it was lowest during pre-monsoon season of the first year (273 ±285 ind.m^{-2}) [Table 4.1, Figure 4.8b].

Mean biomass of polychaetes during the entire study was 23.29 ± 23.26 g.m^{-2} but was highest in second year (32.37 ± 26.11g.m^{-2}) compared to the first year (14.22± 16.43 g.m^{-2}). There was a significant annual (ANOVA F (1,144) = 5.107, p =0.025) and spatial (ANOVA F (5,144) = 11.94, p =0.000) variation in polychaete biomass. Spatially polychaete biomass was highest in station 5 (12.5 ±16.4 g.m^{-2}) and station 6 (9.4±10.7 g.m^{-2}) [Figure 4.8a].

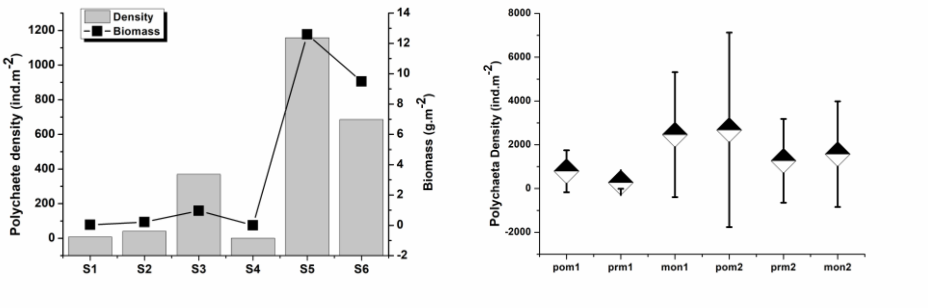

Figure 4.8 Polychaetes **a)** spatial variation in density and biomass **b)** seasonal variation in density in Cochin mangroves during 2010-2012 period.

c. Molluscs

Molluscs represented by bivalves and gastropods forms the major standing stock in terms of their biomass (64%) in mangrove ecosystem. Among the molluscs, bivalves constituted predominant group with few representations from gastropods. The contribution of bivalves was 11.9% and that for gastropods was 0.87 % to overall macrofaunal density. The mean density of molluscs was 209±539 ind.m^{-2} during the entire period of study and that for the first year was 133 ± 375 ind.m^{-2} and 285 ± 657 ind.m^{-2} for the second year survey. Analysis of variance for molluscan density showed significant variations annually (ANOVA F (1,144) = 3.919, p =0.050), temporally (ANOVA F (5,144) = 10.260, p =0.000) and spatially ANOVA F (5,144) = 3.279, p =0.008). The highest abundance of molluscs was observed at station 5 (593 ± 835 ind.m^{-2}) and station 6 (593±799 ind.m^{-2}), however in station 1, molluscs were not encountered during the entire period of sampling [Figure 4.9a]. Seasonal distribution was synonymous to malacostracans with maximum density noticed in pre-monsoon season of second year (1708 ± 2533 ind.m^{-2}) and lowest during pre-monsoon of first year (153±311 ind.m^{-2}) [Figure 4.9b]. Variations in biomass of molluscs were not statistically significant at yearly and seasonal surveys, while it was significant spatially (ANOVA F (5,144) = 10.267, p =0.000). On a spatial scale, station 5 (68.3%) and station 6 (31.5%) principally contributed (99 %) to biomass of mollusc with a mean value of 54.97± 71.24 g.m^{-2} and 25.36±47.93 g.m^{-2} respectively [Figure 4.9a].

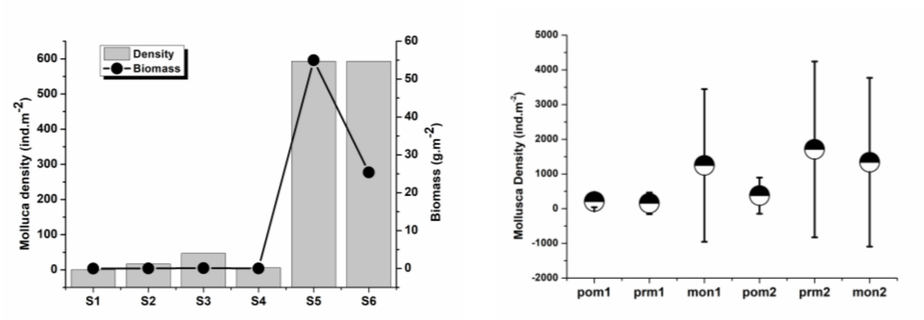

Figure 4.9 Molluscs **a)** spatial variation in density and biomass **b)** seasonal variation in density in Cochin mangroves during 2010-2012 period.

d. Others

Oligochaetes, insects, collembolans, nemerteans, nematodes, platyhelminthes and pisces were the random representatives in mangrove ecosystem which were grouped as 'Others'. They contributed to 9 % of the total numerical density of macrofauna. Out of the 768 individuals collected from 144 grab samples, 611 oligochaetes (79.56%), 141 insects (18.36%), 1 collembolan (0.13%),1 nematode (0.13%), 2 platyhelminthes (0.26%), 3 nemerteans (0.39%) and 9 pisces (1.17%) were sorted out. Oligochaetes and insects formed the dominant taxonomic groups among 'Others' with regard to density. In the first year numerical density was higher (18%) compared to second year (3%) with a mean density of 238 ±1117 ind.m^{-2} and 58±104 ind.m^{-2} respectively [Figure 4.10a]. Higher density in the first year was mainly contributed by greater representation of oligochaete fauna with 508 individuals while in second year it was only 103 individuals. Spatially highest mean density was observed at station 1 (515±1882 ind.m^{-2}) and lowest at station 6 (41±88 ind.m^{-2}) however on a seasonal scale post-monsoon (2130±4023 ind.m^{-2}) and monsoon (560±408 ind.m^{-2}) of first year have maximum density and pre-monsoon of same year have lowest density (167±178 ind.m^{-2}). ANOVA results showed no significance due to the higher spatial variability in density as well as biomass. The overall mean biomass of “others” was 2.34 ± 7.54 g.m^{-2} and was only 2 % of total biomass of macrobenthos in mangroves. On a spatial scale, biomass was highest in station 2 (1.49±6.75 g.m^{-2}) and lowest in station 3 (0.06±0.13 g.m^{-2}). Seasonally post-monsoon season of first year (6.86±13.31) favoured maximum biomass while pre-monsoon (0.15±0.16) accounted for the lowest biomass. Spatial variation in density and biomass is plotted in Figure 4.10b.

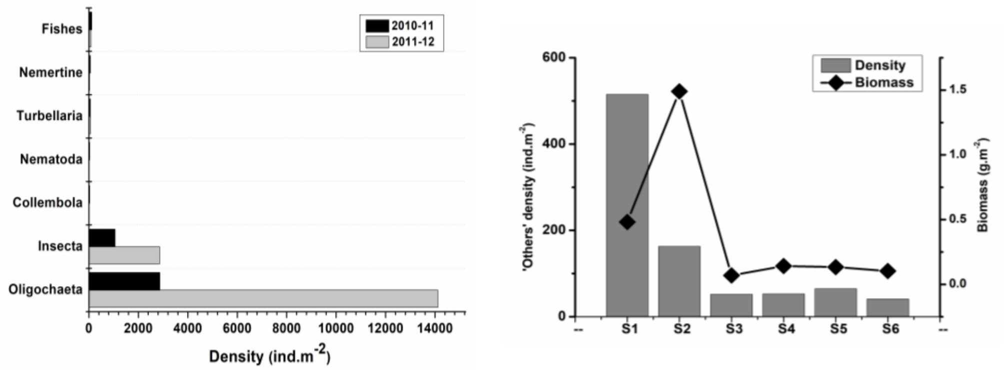

Figure 4.10 ‘Others’ **a)** annual variation in density **b)** spatial variation in density and biomass in Cochin mangroves during 2010-2012 period.

4.2.3 Meiobenthic standing stock in mangrove stands of Cochin

Meiofauna was collected on a seasonal basis for one year (2011-2012) from the mangroves of Cochin. The numerical abundance of meiofaunal organisms was expressed in ind.10 cm^{-2}.They were identified up to group level exhibiting mean numerical density of 539 ± 1439 ind.10 cm^{-2}. Of these, 72.32 %were nematodes, which were the dominant group, followed by foraminiferans (25.14 %), harpacticoid copepods (1.70%) and “other” organisms (0.85%) that include tanaids (0.08 %), ostracods (0.15 %), polychaete larvae (0.31 %), crustacean nauplii (0.15%) and few unidentified fauna (0.15%) [Figure 4.11]. Spatially significant differences in numerical density was observed between stations (ANOVA F (5, 18) = 7.014, p = 0.005) and not with seasons. Mean density varies from zero (Station 4) to 2438 ± 2994 ind.10 cm^{-2} (station 3). Station 2 (283±552 ind.10 cm^{-2}) and station 5(415±810 ind.10 cm^{-2}) exhibited a moderate density while station 1(40±42 ind.10 cm^{-2}) and station 6 (58±83 ind.10 cm^{-2}) depicted lower meiofaunal density [Figure 4.12a]

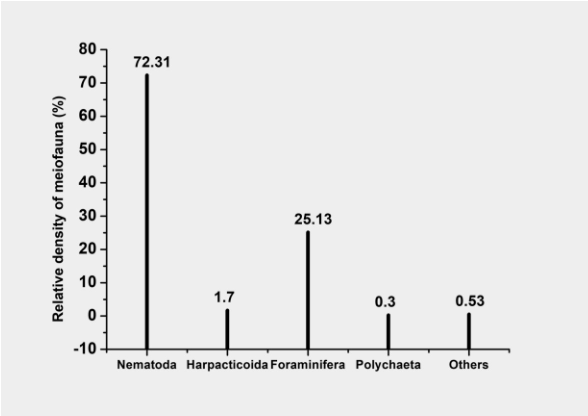

Figure 4.11 Mean percentage contribution of meiofauna in mangrove stands of Cochin during 2011-2012 period.

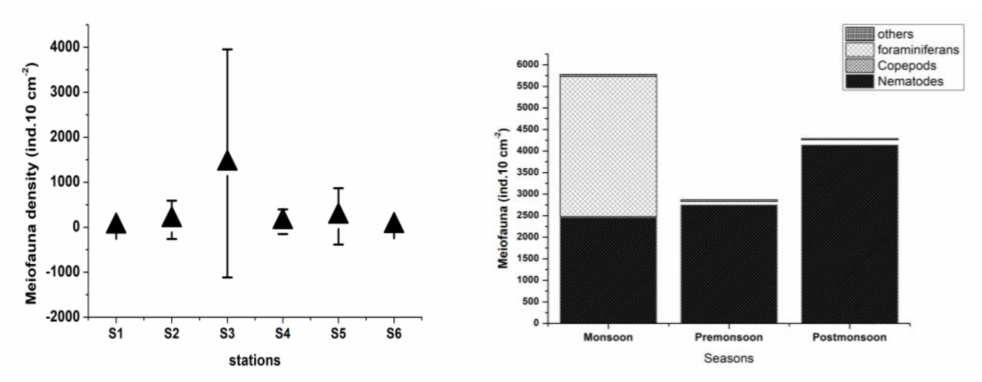

Figure 4.12 Meiofaunal density (ind.10 cm^{-2}) a) spatial variation b) seasonal variation in Cochin mangroves during 2011-2012 period.

Seasonally, monsoon favour highest meiofaunal density of 5780 ind.10 cm^{-2} having a mean value of 963 ± 1821 ind.10 cm^{-2} [Figure 4.12b]. The foraminiferans (56.23%), showed maximum percentage abundance followed by nematodes (42.56%) during monsoon while harpacticoid copepods (0.35%) and 'others'(0.87%) were least represented. In post-monsoon season, the density was 4290 ind.10 cm^{-2} with a mean of 715 ± 1518 ind.10 cm^{-2}, from which 96.50% of assemblage was nematodes, forming the dominant taxonomic group, followed by harpacticoids (2.80%) and 'others'(0.70%).The lowest density was observed in pre-monsoon (2870 ind.10 cm^{-2}) with a mean value of 478 ± 695 ind.10 cm^{-2} and percentage abundance of fauna follows similar trend as that of post-monsoon with higher abundance of nematodes (95.82%) and absence of foraminiferans. In all the seasons, station 3 exhibited remarkable numerical density related to other stations ranging from 350 ±634 ind.10 cm^{-2} (Pre-monsoon) to 1958±1588 ind.10 cm^{-2} (Monsoon).

4.3 Discussion

4.3.1 Macrobenthic stock in Kerala mangroves

Benthic standing stock determines the productivity and ecological stability of any ecosystem. In particular, mangrove benthos are important group that strongly influence the energy flow and food web structure by consuming litter shed by mangrove trees and promote nutrient recycling in the coastal habitats. They also play major role in shaping the structure and function of mangrove ecosystem. Kerala mangrove resources have dwindled from 700km^2 to about 9 km^2 (India State of Forest report, 2017). Consequently, several prized species of plants and animals have disappeared from the wetland habitats of the Kerala State. Now the major halves of mangrove forests are spread over the northern districts of Kozhikode, Kannur and Kasaragod. Kannur has the largest extent followed by Kozhikode and Ernakulam. Recent studies have identified 18 true mangrove species (Bijoy Nandan *et al*., 2015, Sreelekshmi *et al*., 2018) from coastal districts of Kerala. Eventhough the mangrove vegetative diversity was higher, the benthic standing stock (279±300 ind.m^{-2}) was lower in the present study compared to Tamil Nadu mangroves (Samidurai *et al*., 2012) and Kachh mangroves,Gujarat (Saravanakumar *et.al*., 2007). Comparative study of macrobenthic density revealed a higher faunal composition in Kannur (512± 364 ind.m^{-2}) that seems to be due to luxuriant mangrove forests which cover almost 80 % of the total mangrove forests of the state and also higher floristic diversity (12 species). Furthermore innumerable rivers, estuaries and wetlands, having comparatively lower human settlements in the coastal areas, less developmental activities and human interference, extensive afforestation by forest department attributed to the rich mangrove vegetation (Bijoy Nandan *et al*., 2015) as well as sustainable benthic communities in Kannur. Thiruvananthapuram recorded lowest density of benthos (21±27 ind.m^{-2}) that might be due to undergoing destruction and lowest floristic diversity and richness of mangroves represented by only 3 mangrove species *Sonneratia caseolaris, Avicennia officinalis,* and *Acrostichum aureum* (Sreelekshmi *et al*., 2018). The benthic stock was also lower in Malappuram (90 ind.m^{-2}) and Kozhikode (111 ind.m^{-2}) due to the varying physical factors and pollution. Eventhough Kollam exhibited maximum floristic diversity of true mangroves (15 species), their benthic production (215 ind.m^{-2}) was lower, mainly due to population pressure and other tourism activities on mangrove habitat as a whole. Crustaceans were the principal fauna in mangrove ecosystem with a mean density of 537±392 ind.m^{-2} and its predominance were seen in districts such as Ernakulam, Alappuzha and Kannur that may be due to their habitual association with aquatic mangrove vegetation where mangrove density was maximum. However, polychaetes were predominant in Kottayam (554 ind.m^{-2}) and also at Kozhikode (222 ind.m^{-2}). Similar trend was also seen in Pichavaram where 73% of benthic fauna was crustaceans and 24% of polychaetes (Murugesan *et al*., 2016). The differential distribution pattern of benthic fauna might be due to variability in abiotic factors such as salinity, sediment grain size, migration of fauna in response to tides and biotic factors such as predation, competition and dynamics of food (Ozolin'sh, 2002).

4.3.2 Benthic stock in Cochin mangroves-environmental and vegetational influence

Benthic production studies are scanty in Cochin mangroves (Sunil Kumar, 1993; Chinnadurai and Fernando, 2006 c). In the present study, density (1628 ± 2283 ind.m^{-2}) as well as biomass (20.85 ± 44.70 g.m^{-2}) of macrofauna showed significant spatio-temporal variation. Spatio-temporal variation in mangrove ecosystem is attributed to multitude of factors such as salinity (Lui *et al*., 2002; Sunil Kumar,1993), depth (Seitz *et al*., 2006), dissolved oxygen, tidal regime and pH (Sasekumar, 1974), rainfall (Staples, 1980), temperature (Meager *et al*., 2011), redox potential (Rosenberg and Ringdahl, 2005), nutrient differences (Kumar and Khan, 2013), sediment grain size, organic matter/organic carbon (Lacerda *et al*.,1995), biogenic structures (Mermillod-Blondin *et al*., 2003), detritus availability and predation (Schrijvers *et al*., 1998),mangrove plant types and density (Alfaro, 2006; Hutchings and Saenger, 1987; Lee, 1998), mangrove stand age (Morrisey *et al*., 2003; Chen *et al*.,2007), varied microniche (Lee, 2008; Bosire *et al*., 2004), trophic limitations (Ozolin'sh, 2002), inappropriate sampling scales (Kelly *et al*., 2001) and sampling methods (Perkins *et al*., 2003).

Benthic density and biomass are the useful parameters to characterize macrobenthic community structure and secondary productivity (Dauer, 1993; Tumbiolo and Downing, 1994). Schwinghamer (1983) has shown that the distribution of biomass among different size classes of benthic organisms is a conservative structural feature that relates to pre-dominant life-styles of the micro-, meio- and macrofauna. Mangrove density and biomass in the present study was comparable with that reported from mangroves of Jiulongjiang Estuary, China (Chen *et al*., 2007), mangrove fringed Segara Anakan lagoon, Indonesia (Nordhaus *et al*., 2009), Pondicherry mangroves (Kumar and Khan, 2013) and Kachchh mangroves, Gujarat (Saravanakumar *et al*., 2007), however lower than that reported from Cochin mangroves (Sunil Kumar, 1993), Cochin estuary (Asha *et al*., 2016) and Kodungallor Azhikode estuary (Jayachandran *et al*., 2019. In the macrobenthic density, 55 % were malacostracan crustaceans, the dominant group during the entire study, 23 % polychaetes, 13 % molluscs and 9% 'others'. However in biomass 64% molluscs, 19% polychaetes, 15% malacostraca and 2% 'others'. Previous studies in Cochin mangroves by Sunil Kumar (1993) reported that polychaetes were dominant in terms of density accounting 51.7% followed by molluscs (26.23%), crustaceans (15.12%), and others (6.95%). Likewise biomass was also highest for polychaetes (51.44%) while the crustacea, mollusca and other groups together contributed only 48.46% (Sunil Kumar, 1993). So a serious change in community pattern and abundance and biomass was observed within two decade period in mangroves of Cochin.

Spatially highest density and biomass was observed in station 5 and station 6 where the sand content (>85%), redox potential (-48 to -66 mV) and dissolved oxygen (>4 mg/l) were higher while organic matter (<16 g/kg) and turbidity (<3 NTU) were lower. Seasonally, highest density was in post-monsoon season, followed by monsoon and pre-monsoon during two year study period (2010-2012). Sunil Kumar (1993) reported similar trend in Cochin mangroves driven by south-west monsoonal rain.

The correlation of biomass and density of macrofauna with various physico-chemical factors revealed that substratum with higher sediment particle usually sand ($r_{density}$=0.169; $r_{biomass}$=0.260) was suitable for macrofauna [Table 4.3]. Sasekumar (1974) also found the importance of sediment particle size in Malayan mangroves. As particle size decreases, the chemical contaminats such as heavy metals, pesticides get adsorbed on to fine-grained sediments make it unfavourable for benthic fauna thereby reducing the density(r= -0.256) and biomass(r=-0.311). It also implies that even though mangroves provides wider niches, majority of mangrove resident fauna opt for lower organic rich ($r_{density}$= -0.293, $r_{biomass}$= -0.279), moderate nutrient ($r_{density}$= -0.-280, $r_{biomass}$= -0.320), less sulphidic ($r_{density}$= -0.223, $r_{biomass}$= -0.301) sediment with higher dissolved oxygen and mixo-mesohaline salinity for their flourishing. However in the present study salinity and DO have no influence on benthic standing stock and biomass.

Lugo and Snedaker (1974) mentioned the existence of a casual association between fauna and type of mangroves. It was also mentioned the importance of structural complexity of mangrove roots, type and density that provides excellent shelter from predators (predator refuge sites) for benthic invertebrate species (Kon *et al.*, 2009). In the current study significant correlation were seen between macrobenthic biomass and density with mangrove plants[Table 4.4] especially to *Acrostichum aureum* ($r_{biomass}$=0.899; $r_{density}$=0.903 and *Rhizophora apiculata* ($r_{biomass}$=0.910; $r_{density}$=0.894). The mangrove fern (*A.aureum*) grow on the landward side of the mangrove, provide shade for other plants and at the same time they take over area with low mangrove trees so rapidly that they form impenetrable thickets which prevent other plants from taking root. These thickets provide safety and shelter for invertebrates (http://www.wildsingapore.com). The soil around the roots of plants (rhizosphere) harbours microbes (Rahaman *et al*., 2018) that promote abundance of macrofauna for feeding. *Acrostichum*, the mangrove fern is densely seen in station 5 (6200 $ind.ha^{-1}$) and 6 (6960 $ind.ha^{-1}$) however relative density of *R.apiculata* is lower compared to other mangroves but dominate with a density of 300 $ind.ha^{-1}$and 240 $ind.ha^{-1}$in these stations respectively where both biomass and density was higher. Sasekumar and Chong (1998) also reported higher density and biomass of epifaunal taxa in mature *Rhizophora apiculata* forest in Malaysia and Kon *et al*. (2007; 2010) also reported higher benthic stock in mangrove forest in Trang province, Thailand with *R.apiculata* as dominant vegetation. The activities of *Rhizophora apiculata* roots are known to lower the pH and alkalinity of sediments (Kristensen *et al*., 1991), further more physical structure of *R.apiculata* facilitates benthic fauna, with canopy shade providing a cool, moist surface layer.

Malacostracan crustaceans were the most dominant of all fauna represented mainly by amphipods, tanaids, isopods and decapods. Among them amphipods (68%) were represented in higher density followed by tanaids (31%), but isopods and decapods were least represented (>1%). Crustaceans were the major group contributing substantially to the total benthos in mangrove environment (Alongi and Sasekumar, 1992, Guerreiro *et al*., 1996). Higher density of crustaceans in Pichavaram mangroves contributed to 73% of total fauna, however in Vellar mangroves they contributed to only 16% (Murugesan *et al*., 2016). Nordhaus *et al*. (2009) also observed higher dominance of crustacea (43.3% of total), followed by gastropoda (32.3%) in mangrove-fringed Segara Anakan lagoon, Indonesia. Significant variation was seen in density and biomass of malacostracans, spatially, temporally and annually in the study area. Annually, in second year the density of malacostraca (1121 ± 1491 $ind.m^{-2}$) doubled over first year (665 ± 962 $ind.m^{-2}$) mainly due to density of amphipods *V.chilkensis*, *Idunella* sp. and tanaid *p. gymnophobia*. Amphipods were prominent among the animals that graze mangrove leaf litter (Odum and Heald, 1975; Boonruang, 1980). Jayachandran (2017), observed that the relative abundance of malacostracans has increased in well-oxygenated sandy sediment, and they avoided organic matter accumulated sediment. Similar results were observed in present study where density correlates negatively to clay (*r*= -0.289), nutrients(*r*= -0.291), organic matter(*r*=-0.212) instead prefer sand dominated sediment with less organic matter as in station 5 and 6, but opportunistic forms especially tanaidaceans prefer organic rich sediments as in station 1. Density was determined by edaphic factors than hydrological factors along with vegetation [Table 4.4] of *A.aureum* (*r*=0.897, *R.apiculata* (*r*=0.891) and *K.candel* (*r*=0.814). Biomass of crustaceans were correlated positively to silt (*r*=0.224) and turbidity (*r*=0.363) and negatively correlated to sand(*r*= -0.169) however mangrove vegetation has no influence on crustacean biomass. Tanaids and decapods contributed to maximum biomass in station 1 as they feed on organic detritus and attain larger size. Tanaids prefer organic and nutrient rich, silty sediment with higher litterfall in mangrove habitats. Higher standing stock of tanaids was observed in mangrove habitats of Rookery bay, Florida (Sheridan, 1997). Mangrove habitats always provide viable condition for decapod abundance (Sasekumar *et al*., 1992) by supplying surplus of organic rich detritus as food along with nursery habitats for juvenile penaeids (Daniel and Robertson, 1990). In Sunderbans, crustaceans were the most dominant fauna (Chaudhuri and Choudhury, 1994), which have greater economic importance and were exploited commercially. Commercially important decapods, especially prawns such as *Penaeus indicus*, *Penaeus monodon*, *Metapenaeus affinis* and crabs mainly *Scylla serrata* of mangroves add to annual fishery production (Kathiresan and Bingham, 2001). Mangrove crabs are considered as ‘Keystone species’ in mangroves because of their role in carbon recycling (Schories *et al*., 2003). They reduce competition between mangrove plant species through selective predation on seedlings (Bosire *et al*., 2005) perhaps having a negative influence on regeneration in mangrove stands (Dahdouh-Guebas *et al*., 1998). The engineering and burrowing activities of crustaceans in mangroves helps in sediment restructuring, assist in flushing toxic substances and modifying the oxidation status of the surrounding sediment. Active feeding on mangrove leaves by crustaceans also (crabs) assists in recycling of organic matter (Nagelkerken *et al*., 2008).

Polychaetes are an important component of macrobenthic community as they often dominate in terms of abundance and biomass in mangroves.They assist in nutrient recycling thereby improving the soil structure and its productivity, a source of food for benthic feeders of the mangrove environment and provide stability to the soil habitat in terms of their diversity. 85% of tropical benthos consists of polychaetes (Longhurst and Pauly, 1987). Polychaete standing stock is essential for tracing fishery structure and productivity for the biotic stability of the area (Sunil kumar, 2002). They are second dominant fauna in mangroves of Cochin with a mean density of 377 ± 976 ind.m^{-2} and a biomass of 23.29 ± 23.26 g.m^{-2}. Compared to previous studies in Cochin mangroves, 51.7% of polychaetes (Sunil Kumar, 1993) come down to 23% within two decade time due to pollution and deforestation in Cochin mangrove forests. However they were predominant in Tamil Nadu mangroves contributing to 64.38% (Thilagavathi *et al*., .2013) and in Malayan mangroves 30-50% (Sasekumar, 1974). Dominance of polychaetes might be due to the varied ecological niche such as roots and soft sediment and dense canopy of the mangroves which offered protection against desiccation (Murugesan *et al*., 2016). In mangroves, they were represented by families Nereididae, Capitellidae and Spionidae. Majority of the polychaetes were infaunal (70%), but the significant percentage of epifaunal species (18%) along with species occurring as both infauna and epifauna (12%) were characteristic of mangroves (Metcalfe and Glasby, 2008). In the present study they showed significant spatio-temporal variation and attained maximum density during monsoon season. Polychaete density was correlated positively to higher dissolved oxygen (r=0.169), lower organic carbon (r = -0.295), sandy sediment (r=0.233) as in station 5 and 6 (Valanthakad). Polychaete biomass were higher in sandy sediment (r=0.266) and but significantly negatively correlated to other sediment variables and their abundance was very lower in station 1 with fine sedment texture and highly sulphidic, organic sediment. Murugesan *et al*., (2016) (Pichavaram mangroves) and Sunil Kumar (1993) (Cochin mangroves) also observed less polychaete abundance at high organic carbon areas, attributed to avoidance of organisms to organic matter, that may adversely affects their abundance and distribution. Pearson and Rosenberg (1978) observed higher abundance of capitellid polychaetes at the mangrove sites with muddy sediments rich in organic matter. Polychaetes include both sensitive and tolerant species that responds quickly to environmental disturbance.

Molluscs form the major biomass producers (64%) in mangroves represented by bivalves and gastropods with a mean of 80.4 ± 88.6 g.m^{-2} which was comparable to Tamil Nadu mangroves (Thilagavathi *et al*., 2013). Their density was comparatively lower (13%) in Cochin mangroves however they were predominant fauna in Australian mangroves (Kelehar *et al*., 1998). Spatial difference in biomass and density was highly significant (p=0.000) and their standing stock was consistently higher in the sediment (S5 and S6) with larger grain size(r=0.262) as sand possess more micro-habitats, excess of oxygen, food particles and good permeability to permanent burrowers. The density is also correlated to dissolved oxygen (r=0.184) as in Todos Santos Bay (Kuk-Dzul and D´ıaz-Casta˜neda, 2016). Molluscs cannot withstand higher organic matter (r= -0.304) and also muddy sediment(r= -253) where anoxic condition prevails as in station 1 where they seem to be completely absent. They occupy entire niche in mangroves and hence seen as epifauna or infauna (live on and in the muds), arboreal (living on the roots and other vegetative parts) or forage in the canopy and some exhibited habitat overlap (Kathiresan and Bhingham, 2001; Dey, 2006). Molluscs occupy all the levels in the mangrove food web such as predators, herbivores, detritus and filter feeders. Gastropods role in grazing on mangrove leaves, consuming litter rich mud of mangroves and filter feeding by bivalves corroborates their role in maintaining the function and productivity of mangroves. In India, more than 100 molluscs were seen associated with mangroves (Dey, 2006). Indian mangroves provide ideal conditions for production of edible oyster *Crassostrea madrasensis* (Rajapandian *et al*., 1990) and commercially important molluscs such as *Villorita cyprinoides* and *Perna viridis*. Molluscs respond quickly to pollution and other physico-chemical parameters and their assemblage was used to assess the health of mangrove forests (Skilleter, 1996; Bosire *et al*., 2004). Molluscs as other benthic fauna seems to be dependent on mangrove vegetation *A.aureum* (r=992) and *R.apiculata* (r=0.892) [Table 4.4] as it provides a solid substrate for them, reduces environmental stresses including dislodgement by tidal waves, high heat and desiccation, which intensively determine the spatial distribution (Yamada, 1989; Cintron and Novelli, 1984).

Certain benthic organisms are transient visitors in mangroves mainly by tidal flow, in search of food and usually low in their density (Macintosh and Ashton, 2002). They are grouped as 'Others' and includes mainly insects, turbellarians, nematodes, nemertines, oligochaetes and benthic fishes in Cochin. Among them oligochaetes usually seen as swarms with a very higher density (80%) while other taxa were in lower numbers. But due to their small size their biomass was lower than other members especially turbellarians, insects and benthic fishes. The standing stock was highest in first year with a mean density of 238 ±1117 ind.m^{-2} and biomass of 2.34± 7.54 g.m^{-2} compared to second year density (58±104 ind.m^{-2}) and biomass (0.67 ±0.72 g.m^{-2}) mainly due to oligochaete swarm encountered during first year. Spatial variation was notable in assemblage that correlates well with silty ($r_{density}$=0.170, $r_{biomass}$=0.211) and clayey ($r_{density}$=0.198, $r_{biomass}$=0.191) texture and also to total sulphur(r=0.164) in the sediment. Giere and Pfannkuche (1982) observed higher densities of oligochaetes in sandy and detritus rich sediments however Schrijvers *et al*. (1995) accounted higher density of oligochaetes (94%) in mud and organic rich sediment in Kenyan mangroves. According to Schrijvers *et al*.(1998), oligochaetes may be regarded as trophic 'dead-ends' as their biomass cannot be transferred further to a higher trophic level perhaps returned to the nutrient pool through natural mortality and decay. Their density depends on mangrove vegetation and correlates [Table 4.4] with *Avicennia officinalis* (r=0.952) and *Bruguiera sexangula* (r=0.885). *Avicennia* spp. harbours rich diversity of benthic fauna in their microhabitats as in mangrove ecosystem of U.A.E, Gulf of Oman (Ismail and Ahmed, 1993).The *Bruguiera* and *Avicennia* trees and their pneumatophores provide rich food sources, shelter and reduce predation pressure that might attract the miscellaneous taxa and juveniles to occupy the varied niche (Al-Khayat and Jones, 1999; Vanhove *et al*., 1992).

Meiofauna are important in converting mangrove primary production to detritus and as a food source for many deposit feeding or surface grazing mangrove animals especially to crabs, penaeid shrimps, mudskippers, and benthic fishes (Sasekumar, 1981). Meiofauna are ubiquitous, representing highly diverse taxa inhabiting most aquatic sediments, often in high densities. However in mangrove sediments, they occur in low abundances (Alongi, 1987). 95% of the total abundance of benthic invertebrates consists of meiofauna dominated by nematodes and harpacticoid copepods (Schwinghamer, 1981). *Daptonema* and *Microlaimus*, represent 80–90% of the meiofauna in mangrove sediments (Giere, 2009). In the present study they exhibited a mean numerical density of 539 ind.10cm^{-2} which was lower than Pichavaram (890 ind. 10 cm^{-2}) and Sydney mangroves (886 ind. 10 cm^{-2}). Nematodes (72%), foraminiferans (25%) and harpacticoid copepods (1.7%) were predominant in Cochin. Dominance of nematodes were reported in Pichavaram mangroves (93.1%) and Cochin mangroves (51.2 to 97.3%) (Chinnadurai and Fernando, 2007; 2006), in Malaysian mangroves (80 to 93%) by Sasekumar (1994), Sydney mangroves (90%) by Dye (2006); while foraminiferans were dominant in Sethukuda Mangrove Area, Tamil Nadu (Thilagavathi *et al*., 2011), Turbellarians in Australian mangroves (Alongi, 1987).

Foraminiferal distributions may be linked to factors such as substrate type, light intensity, water temperature, food availability, oxygen, salinity, depth and current energy (Murray, 1991). Giere (2009) reported that the torrential rainfalls of monsoons (as in tropical areas) have a negative impact on meiofauna, however in the present study, monsoon season exhibited higher density (963 ind.10 cm^{-2}) during which higher rainfall was observed that leads to mixing and disturbance in sediments. Dye (2006) observed 2–3-fold increase in density of meiobenthos in disturbed sediments. On contrary to this Ferns *et al*. (2000); Kaiser and Spencer (1996) observed permanent reduction in abundance due disturbance due to bottom trawling or mechanical shellfish harvesting. If the disturbance is not continuous

(Gheskiere *et al*., 2005), due to their great productivity and turnover, they could recover rapidly by a transient increases in density, after an initial decrease, in response to physical disturbances (Sherman and Coull, 1980; Hall *et al*., 1994). According to Alongi (1987, 1990) meiofaunal distribution is linked to physico-chemical factors such as sediment grainsize, temperature and salinity. In coarser sediments, epistrate feeders are common on roots and leaf litters while in silty sediment deposit feeders were dominant while in the high water zone omnivores and predators dominated (Alongi 1987; Nicholas *et al*., 1991; Alongi, 1990; Ólafsson, 1995). However in my study meiofaunal density does not show any significant correlation to environmental variables as observed in Zanzibar mangroves, eastern Africa (Olafsson, 1995) but exhibited higher correlation to biotic factors especially to mangrove vegetations. Meiofaunal variation within the sites might be linked to food availability, sediment chemistry and water level (Hodda and Nicholas, 1985; Olafsson, 1995).

Meiofaunal distribution in sediment is directly linked to mangrove plant density (Dye, 1983a) while plant type or species have little effect (Gee and Somerfield, 1997). In the present study, plant type was more correlated to meiobenthos than its density [Table 4.5]. Here the meiobenthos attained maximum density (1420±2533 ind. 10 cm^{-2}) at station 3 (Puthuvypin) the only site where *Avicennia marina* (*r*=985) and *Sonnereatia alba* (*r*=985) was observed in Cochin area. The meiofaunal abundance in *Avicennia* and *sonneratia* stands were previously reported in various mangrove habitats (Chinnadurai and Fernando, 2007; 2006; Sasekumar, 1994; Alongi, 1987), furthermore, Tietjen and Alongi (1990) found a significant correlation between biomass of *Avicennia marina* litter, bacterial abundance, and nematode abundance. *Avicennia* plants with their high initial nitrogen content, low C: N ratio and low hydrolyzable tannin concentration has attracted meiobenthos to assemble in *Avicenna* rich vegetative sediments (Robertson, 1988; Alongi, 1987). Their density seems to be lower in station 1 that might be due to varying factors such as food content, grain size and organic content of the mangrove sediment (Hodda, 1990).

Table 4.3 Pearson correlation analysis of environmental variables with macrobenthic density and biomass in Cochin mangroves during 2010-2012 period.

Environmental variables	Total macrofauna		Malacostraca		Polychaeta		Mollusca		Others	
	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
W.temperature	-0.056	0.03	-0.044	-0.052	-0.032	0.02	0.148	0.037	-0.152	-0.017
W.pH	0.028	0.054	0.009	-0.014	0.103	0.059	0.058	0.049	-0.1	-0.021
Salinity	-0.07	-0.093	0.069	0.057	-0.102	-0.031	-0.095	-0.103	-0.123	-0.157
Do	0.152	0.127	0.094	-0.073	0.169*	0.125	0.184*	0.123	-0.048	0.028
Turbidity	0.001	-0.105	0.092	.363**	-0.16	-0.194*	-0.138	-0.129	0.147	0.099
S.temperature	-0.119	-0.077	-0.064	-0.049	-0.125	-0.063	0.076	-0.063	-0.135	-0.069
S.pH	0.011	0.053	0.007	0.014	0.055	0.021	0.02	0.052	-0.059	-0.038
Org.matter	-0.293**	-0.279**	-0.212*	0.082	-0.295**	-0.332**	-0.304**	-0.247**	0.067	0.08
Sand	0.169*	0.260**	0.131	-0.169*	0.233**	0.266**	0.262**	0.256**	-0.188*	-0.220**
Silt	-0.133	-0.226**	-0.079	0.224**	-0.211*	-0.239**	-0.244**	-0.234**	0.170*	0.211*
Clay	-0.256**	-0.311**	-0.289**	-0.092	-0.245**	-0.290**	-0.253**	-0.266**	0.198*	0.191*
S.Eh	0.075	0.12	0.052	0.03	-0.015	0.03	0.101	0.122	0.081	-0.023
T.Sulphur	-0.223**	-0.301**	-0.164*	0.152	-0.272**	-0.321**	-0.291**	-0.285**	0.153	0.164*
T.Phosphorus	-0.280**	-0.320**	-0.291**	-0.022	-0.204*	-0.318**	-0.279**	-0.279**	0.1	0.099
TOC	-0.293**	-0.279**	-0.212*	0.082	-0.295**	-0.332**	-0.304**	-0.247**	0.067	0.08

Significant correlation at a level of $p < 0.01$ (**), $p<0.05$ (*)

Table 4.4 Pearson Correlation analysis of mangrove plant density with macrobenthic density and biomass in Cochin mangroves during 2010-2012 period.

Mangrove plants	Total macrofauna		Malacostraca		Polychaeta		Mollusca		Others	
	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
A.ilicifolius	0.599	0.499	0.62	0.352	0.477	0.643	0.764	0.444	-0.322	-0.16
A.officinalis	-0.292	-0.367	-0.249	0.435	-0.523	-0.508	-0.551	-0.405	.952**	0.525
R.mucronata	0.51	0.301	0.554	0.74	0.263	0.347	0.422	0.211	0.333	0.182
A.aureum	.903*	.899*	.897*	0.399	.863*	.963**	.992**	.877*	-0.431	-0.381
E.agallocha	0.587	0.714	0.56	-0.005	0.657	0.748	0.741	0.742	-0.579	-0.543
B.gymnorrhiza	-0.455	-0.361	-0.472	-0.528	-0.315	-0.328	-0.323	-0.308	-0.285	-0.518
R.apiculata	.894*	.910*	.891*	0.513	0.805	.902*	.892*	.884*	-0.169	-0.006
S.caseolaris	0.509	0.477	0.537	0.656	0.272	0.4	0.386	0.425	0.443	0.503
K.candel	0.789	0.714	.814*	0.677	0.578	0.742	0.79	0.653	0.056	0.073
B.Sexangula	0.07	-0.123	0.138	0.805	-0.282	-0.174	-0.136	-0.205	.885*	-0.019
B.cylindrica	-0.5	-0.51	-0.532	-0.603	-0.236	-0.457	-0.47	-0.465	-0.346	-0.292
S.alba	-0.22	-0.305	-0.244	-0.304	-0.008	-0.253	-0.267	-0.287	-0.254	-0.296
A.marina	-0.22	-0.305	-0.244	-0.304	-0.008	-0.253	-0.267	-0.287	-0.254	-0.296

Significant correlation at a level of p < 0.01 (**), p<0.05 (*)

Table 4.5 Pearson Correlation analysis of mangrove plant density with meiofaunal density in Cochin mangroves during 2011-2012 period.

Mangrove vegetation	Nematodes	Harpacticoids	Foraminiferans	Others	Total meiofauna
A.ilicifolius	-0.323	-0.322	-0.314	0.732	-0.321
A.officinalis	-0.202	-0.089	-0.191	0.185	-0.198
R.mucronata	-0.096	-0.029	-0.116	.815*	-0.1
A.aureum	-0.256	-0.32	-0.35	0.344	-0.291
E.agallocha	-0.364	-0.436	-0.418	-0.085	-0.388
B.gymnorrhiza	-0.029	0.057	0.125	-0.42	0.024
R.apiculata	-0.322	-0.44	-0.495	0.331	-0.387
S.caseolaris	-0.483	-0.537	-0.624	0.5	-0.536
K.candel	-0.469	-0.494	-0.561	0.691	-0.504
B.Sexangula	-0.392	-0.125	-0.27	0.653	-0.346
B.cylindrica	.829*	.840*	.908*	-0.562	.864*
S.alba	.964**	.982**	1.000**	-0.387	.985**
A.marina	.964**	.982**	1.000**	-0.387	.985**

Significant correlation at a level of $p < 0.01$ (**), $p<0.05$ (*)

Chapter 5

COMMUNITY ORGANISATION OF BENTHOS FROM COCHIN MANGROVES

"To protect benthic communities and habitats so that biological diversity and ecological integrity are maintained"

Environmental protection Authority, 2016

[Environmental objective]

5.1 Introduction

The EPA's environmental objective for benthic communities recognises that benthic communities are important components of almost all aquatic ecosystems, and are fundamental to the maintenance of ecological integrity and biological diversity of the environment as a whole (EPA, 2016). Furthermore the analysis of benthic community structure is a good tool for describing time scale changes in coastal habitats particularly in dynamic and complex tropical mangroves which are facing the extremities of both terrestrial and aquatic interactions. The limited mobility and permanent habitation in and on the sediment surface made benthic organisms sensitive to local disturbances and facing deteriorating conditions within the water or sediment. They respond to these conditions by altering their species structure and community composition by the mortality of sensitive species and dominance of tolerant species (Warwick and Clarke, 1993). Moreover, the ecological relationships between benthic biota and mangrove habitat are essential for impact assessment and coastal zone management (Ellison, 2008). Most of the environmental indicators and indices are based on macrobenthic fauna to study sediment quality and ecosystem function in relation to stress due to habitat heterogeneity, pollution etc.

The resident benthic organisms in mangroves belong to Phylum Annelida (polychaetes, oligochaetes), Phylum Arthropoda (amphipods, isopods, decapods, tanaids) and Phylum Mollusca (bivalves, gastropods). However phylum Cnidaria, Echinodermata, Platyhelminthes, Porifera, Nematoda and minor Phylum

Sipunculoidea are temporary visitors. The abiotic and biotic factors play a part in shaping the communities and also in the distribution and abundance of species (Angermeier and Winston, 1998). The complex system of mangrove trunks, roots and debris along with abiotic factors such as, high turbidity and soft sediment reduce competition and predation (Robertson and Duke, 1987; Odum and Heald, 1972), while the dense layer of leaf litter and detritus on the substratum and provides food particles (Daniel and Robertson, 1990). The environmental factors that control macrobenthic species and communities are habitat structure (Robertson and Duke, 1987), hydrological parameters such as salinity, temperature, dissolved oxygen (Benfield *et al*., 1990; Bingham and Young, 1995; Marakala *et al*., 2005) edaphic factors such redox potential, total organic carbon (Kristensen *et al*., 2008; Ansari *et al*., 1993; Rosenberg and Ringdahl, 2005), sediment grain size (Sasekumar,1974), pollutants such as heavy metals (Dauvin, 2008; Ragi *et al*., 2017), natural events of severe storms, wave and current scour (Whitlach *et al*., 1998). Eventhough abiotic factors determine patterns in the distribution and abundance of species over broad scales; biotic factors are of relative importance in local scales. Mangrove tree species density, stand age, litter chemical composition, detritus availability (Morrisey *et al*., 2003; Schrijvers *et al*., 1998) and competition and predation (Lee, 2008; Smith *et al*., 1989) are the biotic factors shaping community. In some groups such as grapsid crabs, cannibalism can be an important process regulating species density and abundance (Kneib *et al*., 1999).

Community analysis is the key concept on biodiversity based measurements such as species richness, evenness, diversity and taxonomic relatedness (taxonomic diversity and distinctness) of the individuals or species in a sample. Very sophisticated statistical techniques are now available to describe and compare the structure of benthic communities. For comparative studies, univariate measures of community, such as diversity measures, are commonly used. However the diversity measures are more sensitive to changes in natural environmental variables in a local scale, and are less sensitive for community changes compared to multivariate methods (Warwick and Clarke, 1993). Multivariate analysis was the most powerful tool, revealing community patterns and to detect community shifts arising from environmental impacts rather than univariate indices (Mistri *et al*., 2000).

Due to the difficulties in taxonomic characterisation and sampling the community level studies of macrobenthos of mangroves are limited and less documented than mangrove forest they inhabit (Lee, 2008). Realizing the importance, a large number of works pertaining to ecology of benthic fauna of mangroves of India has been carried out (Das, 2016; Saha and Jana, 1999; Saha *et al*., 2000; Mitra *et al*., 2008) but community level studies were limited. In east coast, Chaudhuri and Choudhury (1994) reported about 476 species of arthropods, molluscs (143 species), annelids (78 species) and nematodes (68 species) from Sunderbans. Colonization and community ecology of macrobenthic intertidal polychaetes was studied (Misra and Choudhury, 1985; Sarkar *et al*., 2005; Chandra and Chakraborty, 2008) and reported 30 species of polychaetes with distinctive assemblage of *Mastobranchus indicus – Dendronereides heteropoda* and *Lumbrinereis notocirrata – Ganganereis sootai– Glycera tesselata* in mangroves. Marine borers (Molluscs) in Godavari mangroves (11 species) were reported by Ganapati and Rao (1959) and Krishna mangroves (9 species) by Radhakrishnan and Janakiram (1975). Radhakrishna and Ganapati (1969) recorded two species of polychaetes, namely, *Eurythoe parvecarunculata* and *Micronereis* sp. from the mangrove zones of the Kakinada Bay which has been replaced by principal species *Diopatra neopolitana* and gastropod *Cerithidia cingulata* during the last four decades, besides the disappearance of echinoderms, crustaceans and molluscs were also observed (Raut *et al*., 2005). Critical Habitat Information System for Coringa Mangroves, Andhra Pradesh (2001) reported 114 species of macrobenthos (41 species of crustaceans, 26 species of polychaetes, 21 species each of gastropods and bivalves and 5 species of other taxa). Sethuramalingam and Khan, (1991); Pravinkumar *et al*. (2013) observed 22 - 44 species of macrofauna from Pichavaram, while 112 species of insects, 14 species of crustaceans and 18 species of molluscs were observed in Muthupet mangroves (Oswin,1998). Macrofaunal diversity and community structure of Pondicherry mangroves were studied and reported 76 species that comprised of molluscs, crustaceans, amphipods, polychaetes, barnacles and oligochaetes (Khan *et al*., 2008; Saravanan *et al*., 2008; Satheeshkumar and Khan, 2013). Samidurai *et al*. (2012); Thilagavathi *et al*. (2013); Sekar *et al*. (2013) compared the macrobenthic communities of developing Vellar mangroves (31-156 species), riverine Pichavaram mangroves (35-252 species) and island mangroves of Gulf of Mannar (31-163 species) and found that more pristine zone was Pichavaram. Rajashekaran and Fernando (2012) recorded 30 polychaetes belonging to eight families and 23 genera from Andaman mangroves. In west coast, studies on benthic faunal assemblage (Sesh Serebiah, 2003) and brachyuran crabs (Saravanakumar, 2007, Shukla *et al*., 2013, Trivedi *et al*., 2012) reported 10-14 species from Kachchh mangroves of Gujarat. Major families include Grapsidae, Portunidae, Ocypodidae, Gecarcinidae and Goneplacidae. Boominathan *et al*. (2012) studied the molluscan fauna of Karwar mangroves, Karnataka, about 215 species of molluscs (133 gastropods, 77 bivalves, four cephalopods, and one polyplacophores) were identified.

Community composition of benthic fauna in Cochin mangroves, Kerala was extensively studied by Sunil Kumar (1993) and recorded a total of 54 species. Polychaete fauna have been extensively studied from Cochin Mangroves (Sunil Kumar and Antony, 1993; 1994a; 1994b). Thirty-three species belonging to 20 genera under 10 families have been reported, of these five polychaetes were newly recorded from mangroves of Cochin (Sunil Kumar, 1999). Among the polychaetes, *Dendronereis aestuarina, Paraheteromastus tenuis, Nereis glandicincta, Marphysa gravelyi, Dendronereides heteropoda* are found to be the most prevailing species. Sunil Kumar and Antony (1994c) reported the existence of pollution indicator polychaete worm, *Paraheteromastus tenuis* from Cochin mangroves.

Since after the work of Sunil Kumar (1993), studies on community composition and taxonomic richness of benthic fauna were extremely scanty from Cochin mangroves and also from Kerala mangroves. Cochin City has now become the most populous metropolitan area and industrial capital of Kerala, consequently there was flooding of developmental projects that took away prime areas of mangroves along the coast. Compared to different districts, maximum extent of mangrove destruction was reported from Ernakulam district where Cochin mangroves are located (Mohandas *et al*., 2014). Thus the study presents the benthic community structure from mangroves of Ernakulam especially in the dwindling habitats due to various anthropogenic factors including the extensive developmental activities.

5.2 RESULTS

5.2.1 Community composition of macrofaunal species

Macrofaunal community of Cochin mangroves comprised of a total of 48 species in 45 genera belonging to 38 families. Among the 48 species of macrofauna collected, Class Malacostraca (Crustacea) formed the dominant group with 17 species belonging to 4 orders. They were Amphipoda (9 spp.), Decapoda (4 spp.), Isopoda (2 spp.) and Tanaidacea (2 spp.). Class Polychaeta constituted second position with 11species and Class Bivalvia (5 spp.) and Gastropoda (4 spp.) in the Phylum Mollusca formed third position (9 spp.) in total macrofaunal species composition. The sporadic representatives were pooled together as 'others' represented by the class Insecta (4 spp.), Collembola (1sp.), Oligochaeta (2spp.) Nemertea (1 sp.), Nematoda (1sp.) Turbellaria (1 sp.) and a chordate class Actinopterygii (1 sp.). Most of the macrobenthic specimens were identified upto species level, and rest of the fauna up to possible lowest taxonomic level. Some of macrobenthic fauna identified were given in Figure 5.13

Annually, a total of 41 species were encountered during first year (2010-2011), and was comparatively higher than second year (40 species). Nearly 8 species encountered during first year was not observed in second year (2011-2012) however 7 more different species were obtained during second year sampling together contributing to overall species diversity. Spatially, station 5 and 6 had maximum species diversity with 26 species each followed by station 3 (25 spp.), then station 2 (22 spp.), station 1 (15 spp.) and station 4 (10 spp.). Seasonally maximum species diversity was seen in pre-monsoon (37spp.) and monsoon (34 spp.) while least diversity in post-monsoon (32 spp.).

a. Malacostraca

They form the most dominant fauna in terms of species structure. The class Malacostraca was represented by 17 species in 11 families and 4 orders. The order Amphipoda includes families such as Eriopisidae (3 spp.), Corophiidae (2 spp.), Aoridae (1 sp.), Liljeborgiidae (1 sp.), Talitridae (1 sp.) and Amphilochidae (1sp), while order Tanaidaceae includes Parapseudidae (1 sp.) and Pagurapseudopsididae (1sp.), order Isopoda includes Hyssuridae (1sp.) and Anthuridae (1sp.), order decapoda includes Penaeidae (4spp.).

The numerically dominant malacostracan species in the study area was amphipods such as *Idunella* sp. (31.24%), *Cheiriphotis geniculata* (26.57 %), *Victoriopisa chilkensis*(6.70%), *Victoriopisa cusatensis* (2.70%), and tanaids such as *Ctenapseudes chilkensis* (22.88%) *Pagurapseudopsis gymnophobia* (7.73 %), while other species were less than 1% in mangroves.

Spatially, station 6 represented maximum species (12 spp.) followed by station 5 (10 spp.), station 1 and station 2 (9 spp.), station 3(8 spp.) and least represented in station 4 (5 spp.). *Idunella* sp. has ubiquitous distribution in all stations with maximum numerical density at station 5 and 6 (Valanathakad zone) and least density at station 4. Similarly *Victoriopisa chilkensis* and *Pagurapseudopsis gymnophobia* and *Ctenapseudes chilkensis* were present in all stations except station 4. Numerical density of *Victoriopisa chilkensis* was highest in station 6 while tanaids was observed in higher density at station 1. In station1, station 2 and station 3 highest numerical densities was represented by *Ctenapseudes chilkensis*. In station 5, *cheiriphotis geniculata* was the dominant species in terms of their density (22335 ind.m^{-2}) followed by *Idunella* sp. (20279 ind.m^{-2}). However in station 6, *Idunella* sp. (15196 ind.m^{-2}) dominated followed by *cheiriphotis geniculata* (11168 ind.m^{-2}). *Amphilochus* sp. and *Apanthura sandalensis* were restricted to station 6 while *Eriopisella* sp. in station 3 and *Grandidierella megnae* in station 4. The station with least numerical density and least species diversity (5sp.) was station 4 where *Idunella* sp., *xenanthura linearis*, *Metapeneaus dobsoni*, *Floresorchestia sp.* and *Grandidierella megnae* represented the malacostracans. Seasonally highest number of species was observed during pre-monsoon of second year (14 spp.) and first year (13 spp.) and least number in monsoon of second year (8 spp.). Certain species of malacostraca exhibited seasonal distributional pattern especially, *Grandidierella megnae* encountered only during monsoon and *Apanthura sandalensis* seen during post-monsoon, however *Victoriopisa chilkensis*, *Victoriopisa cusatensis*, *Pagurapseudopsis gymnophobia*, *Ctenapseudes chilkensis*, *Idunella* sp. and *Cheiriphotis geniculata* were seen in all seasons. Among them *V. chilkensis*, *Idunella* sp. and *P. gymnophobia* exhibited maximum numerical density during pre-monsoon season while *C. geniculate*, *C. chilkensis* in post-monsoon and *Victoriopisa cusatensis* in monsoon.

Malacostracans were represented by a total of 17 species for the two year period of study under four orders. Numerical density was highest in second year however species diversity was higher in first year with 16 species while second year with 15 species. Amphipod *Grandidierella megnae* and isopod *Xenanthura linearis* were seen only in first year while *Apanthura sandalensis* in second year. Maximum numerical density of malacostraca was observed during second year (2011-2012) represented by *Idunella* sp. (32808 ind.m^{-2}) however in first year (2010-2011), highest numerical density was attained by *Cheiriphotis geniculata* (19529 ind.m^{-2}). Spatial mean density of Malacostracan species were represented in Table 5.1

Table 5.1 Spatial mean density of Malacostracan species (ind.m^{-2}) in Cochin mangroves during 2010- 2012 period.

Family	Species	S1	S2	S3	S4	S5	S6
Order Amphipoda Eriopisidae	*Victoriopisa chilkensis*	130	23	61	0	61	83
Eriopisidae	*Victoriopisa cusatensis*	0	0	0	0	66	79
Eriopisidae	*Eriopisella* sp.	0	0	14	0	0	0
Corophiidae	*Cheiriphotis geniculata*	0	0	28	0	930	465
Corophiidae	*Americorophium triaenonyx*	0	6	0	0	1	2
Aoridae	*Grandidierella megnae*	0	0	0	15	0	0
Talitridae	*Floresorchestia* sp.	0	0	0	1	0	2
Liljeborgiidae	*Idunella* sp.	54	76	59	6	845	633
Amphilochidae	*Amphilochus* sp.	0	0	0	0	0	1
Order Tanaidaceae Parapseudidae	*Ctenapseudes chilkensis*	454	131	220	0	50	0
Pagurapseudopsididae	*Pagurapseudopsis gymnophobia*	185	6	100	0	79	3
Order Isopoda Hyssuridae	*Xenanthura linearis*	5	0	0	1	10	372
Anthuridae	*Apanthura sandalensis*	0	0	0	0	0	45
Order Decapoda Penaeidae	*Metapenaeus affinis*	12	1	0	0	1	5
Penaeidae	*Metapenaeus dobsoni*	8	1	0	2	0	5
Penaeidae	*Penaeus indicus*	2	5	2	0	2	0
Penaeidae	Penaeidae	2	1	5	0	0	2

b. Polychaeta

They formed the second dominant fauna in terms of species structure. and were represented by 11 species in 7 families. The polychaete families includes Nereididae (4spp.), Capitellidae (2 spp.), Spionidae (1 sp.), Phyllodocidae (1 sp.), Opheliidae (1 sp.), Maldanidae (1 sp.) and Eunicidae (1 sp.).

The numerically dominant polychaete species in the study area was *Dendronereis aestuarina* (71.46%), *Capitella* sp. (12.94 %), *Parheteromastus tenuis* (4.55%) *Namalycastis indica* (4.50 %), *Prionospio cirrifera* (4.25 %), *Dendronereids* *heteropoda* (1.69%) while other species such as *Marphysa sanguinea*, *Ophelia* sp., *Ceratonereis costae*, *Maldane sarsi and Phyllodoce* sp. were least represented.

Spatially station 3 represented maximum species (9 spp.) followed by station 5 and 6 (5spp.), station 2 (4 spp.), Station 1 (2spp.) and Station 4 with only one species. *Ceratonereis costae*, *Ophelia* sp., *Dendronereids heteropoda*, *Phyllodoce* sp. were encountered only from station 3. *Maldane sarsi* limit their distribution in station 5 and *Marphysa sanguinea* in station 6. *Prionspio cirrifera*, *Dendronereis aestuarina*, *Namalycastis indica* were seen in all stations except at station 1 and 4. Capitellids such as *Capitella* sp. were absent in station 5 and station 6 while *Parheteromastus tenuis* was absent in station 2 and station 4. Maximum species diversity was observed during post-monsoon of first year and monsoon of second year (8spp.) and least number in pre-monsoon of second year (5 spp.). Certain species of polychaetes exhibited seasonal distribution pattern especially, *maldane sarsi* and C*eratonereis costae* seen during monsoon, while *Phyllodoce* sp., *Ophelia* sp. seen in post-monsoon. *Prionspio cirrifera*, *Dendronereis aestuarina*, *Namalycastis indica*, *Parheteromastus tenuis* and *Capitella* sp. were seen in all seasons. The numerical density of most of the species was higher during monsoon. The dominant polychaete species *Dendronereis aestuarina* was seen abundantly during post-monsoon (14529 ind.m^{-2}) and lowest in pre-monsoon season (1028 ind.m^{-2}). A total of 9 species each were recorded during first and second year, of which species such as *D.heteropoda* and *Ophelia* sp. were collected only in first year while *Maldane sarsi* and *Ceratonereis costae* were collected only during second year. Highest numerical density was attained by *D.aestuarina* both in first (11279 ind.m^{-2}) and second year (27530 ind.m^{-2}). Spatial mean density of polychaete species are listed in Table 5.2

Table 5.2 Spatial mean density of polychaete species (ind.m^{-2}) in Cochin mangroves during 2010- 2012 period

Family	Species	S1	S2	S3	S4	S5	S6
Nereididae	*Dendronereis aestuarina*	0	5	2	0	1021	589
Nereididae	*Dendronereides heteropoda*	0	0	38	0	0	0
Nereididae	*Namalycastis indica*	0	9	2	0	52	38
Nereididae	*Ceratonereis costae*	0	0	2	0	0	0
Eunicidae	*Marphysa sanguinea*	0	0	0	0	0	5
Capitellidae	*Parheteromastus tenuis*	2	0	8	0	59	34
Capitellidae	*Capitella sp.*	6	2	284	1	0	0
Spionidae	*Prionospio cirrifera*	0	24	27	0	24	21
Opheliidae	*Ophelia* sp.	0	0	3	0	0	0
Maldanidae	*Maldane sarsi*	0	0	0	0	1	0
Phyllodocidae	*Phyllodoce* sp.	0	0	2	0	0	0

c. Mollusca

They were represented by total of 9 species in 9 families. Class Bivalvia includes families Donacidae (1sp.) Cardiidae (1sp.) Cyrenidae (1sp.) Myidae (1sp.) and Tellinidae (1sp.) while class Gastropoda includes Turritellidae (1sp.), Cerithiidae (1sp.), Nassariidae (1sp.) and Hydrobiidae (1sp.). The numerically dominant molluscs were *Indosphenia* sp. (79.07%), *Villorita cyprioides* (10.59%), *Nassodonta insignus* (3.13%) *Tellina* sp. (2.85%) *Hydrobia* sp. (2.02%) and *Turritella* sp. (1.01%), other species were < 1 % in density.

Spatially maximum number of molluscs was observed at station 3 and station 5 with 6 species each while in station 1 molluscan fauna was not encountered. In station 5 and station 6 *Indosphenia* sp. attained maximum numerical density of 11001 ind.m^{-2} and 12751 ind.m^{-2} respectively. *Nassodonta insignis* and *Villorita cyprinoides* were restricted to Valanthakad zone (station 5 and 6). In station 2 and station 3 *Tellina* sp. was the dominant one. Maximum species diversity was observed during pre-monsoon and monsoon of second year with 8 species each dominated by *Indosphenia* sp. which exhibited a ubiquitous distribution in all season. However least density was observed in pre-monsoon of first year having only 3 species. During first year 7 species of molluscs were collected from Cochin mangroves while second year with 9 species. *Indosphenia* sp. was the most dominant species in first and second year that attained maximum numerical density (17001 ind.m^{-2}) during second year compared to first year (6834 ind.m^{-2}) followed by *Villorita cyprinoides*. Spatial mean density of Molluscan species were listed in Table 5.3

Table 5.3 Spatial mean density of Molluscan species (ind.m^{-2}) in Cochin mangroves during 2010- 2012 period

Family	Species	S1	S2	S3	S4	S5	S6
Class Bivalvia Donacidae	*Donax pulchellus*	0	0	5	2	0	0
Cardiidae	Cardiidae sp.	0	0	2	0	0	0
Cyrenidae	*Villorita cyprinoides*	0	0	0	0	93	41
Myidae	*Indosphenia* sp.	0	0	0	3	458	531
Tellinidae	*Tellina* sp.	0	16	20	0	0	0
Class Gastropoda Turritellidae	*Turritella* sp	0	0	10	0	2	0
Cerithiidae	*Cerithidium* sp.	0	0	6	0	1	0
Nassariidae	*Nassodonta insignis*	0	0	0	0	20	20
Hydrobiidae	*Hydrobia* sp.	0	1	5	0	19	1

d. Others

"Others" were represented by 11 species of 11 families. It includes oligochaetes of families Naididae (1sp.) and Enchytraeidae(1sp.) under class Clitellata, Chironomidae (1sp.), Dytiscidae (1sp.), Coenagrionidae (1sp.), Ceratopogonidae (1sp.) of class Insecta Entomobryidae (1sp) of class Collembola and Gobiidae (1sp.) of class Actinopterigii. Other members of the group include Phylum Nemertea (1sp.), Class Turbellaria (1sp) and Phylum Nematoda (1sp).

The oligochaete species, *Tubificoides pseudogaster* (79%) and chironomid larvae (18%) together contributed to 97 % of "others" density. Station 2 showed highest species count (7 spp.) followed by station 5 and 6 (5 spp.), station 1 (4 spp.) and least species density was at station 3 and 4 (2 spp.). Chironomid larvae showed universal distribution in all the stations. Most of insect species were seen in Valanthakad station. Nemerteans and Enchytraeidae species (oligochaetes) were seen only in station 2 while nematodes in station 1. The most abundant oligochaete, *Tubificoides pseudogaster* was present in all mangrove stations except at station 4 and attained maximum density at station 1 (12056 ind.m-2). Station 4 includes chironomids in highest density (1250 ind.m^{-2}) of all other stations. Monsoon seasons of both first and second year (5 spp.) and also pre-monsoon of second year and post-monsoon of first year (5spp.) represented highest species composition while least species were seen in post-monsoon (2 spp.) of second year. *T.psuedogaster* was seen in all seasons with higher density during post-monsoon. Chironomids attained maximum density (2306 ind.m-2) in monsoon. Comparatively higher species density was observed in first year (9 spp.) than second year (7 spp.). *T.psuedogaster* was the most dominant fauna in both first and second year but maximum density was noted during second year (14084 ind.m^{-2}). Enchytridae sp., *Pseudosinella* sp., Coenagrionidae sp. and Ceratopogonidae sp. were encountered only during first year. However, Dytiscidae sp. and nematode were seen only during second year. Spatial mean density of ‘others’ species are listed in Table 5.4

Table 5.4 Spatial mean density of ‘others’ (ind.m^{-2}) in Cochin mangroves during 2010- 2012 period

Families	**Species**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Naididae	*Tubificoides pseudogaster*	502	141	32	0	10	20
Enchytraeidae	Enchytraeidae	0	1	0	0	0	0
Diptera	Chironomidae	8	14	20	52	49	17
Entomobryidae	*Pseudosinella* sp.	0	0	0	0	0	1
Dytiscidae	Dytiscidae	0	0	0	0	1	0
Coenagrionidae	Coenagrionidae	0	1	0	0	0	0
Ceratopogonidae	Ceratopogonidae	0	0	0	0	0	1
Nematoda	Nematoda	1	0	0	0	0	0
Turbellaria	Turbellaria	0	1	0	0	2	1
Nemertea	Nemertea	0	3	0	0	0	0
Gobiidae	*Callogobius mannarensis*	3	1	0	1	2	0

5.2.2 Statistical and Graphical methods of community analysis

a. Univariate diversity indices

The diversity of benthic macrobenthos in the study area was estimated both spatially and temporally by the Shannon index (H'[log_2]), Margalef index (d), Pielou index (J') and Simpson index (1-λ'). Shannon diversity index ranged from 1.9 to 3.25, that of Margalef richness index was 1.1 to 2.3, that of Pielou evenness index was 0.57 to 0.70 and Simpson dominance index was 0.59 to 0.84.

The macrofaunal Margalef species richness (d) varied from 0.10 ± 0.12 in station 4 to 0.84 ± 0.29 in station 6 with an overall mean of 0.51 ± 0.27. Seasonally, it varied from 0.44 ± 0.31 in the post-monsoon of the first-year (2010-2011) to 0.69 ± 0.44 during pre-monsoon of the second year (2011-2012). Species richness was comparatively higher in second year (0.62±0.40) than first year (0.49±0.33).

A relatively low Pielou's evenness index (J') was recorded during the study with mean value of 0.79 ± 0.16, and it varied from 0.68 ± 0.17 in station 5 to 0.94 ± 0.12 in station 4. Seasonally, it varied from 0.65 ± 0.21 in post-monsoon of the first year to 0.82± 0.14 during pre-monsoon of the first year. Species evenness was observed higher in second year (0.77±0.15).

Table 5.5 Diversity indices of macrofauna for each station in Cochin mangroves during 2010-2012 period [richness (d), diversity (H' [log_2]), evenness (J'), dominance (1-λ')].

Station	d	J'	H'	1-λ'
S1	0.41±0.21	0.77±0.15	1.35±0.57	0.52±0.19
S2	0.38±0.32	0.76±0.20	0.98±0.79	0.40±0.25
S3	0.48±0.43	0.86±0.16	1.34±0.88	0.50±0.27
S4	0.10±0.12	0.94±0.12	0.16±0.36	0.21±0.25
S5	0.83±0.24	0.68±0.17	1.95±0.53	0.63±0.15
S6	0.84±0.29	0.70±0.14	2.01±0.58	0.66±0.14
Mean	0.51±0.27	0.79±0.16	1.30±0.62	0.49±0.21

Shannon index (H'[$\log_2$]) was highest in station 6 (mean 2.01 ± 0.58) and lowest value in the station 4 (mean 0.16 ± 0.36). Seasonally lowest values were recorded during post-monsoon of the first year (mean 1.04 ± 0.81) and highest during pre-monsoon of the second year (mean 1.47 ± 1.01) with an overall mean of 1.29± 0.88. The species diversity was highest during the second year (1.38 ± 0.94) compared to first year period (1.21 ± 0.83).

The mean Simpson dominance (1-λ') index for macrofaunal communities varied from 0.20 ± 0.25 in station 4 to 0.65 ± 0.14 in station 6. Seasonally, it varied from 0.40 ± 0.26 during post-monsoon of the first year to 0.57± 0.26 during pre-monsoon of the second year. Species dominance index was highest in second year (0.55±0.23) than first year (0.48±0.24). Spatial variation in macrofaunal diversity indices are given in Table 5.5 and Figure 5.1 and seasonal variation in Table 5.6 and Figure 5.2.

Table 5.6 Diversity indices of macrofauna for each season in Cochin mangroves during 2010-2012 period [richness (d), diversity (H' [$\log_2$]), evenness (J'), dominance (1-λ')].

Season	d	J'	H'	1-λ'
Pom 2010-11	0.44±0.31	0.65±0.21	1.05±0.82	0.41±0.26
Prm 2010-11	0.54±0.32	0.75±0.19	1.20±0.80	0.53±0.21
Mon 2010-11	0.50±0.32	0.82±0.14	1.33±0.85	0.56±0.21
Pom 2011-12	0.69±0.44	0.77±0.15	1.48±1.02	0.58±0.26
Mon 2011-12	0.53±0.40	0.74±0.19	1.27±0.84	0.50±0.23
Prm 2011-12	0.64±0.43	0.81±0.13	1.46±1.01	0.57±0.24
Mean	0.56±0.37	0.76±0.17	1.30±0.89	0.52±0.24

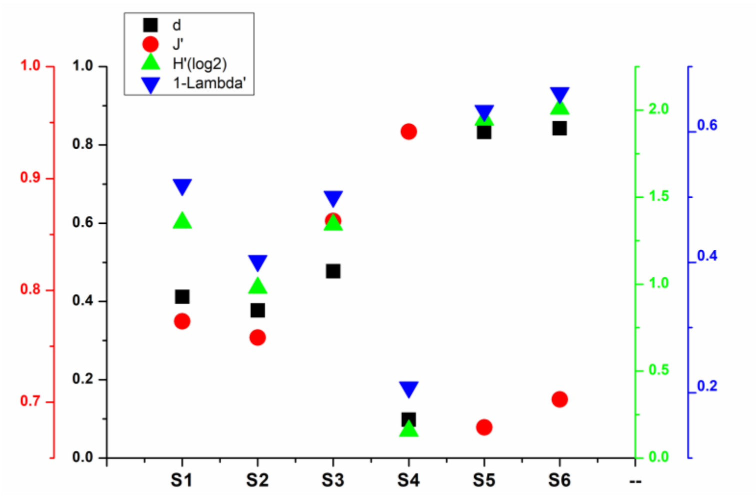

Figure 5.1 Diversity indices of macrofauna for each station in Cochin mangroves during 2010-2012 period [richness (d), diversity (H’ [$\log_2$]), evenness (J’), dominance (1-λ’)]

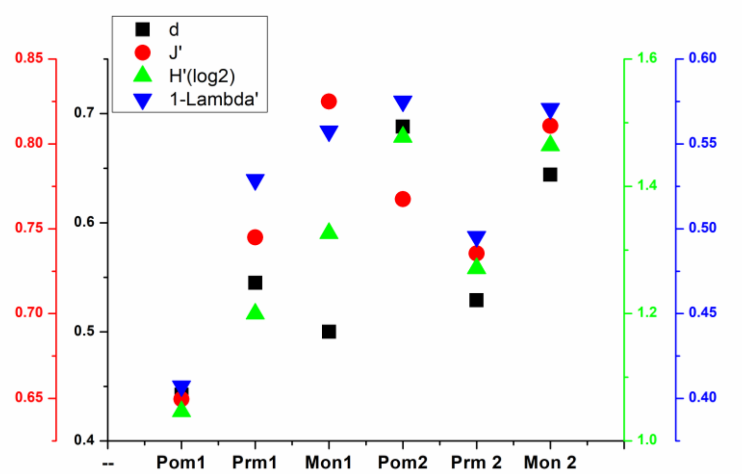

Figure 5.2 Diversity indices of macrofauna for each season in Cochin mangroves during 2010-2012 period [richness (d), diversity (H’ [$\log_2$]), evenness (J’), dominance (1-λ’)].

b. Species accumulation plot and species estimator

Species-accumulation curve is the graphical representation that measure the rate of accumulation of different species as the area sampled is increased. It helps to determine if the species collected during the survey adequately describe the actual species composition of the study area. Species-accumulation curves reached the upper asymptote, indicating that the study area was sampled sufficiently [Figure 5.3]. During the end of first year period of monthly sampling, 41 species were obtained, and during the second year period, 7 more species were found in addition to first year, indicating sufficient sampling by second year period.

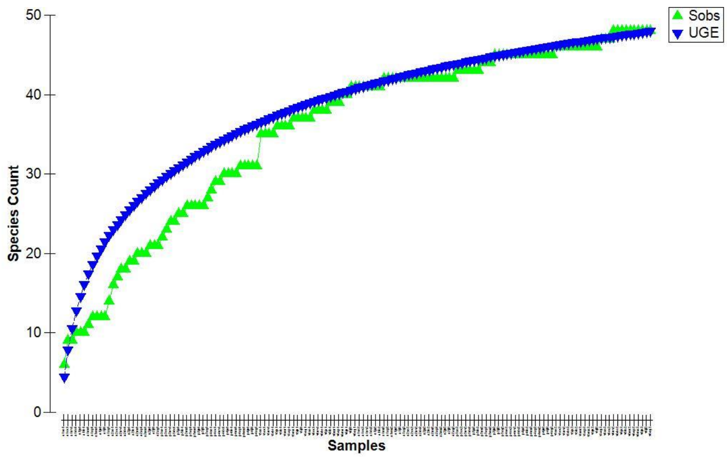

Figure 5.3 Species accumulation plot of macrobenthic species in Cochin mangroves during 2010-2012 period

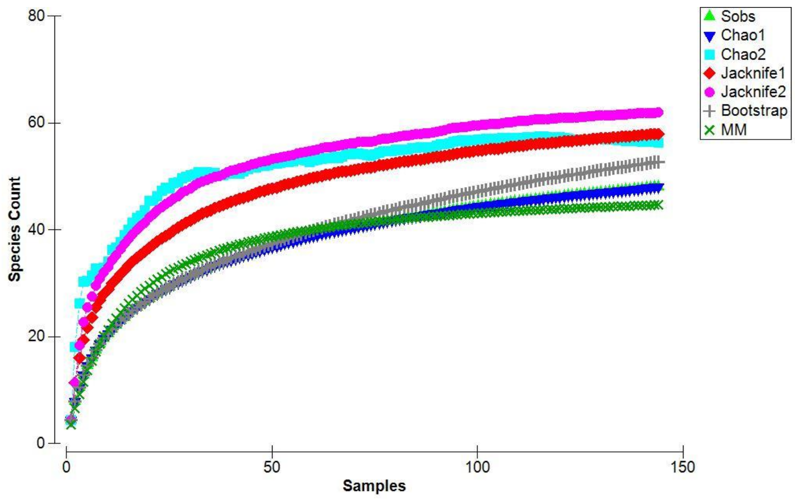

Figure 5.4 Species estimators of macrobenthic species in Cochin mangroves during 2010-2012 period

Species estimators are used to predict the actual number of species that would observe as the number of samples tends to be infinity. It is used to estimate the expected number of new species to be detected given a level of additional sampling effort, which can lead to efficient planning and sampling protocols. The total number of species estimated by the species estimators varied from 45 to 62 species [Figure 5.4]. The minimum estimate was given by MM (Michaelis-Menten),a parametric estimator (45 spp.), which is less than the number of species in sample (48 spp.). The maximum rating was given by Jacknife 2 (62 spp.) then by Jacknife1 (58 spp.), Chao 2 (56spp.) and Bootstrap (53spp.). The number of macrofaunal species estimated by Sobs (Observed number of species), Chao1 were 48 which give the exact number of species sampled.

c. TAXDTEST analysis

Taxonomic diversity and distinctness are measures of taxonomic relatedness of individuals or species in a sample. This concept of taxonomic relatedness is totally independent of the numbers of species present. Average taxonomic distinctness index ($\Delta +$) and variation in taxonomic distinctness (Λ+) were used to construct funnel plots to test for any significant variation of species from the expectation (Warwick and Clarke, 2001). Unimpacted assemblages of species have a wider taxonomic spread and the species belong to many different genera, families, orders, classes, and phyla, however in impacted assemblages taxonomic spread is minimised. Warwick and Clarke (1998) reported that chronically disturbed locations would exhibit greater variation and reduced taxonomic distinctness. Mangrove stations were compared for funnel plot for Average taxonomic Distinctness (Δ+) [Figure 5.5] and Variation in Taxonomic Distinctness (Λ+) [Figure 5.6] depicted wider taxonomic spread (higher taxonomic distinctness) in species for stations such as S2,S3,S5 and S6 that lies within the expected limit of 95% confidence funnel which are considered to be less impacted. However, stations 1 and 4 are mostly out of the confidence funnel or on the border indicating less species spread (lower taxonomic distinctness) and most impacted of mangrove stations. Taxonomic evenness between species across the hierarchical taxonomic tree was tested for ‘departure from expectation from 95 % confidence funnel and found some above the upper limit of the funnel (S3,S5 and S6) that seems to have higher Λ+ reached at 800 while S4 and S1 have lower Λ+ as their values lie at 0.

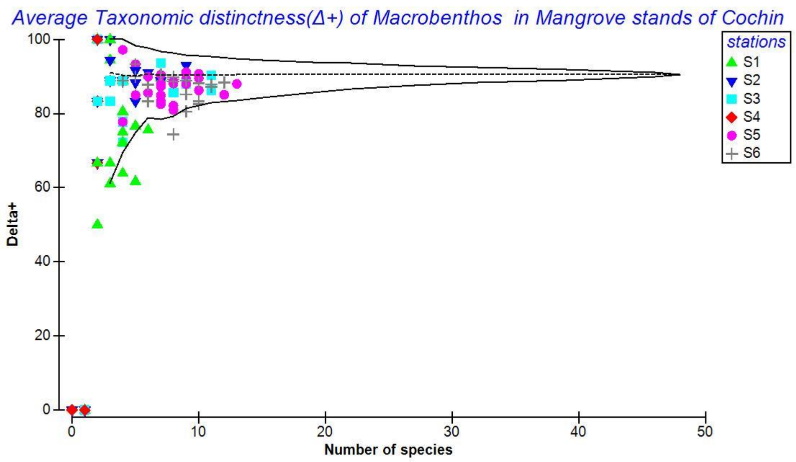

Figure 5.5 Confidence funnels for taxonomic distinctness (Δ+) randomised TAXDTEST analysis of benthic community assemblage of different stations in Cochin mangroves during 2010-2012 period.

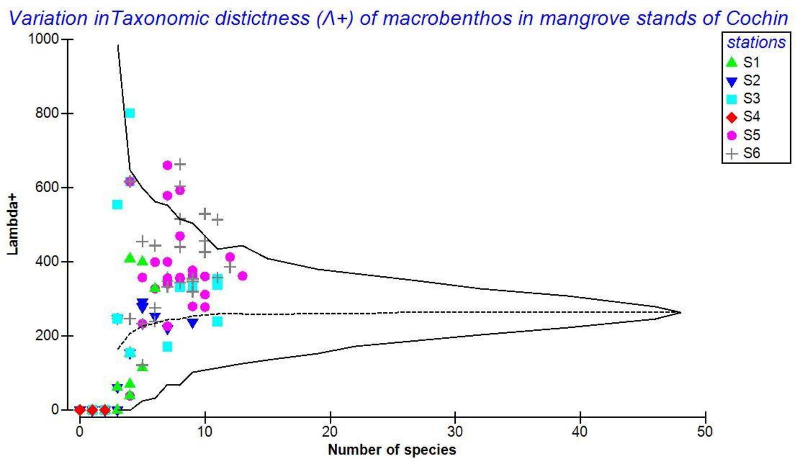

Figure 5.6 Confidence funnels for Variation in Taxonomic Distinctness (Λ+) randomised TAXDTEST analysis of benthic community assemblage of different stations in Cochin mangroves during 2010-2012 period.

d. *k*-dominance curve

The *k*-dominance curve is a powerful tool for measuring dominance and abundance trends in communities over time. The *k*-dominance curves are the cumulative ranked abundance against a log species rank (Jennings *et al*., 2001). The curve indicates that the species that can tolerate perturbation will thrive and the rest will decline or disappear. Thus, the steepest and most elevated curve shows the lowest diversity and the most perturbed system state (Rice, 2000). The dominance index is a useful tool to finding out the influential species within the habitats (Pearson and Rosenberg, 1978), where species are ranked in order of importance along the horizontal axis while the cumulative contribution of total macrofaunal density is plotted along the vertical axis. In the present study, *k*-dominance plots are constructed for the annual, seasonal, and spatial pattern of macrofauna using PRIMER *v* 6.

The *k*-dominance plot indicated higher species dominance and diversity in first year (2010-2011) than second year [Figure 5.7a]. Amphipod species *Cheiriphotis geniculata* (20.3%) tanaid *Ctenapsuedes chilkensis* (14.9%) and oligochaete *Tubificoides psuedogaster* (14.7%) together contributed to 50% of species dominance in first year. *Dendronereis aestuarina* (11.7%), *Idunella* sp. (7.6%), *Indosphenia* sp. (7.1%), a swarm of *Capitella* sp. (6.5%), insect larva chironomid (2.9)% and *Pagurapseudopsis gymnophobia* (2.8)%) were the other representatives. In second year *Idunella* sp. (23.6%), *Dendronereis aestuarina* (19.8%), *Indosphenia* sp. (12.2%), accounted for 50% of dominance. However *Ctenapsuedes chilkensis* (10.9%) *Cheiriphotis geniculata* (10.5%), *Pagurapseudopsis gymnophobia* (5.2%) *Victoriopisa chilkensis*(5%), *Tubificoides psuedogaster* (2%) also adds to species dominance. In second year *Tubificoides psuedogaster* showed tremendous decline in their numerical density that of first year from 14084 ind.m^{-2} (14.7%) to 2861 ind.m^{-2} (2%), similarly *Cheiriphotis geniculata*, the most abundant fauna in first year also declined in second year from 19529 ind.m^{-2} (20.3%) to 14640 ind.m^{-2} (10.5%). While species such as *Idunella* (7362 ind.m^{-2} to

32808 ind.m^{-2}), *Dendronereis aestuarina* (11279 ind.m^{-2} to 27530 ind.m^{-2}) and *Indosphenia* sp. (6834 ind.m^{-2} to 17001 ind.m^{-2}) has attained two fold increase in their density in second year.

The *k*-dominance curve of species abundance data pooled for each station is presented in Figure 5.7b. The curve for station 4 is at the most elevated position that indicated lowest species diversity and station 5 and 6 represented lowest of all curves indicating high species diversity. At station 1 the dominant species observed were oligochaete *Tubificoides psuedogaster* (36.5%), tanaids *Ctenapsuedes chilkensis* (32.9%) and *Pagurapseudopsis gymnophobia* (13.4%) together contributing to 82 % of total fauna in S1, then amphipod *Victoriopisa chilkensis* (9.4%) and *Idunella* sp.(4%) were the other representing species. In station 2, *Tubificoides psuedogaster* (29.9%), *Ctenapsuedes chilkensis* (27.7%), *Idunella* sp.(16.2%) were the most dominant fauna along with *Prionospio cirrifera* (5.1%), *V.chilkensis* (4.9%). In station 3 pollution indicator species *Capitella* sp. (29.6%) was the most dominant, then *Ctenapsuedes chilkensis* (22.9%), *Pagurapseudopsis gymnophobia* (10.3%) *Victoriopisa chilkensis* (6.4%) and *Idunella* sp.(6.1%) were other abundant fauna. Station 4, the least diverse station was characterised by dominance of chironomid larve contributing to 60.8% of total fauna in the station followed by amphipod *Grandidierella megnae* (17.5%). Station 5 and station 6 (Valanthakad zone) have almost similar species abundance pattern, but in S5 the dominant fauna was polychaete *Dendronereies aestuarina* (26.4%) and in S6 it was amphipod *Idunella* sp. (20.9%) eventhough the numerical density of *Idunella* sp. was higher in S5. Other dominant species in S5 were *Cheiriphotis geniculata* (24.1%), *Idunella* sp. (21.8%), *Indosphenia* sp.(11.8%) while in S6 were *Dendronereies aestuarina* (19.5%), *Indosphenia* sp. (17.6%) C*heiriphotis geniculata* (15.4%) and *Ctenapsuedes chilkensis* (12.3%).

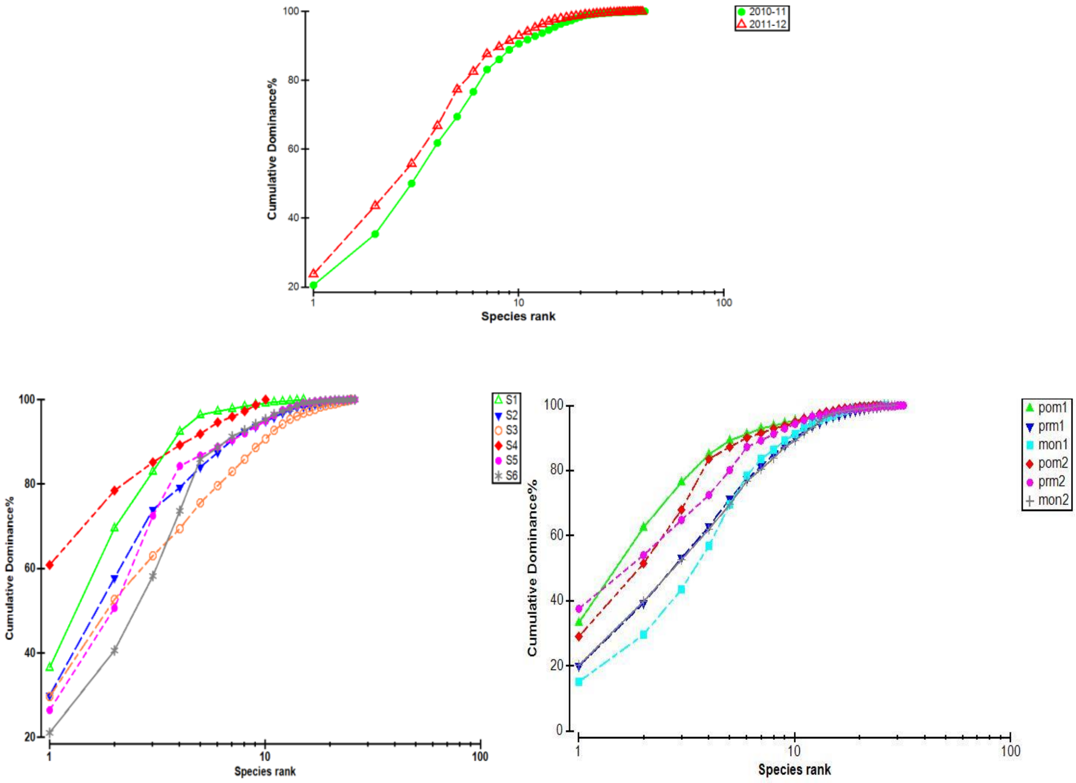

Figure 5.7 a) Annual **b)** spatial and **c)** temporal variation of *k*-dominance curve of macrofauna species in Cochin mangroves during 2010-2012 period.

The *k*-dominance curve of species abundance data pooled for each season is presented in Figure 5.7c.The *k*-dominance plot indicated higher species dominance and diversity during pre-monsoon of 2010-2011(first year).This is followed by monsoon of first and second year. However lowest diversity was during post-monsoon of first year. In monsoon season *Dendronereies aestuarina* (15%), *Ctenapsuedes chilkensis* (14.5%), *Indosphenia* sp. (13.8%) *Cheiriphotis geniculata* (13.4%) *Capitella* sp. (12.6%) and *Idunella* sp. (8.8%) were dominant however in second year monsoon, *Dendronereies aestuarina* (20.3%) and *Indosphenia* sp.(19.5%), *Idunella* sp.(12.5%), *Ctenapsuedes chilkensis* (9.4%), *Cheiriphotis geniculata* (7.6%), *Pagurapseudopsis gymnophobia* (7.1%). Moreover, *D.aestuarina*, *C. chilkensis*, *Indosphenia* sp., *Idunella* sp. and *C.geniculata* were dominant in monsoon season. Furthermore *Capitella* sp. which were dominant in first year was not in second year similarly *P. gymnophobia* was dominant in second year was not seen in first year. In pre-monsoon, a different assemblage structure was seen during first and second year of study. In first year, *Cheiriphotis geniculata* (19.9%) *Ctenapsuedes chilkensis* (19.2%), *Idunella* sp.(13.9%), *P.gymnophobia* (9.6%), *D.aestuarina* (8.4%) were the dominant fauna, however in second year *Idunella* sp. (37.5%), *Indosphenia* sp.(16.3%), *D.aestuarina* (11%), *V.chilkensis* (7%) and tanaids (*C.chilkensis* and *P.gymnophobia*) (7%) were dominant. Post-monsoon also characterised by a different community pattern of benthic fauna. In first year post-monsoon, *Tubificoides pseudogaster* (33.2%), *C.geniculata* (29.1%) and *C.chilkensis* (13.8%) and *D.aestuarina*(8.7%) forms the dominant species while in second year *D.aestuarina* (29.3%) dominated replacing *Tubificoides pseudogaster* followed by *C. geniculata* (22.4%) *Idunella* sp. (16.3%), *C. chilkensis* (15.5%).

e. Abundance-Biomass Curve (ABC)

The abundance biomass curves (ABC) for macrobenthic fauna of mangrove stands was plotted for sampling stations to find the state of benthos in the suite of environmental stress. The species are ranked in order of importance in terms of abundance and biomass on the x-axis (logarithmic scale) with percentage dominance on the y-axis (cumulative scale).

In ABC plot, Warwick values (W-value) lie between -1 to +1 for macrofaunal assemblages and when the biomass curve lies above the abundance curve of ABC plot it gets the positive values that indicated undisturbed benthic communities with the dominance of K-selected species [Figure 5.8a]. In station 1, the abundance and biomass curves lie closer and intersects with a negative W-value (W=-0.004) indicating moderately disturbed condition similarly station 3 also exhibit negative W value (W=-0.033) with the abundance curve that lies above the biomass curve depicting the disturbed benthic communities with the dominance of r-selected species in the assemblages. In station 4, W value does not have a negative value but

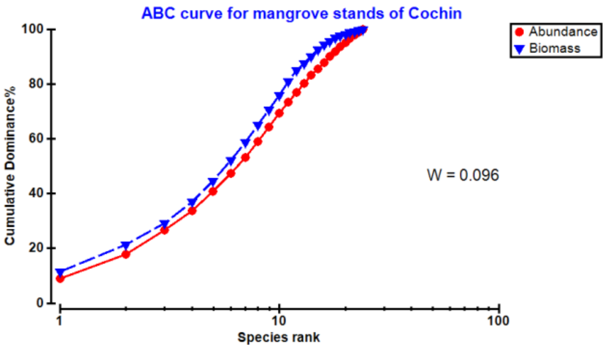

Figure 5.8 (a) Abundance biomass (ABC) curves of macrofaunal assemblage in Cochin mangroves during 2010-2012 period

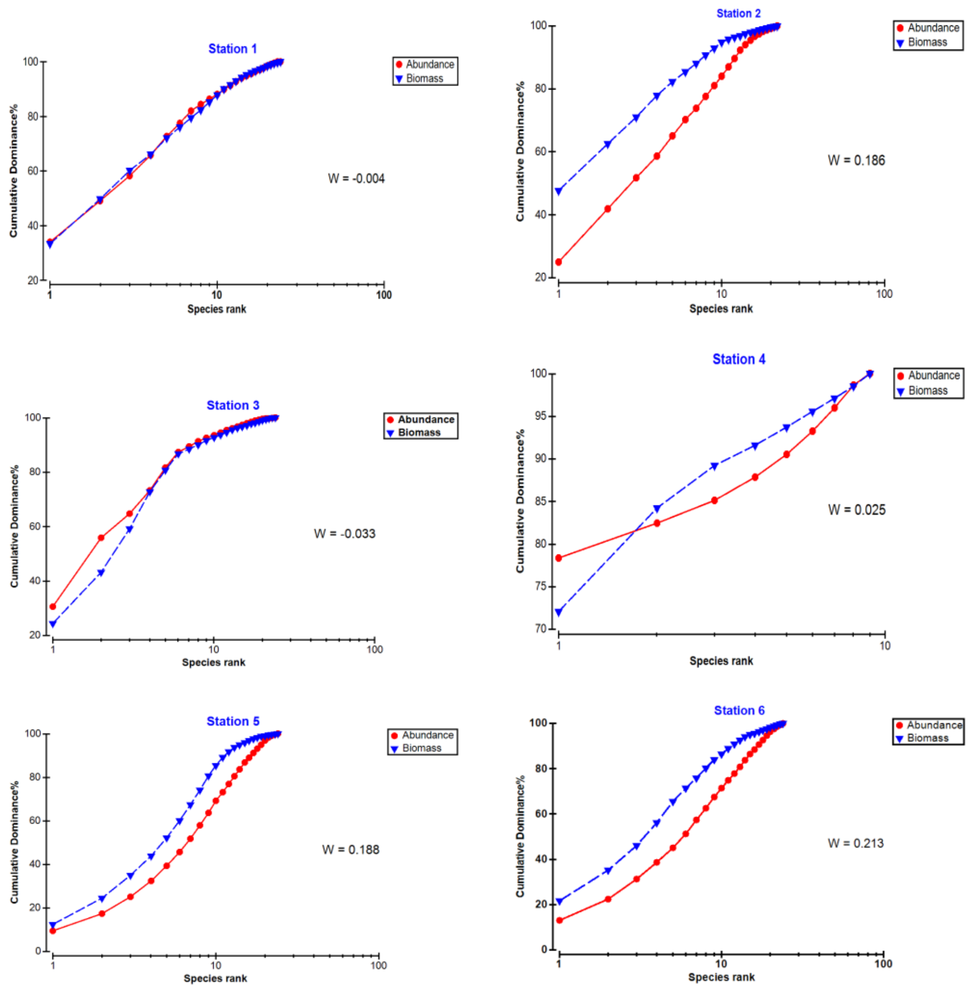

Figure 5.8 (b-g) Abundance biomass (ABC) curves of macrofaunal assemblage in each study station of Cochin mangrove habitats during 2010-2012 period.

almost closer to zero indicating stressed condition (W=0.025). In contrast station 2 (W =0.186), station 5 (W =0.188) and Station 6 (W=0.213) where biomass lies above abundance curve with positive W-value indicating stress free benthic communities. Similarly ABC curve of entire mangrove stands gives a positive W-value 0.096 where biomass curve lies above abundance curve but much closer indicating overall good condition with slight stress to benthic fauna [Figure 5.8 b-g]

f. Biotic indices

Biotic index is a scale to measure the quality of the environment. Present study used two biotic indices BENTIX and AMBI index were used to check the ecological status of the selected mangrove stations using macroinvertebrates as indicators.

AZTI's Marine Biotic Index (AMBI)

In AMBI classification macrofauna were classified into five ecological groups (EG) based on the organism's sensitivity to stress. Mangrove station 1 was characterised by higher abundance of oligochaete *Tubificoides psuedogaster* which are first order opportunistic species under EG 5 and tanaids (*Ctenapsuedes chilkensis* and *pagurapsuedopsis gymnophobia*) which are tolerant to organic pollution coming under EG 3, indicating an ecologically unstable condition with a mean value of 2.8±1.2.

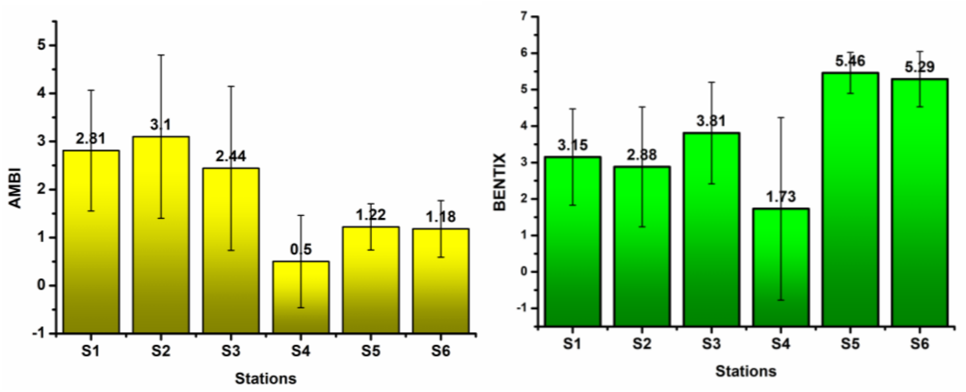

Figure 5.9 a) AMBI and **b)** BENTIX index showing the ecological status of mangrove stands of Cochin during 2010-2012 period.

Station 2 also have a similar ecological condition due to higher density of oligochaete *Tubificoides psuedogaster* (EG5); *Ctenapsuedes chilkensis* (EG3), *Idunella* sp. (EG2), chironomid larvae (EG3) and presence of nemertines, turbellarians (EG3) which exhibited a mean value of (3.1±1.7) implying a slightly to moderately disturbed condition. In station 3 *Capitella capitata* (EG 5), *Ctenapsuedes chilkensis* and *pagurapsuedopsis gymnophobia* (EG3) were dominant and the AMBI values (2.4±1.7) showed moderately disturbed condition as that of station 1 and 2. In station 4, species diversity was less, eventhough Chironomid larve (EG3) and *Grandidierella meghnae* (EG1) dominated but the AMBI value was lowest 0.50±0.96 indicating unpolluted condition. Station 5 and 6 have similar composition of benthic fauna mostly belongs to EG1 and EG2 especially dominant fauna of *Dendronereies aestuarina*(EG1) *Cheiriphotis geniculata*(EG2), *Idunella* sp.(EG2), *Indosphenia* (EG1) with an AMBI value of 1.2±0.48 and 1.2 ±0.58 indicating an unpolluted to slightly polluted condition [Figure 5.9a].

BENTIX

BENTIX index can vary from zero (bad ecological status) to six (high ecological status).In station 1 the mean index value was 3.15, while in station 2 with 2.88 and that for station 3 was 3.81.Thus in station 1, 2 and 3 the BENTIX value lies between 2.5 to 3.5 indicating a moderate ecological condition, however in station 4 the value (1.73) lies below 2 indicating a bad ecological condition. The station 5 and station 6 (valanthakad region) have an index of 5.46 and 5.29 respectively indicating a pristine condition of mangrove zone [Figure 5.9b].

g. Multivariate analysis

Multivariate analysis such as Bray-Curtis similarity matrix, ANOSIM, SIMPER were carried out on macrofaunal data after square root transformation in PRIMER software.

In Bray-Curtis hierarchial clustering and SIMPROF test, two distinct assemblage clustering pattern was observed [Figure 5.10]. First cluster between the stations S5 and S6 forming HDD (High Density and Diversity) group with 81.4% (p=100%) of similarity characterised by high diversity and higher density of macrofauna while S1, S2 and S3 form LDD (Low Density and Diversity) group with 53.4% (p=31.9%) similarity characterised by lower diversity and lower density of macrofauna, and station 4 is an outlier.

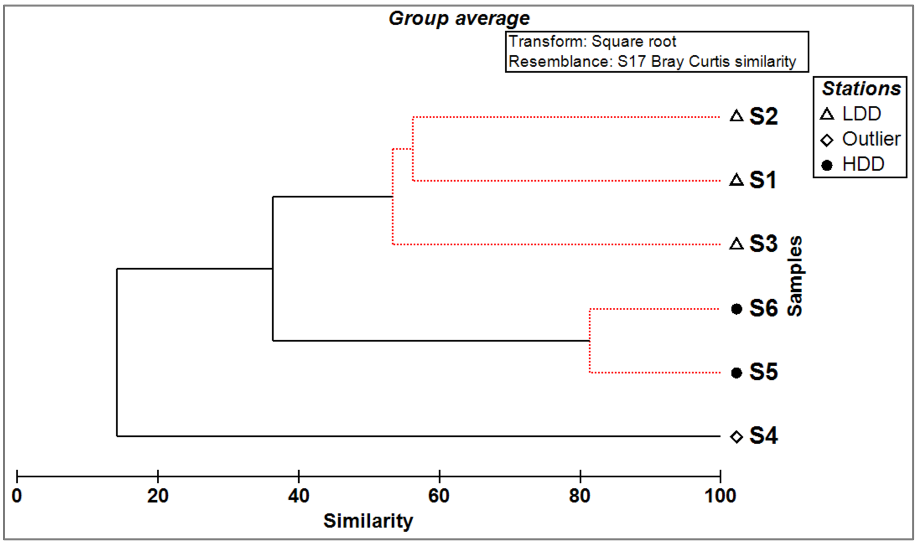

Figure 5.10 Dendrogram for macrofaunal species in each station in Cochin mangroves during 2010-2012 period (LDD group -stations 1, 2, 3; HDD group-stations 5, 6; outlier –station 4).

Analysis of Similarities with one way ANOSIM was applied to test the null hypothesis, that there was no significant difference in faunal composition between these clustered groups of stations [Figure 5.11]. ANOSIM showed significant difference between clustered stations where R value lies away from 95% confidence limit or null distribution (ANOSIM, Global R = 0.401, p = 0.1 %). Pair wise test of ANOSIM gives the significant difference between HDD and LDD (ANOSIM, R=0.311, p=0.1%); HDD and Outlier (ANOSIM R=0.845, p=0.1%) LDD and Outlier (ANOSIM R=0.395, p=0.1%).The similarities or dissimilarities between the mangrove stations were due to difference in species assemblages, presence or absence of some unique species or the variation in abundance of predominant species.

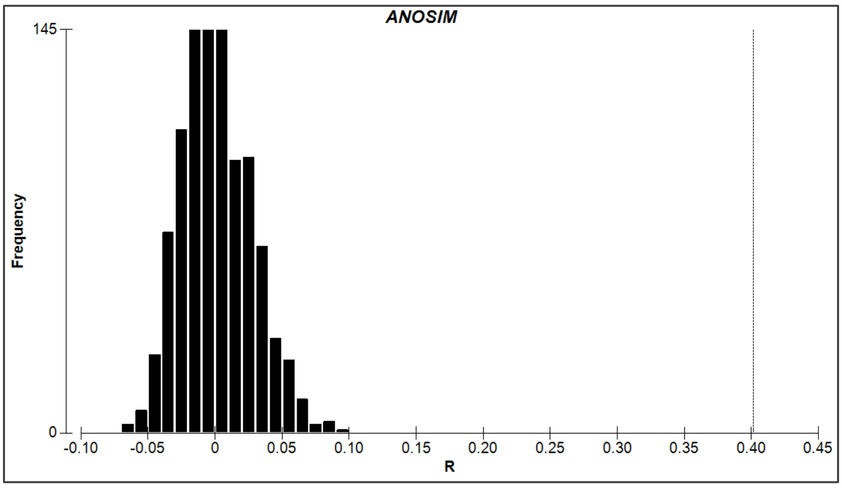

Figure 5.11 ANOSIM showing significance in macrofaunal communities between clustered stations in Cochin mangroves during 2010-2012 period.

SIMPER analysis was carried out to detect the fauna responsible for these clusters [Table 5.7]. In HDD (S5 and S6), 8 species were responsible for formation of this group such as *Dendronereis aestuarina* (27.53%) *Idunella* sp. (21.83%), *Cheiriphotis geniculata* (16.93%), *Indosphenia* sp (9.67%) are major species, followed by *Namalycastis indica*, *Victoriopisa cusatensis*, *Ctenapsuedes chilkensis*, *Villorita cyprinoides*. However in LDD (S1, S2, S3),7 species such as *Ctenapsuedes chilkensis* (34.15%), *Tubificoides psuedogaster* (18.69%), *Idunella* sp. (13.38%), *Victoriopisa chilkensis* (10.53%) were showing maximum contribution followed by *Pagurapseudopsis gymnophobia*, *Prionospio cirrifera* and *Chironomid* sp.

Dissimilarity between clustered group of stations such as HDD and LDD were 89.85% that was mainly due to difference in abundance pattern of species such as *D.aestuarina* (15.21%), *C.geniculata*(13.44%), *Idunella* sp. (12.71%), which were in higher abundance in HDD, furthermore *Indosphenia* sp. *V.cusatensis V. cyprinoides* were absent in LDD similarly *Capitella* sp. was absent in HDD. Dissimilarity between HDD and Outlier is 98.23% contributed by *D.aestuarina* (17.93%), *Cheiriphotis geniculata* (15.81%), *Idunella* sp. (15.50%) and *Indosphenia* sp. (10.90%), which was found to be in higher density in HDD. Dissimilarity between LDD and Outlier is 98.62% which might be due to the absence or low abundance of following species *C.chilkensis* (16.46%), *T.psuedogaster* (12.73%), *Idunella* sp. (10.05%) *V. chilkensis* (7.22%), *P.gymnophobia* (6.49%) in outlier.

Table 5.7 SIMPER test results showing the dissimilarity of macrobenthic communities in Cochin mangroves during 2010-2012 period.

SIMPER	S1, S2, S3 (LDD)	S5 & S6 (HDD)	Average dissimilarity = 89.85 %		
Species	**Av. Abundance**	**Av. Abundance**	**Av. Dissimilarity**	**Percentage contribution**	**Cumulative percentage**
D.aestuarina	0.25	23.00	13.67	15.21	15.21
C. geniculata	0.36	18.98	12.08	13.44	28.65
Idunella sp.	4.33	21.44	11.42	12.71	41.37
Indosphenia sp.	0.00	14.60	8.51	9.47	50.84
C. chilkensis	9.29	7.49	6.88	7.66	58.50
T.pseudogaster	6.53	1.22	3.92	4.37	62.87
P.gymnophobia	4.43	4.47	3.89	4.33	67.19
V. chilkensis	4.26	4.86	3.88	4.32	71.52
V.cusatensis	0.00	5.67	3.34	3.72	75.23
V. cyprinoides	0.00	5.01	3.05	3.39	78.63
N. indica	0.56	4.96	2.94	3.28	81.90
P.tenius	0.48	4.25	2.35	2.61	84.51
P. cirrifera	1.99	2.67	2.13	2.37	86.88
Chironomid sp.	1.39	2.53	1.91	2.13	89.01
Capitella sp.	2.60	0.00	1.31	1.45	90.46

5.2.3 Influence of environmental factors on macrobenthic species assemblages

Redundancy analysis (RDA) is a multivariate method used to analyse the interrelationship of environmental parameters with biological parameters. RDA clearly defined spatial variations in environmental parameters and also represented how they influenced the benthic community structure. The stations with comparatively higher sand texture and higher Eh (S5 and S6) were found to harbour larger number of species.

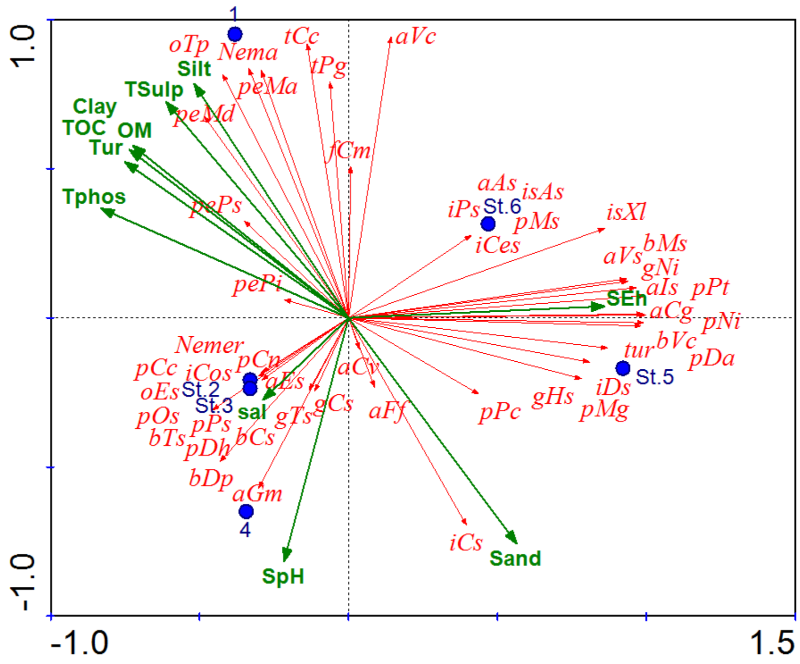

Figure 5.12 Redundancy analysis (RDA) to determine the macrofaunal distribution in the suite of environmental parameters in Cochin mangroves during 2010-2012 period.

Majority of polychaete species such as *Dendronereis aestuarina*, *Marphysa sanguinea*, *Prionospio cirrifera*, *Namalycastis indica*, *Parheteromastus tenuis*, *Maldane sarsi* and amphipod species such as *Victoriopisa cusatensis*, *Cheiriphotis geniculata*, *Idunella* sp., *Amphilochus* sp., isopods *Xenanthura linearis*, *Apanthura sandalensis*, mostly all insects such as *Pseudosinella* sp. Ceratopogonidae, Dytiscidae, Chironomidae, molluscs such as *Villorita cyprinoides*, *Indosphenia* sp., *Nassodonta insignis*, *Hydrobia* sp., Turbellaria were seen in stations (S5 and S6) with higher redox potential and sandy texture [Figure 5.12]. However species such as *Tubificoides psuedogaster*, tanaids such as *Ctenapseudes chilkensis*, *Pagurapseudopsis gymnophobia*, all the penaid species *Metapenaeus affinis*, *Metapenaeus dobsoni*, *Penaeus indicus*, Penaeidae, nematodes, benthic fishes *Callogobius mannarensis* and amphipod *Victoriopisa chilkensis* were the fauna seen in station 1 with higher organic enrichment, silty clay texture, turbidity, total sulphur, total phosphorus and low redox potential. Station 3 was characterised by higher salinity due to proximity to sea and species tolerant to salinity was seen here especially polychaetes *Ophelia* sp., *Capitella sp., D.heteropoda, Phyllodocid* sp., *Ceratonereis costae,* amphipod *Eriopisella sp.,* molluscs *Donax pulchellus* , *Turritella* sp., Tellina sp., cardidae sp. while station 4 was characterised by alkaline pH and species seen here were *Cerithidium sp., Grandidierella megnae, Floresorchestia* sp.etc. Station 2 harbours species such as nemertean, oligochaete Enchytraeidae, insect Coenagrionidae, amphipod *Americorophium triaenonyx* etc. The subset of macrofaunal species for RDA analysis were listed in Table 5.8

Table 5.8 Subset of macrofaunal species used for multivariate redundancy analysis (RDA)

Species (Abbreviation)	Species (Abbreviation)
Dendronereis aestuarina (pDa)	*Xenanthura linearis* (isXl)
Marphysa sanguinea (pMs)	*Apanthura sandalensis*(isAs)
Parheteromastus tenuis(pPt)	*Metapenaeus affinis* (peMa)
Capitella sp. (pCc)	*Metapenaeus dobsoni* (peMd)
Namalycastis indica (pNi)	*Penaeus indicus* (pePi)
Prionospio cirrifera (pPc)	*Penaeidae* (pePs)
Ophelia sp. (pOs)	Chironomidae (iCs)
Dendronereides heteropoda (pDh)	*Pseudosinella* sp.(iPs)
Maldane sarsi (pMg)	Dytiscidae (iDs)
Phyllodoce sp. (pPs)	Coenagrionidae (iCos)
Ceratonereis costae (pCn)	Ceratopogonidae (iCes)
Tubificoides pseudogaster (oTp)	*Donax pulchellus*(bDp)
Enchytraeidae (oEs)	Cardiidae sp.(bCs)
Victoriopisa chilkensis (aVc)	*Villorita cyprinoides* (bVc)
Victoriopisa cusatensis (aVs)	*Indosphenia* sp (bMs)
Cheiriphotis geniculata (aCg)	*Tellina* sp. (bTs)
Grandidierella megnae (aGm)	*Turritella* sp. (gTs)
Americorophium triaenonyx (aCt)	*Cerithidium* sp.(gCs)
Idunella sp.(aIs)	*Nassodonta insignis* (gNi)
Floresorchestia sp. (aFf)	*Hydrobia* sp.(gHs)
Eriopisella sp.(aEs)	Nematode (Nema)
Amphilochus sp.(aAs)	*Turbellaria* (tur)
Ctenapseudes chilkensis (tCc)	Nemertea (Nemer)
Pagurapseudopsis gymnophobia (tPg)	*Callogobius mannarensis* (fCm)

Figure 5.13 Some macrofaunal species identified from Cochin mangroves

a) *Parheteromastus tenuis* **b)** *Chironomid larva* **c)** Coenagrionidae **d)** *Pagurapseudopsis gymnophobia* **e)** *Pseudosinella* sp **f)** *Ophelia* sp **g)** *Xenanthura linearis* **h)** *Nassodonta insignis* **i)** Dytiscidae **j)** *Ctenapseudes chilkensis* **k)** *Tubificoides pseudogaster* **l)** *Indosphenia* sp **m)** *Dendronereides heteropoda* **n)** *Prionospio cirrifera* **o)** *Namalycastis indica* **p)** *Capitella* sp **q)** Nematode **r)** *Dendronereis aestuarina* **s)** *Villorita cyprinoides*

5.3 Discussion

5.3.1 Community composition of macrobenthic fauna

Biodiversity of a benthic community can be measured by relative species richness in a particular area at a particular time. Benthic community in Cochin mangroves is relatively poor comprised of 48 species of 11 taxa under 38 families. Species richness was comparatively lower than that reported from previous literatures in Cochin estuarine-mangrove area (Sunil Kumar, 1993; Asha *et al*., 2016; Martin *et al*., 2011). Malacostraca was dominated with 17 species over the polychaetes (11 species) and molluscs (9 species). However most of the mangrove habitats have reported to have a higher composition of polychaete species rather than crustaceans. Australian mangroves with 68 species of polychaetes (Metcalfe and Glasby, 2008), Cochin mangroves with 33 species (Sunil Kumar, 1993), Tamil Nadu mangroves with 27 species (Samidurai *et al*., 2012), Hong Kong mangroves with 23 species (Lee, 1999). An overall 62 species in 35 genera of polychaetes were identified from Indian mangroves (Sunil Kumar, 2001). Since mangrove ecosystem is a transition zone where there may be higher range of fluctuations of environmental factors as well as biotic factors, high nutrient enrichment especially carbon, sulphur and nitrogen, derived during putrefaction of litter, anoxic conditions of deep soil, tidal actions etc, the species present here would be adapted to various features of mangrove habitats or may develop tolerance in many aspects. The polychaete abundance may be linked to their high adaptability to wide range of fluctuation of these environmental factors (Sunil Kumar, 2003). However in the present study a severe decline or disappearance of polychaetes in contrast to earlier studies by Sunil Kumar (1993), was noted from 33 to 11 species while malacostracans were increased from 9 species (Sunil Kumar,1993) to 17 species especially amphipods in present study.

Nereididae, Capitellidae and Spionidae were the major families of polychaetes seen in mangroves (Metcalfe and Glasby, 2008). Furthermore Sunil Kumar, (2003) observed the family Nereididae and Eunicidae in mangrove soil of Asia in terms of species diversity followed by Glyceridae, Spionidae and Capitellidae. Similarly in the present study also Nereididae represented maximum of 4 species of which *Dendronereis aestuarina* determined the assemblage structure contributed to 72% of total density among the polychaetes and occupy second position next to amphipod *Idunella* sp. in density (38808 ind.m^{-2}) of the total macrofaunal species in Cochin mangroves. *Dendronereis aestuarina* was common in estuarine and mangrove areas of Kerala (Khan and Murugesan,2005) and reported in Kodungalloor –Azhikode estuary (Jayachandran *et al*., 2019),Cochin estuary (Pillai, 2001; Asha *et al*.,2016) Kadalundy estuary (Aarif, 2009), Cochin mangroves(Sunil Kumar,1993; 2001).They were seen in brackish waters and can even live in fresh waters. The mass reproductive swarms of *Dendronereis aestuarina* was reported from the fresh water zone of Periyar River of the south west coast of India (Jayachandran *et al*., 2015). In the present study they were seen in all seasons throughout the year in station 5 and 6 (Valanthakad region) where salinity was lower and sediment was sandy with low organic matter. A swarm of capitellid, *Capitella* sp. (284±1196 ind.m^{-2}) were encountered from the highly saline, silty sand textured station (station 3, Puthuvype), which is an upcoming major industrial area in Cochin. They were not encountered from pristine Valanthakad region however *Parheteromastus tenuis*, another capitellid were encountered mainly from this zone. Capitellids are cosmopolitan and opportunistic and indicator species (Grassle and Grassle, 1976) that usually prefer organic rich soils and their assemblage indicates organic pollution (Zhang *et al*., 2013). All other polychaete species were in lower abundance in mangroves. It was noted that polychaete diversity was maximum in station 3 as majority of them were marine due to proximity to sea. *Dendronereids* *heteropoda*, *Ceratonereis costae*, *Phyllodoce* sp., *Ophelia* sp. were restricted to this station as they are marine invaders to mangroves.

Among the malacostracan crustaceans, amphipods represent maximum species (9 spp.). Dittmann (2001) observed higher abundance of amphipods only in mangroves and not in mudflats of Missionary bay, Australia. Species richness might be due to their litter favourablity and substrate preference. Over and above the euryphagic nature (Chintiroglou *et al*., 2004) along with extensive parental care (Thiel, 1998) made them adapted to live and utilise various microhabitats provided by mangroves. Family Eriopisidae represents maximum number of species (3 species), two from *Victoriopisa* genus (Philomina *et al*., 2018b) and one *Eriopisella.* The family is characterized by marine, epigean and hypogean fauna with cosmopolitan distribution (Lowry and Myers (2013). *Victoriopisa chilkensis* (previously under genus *Eriopisa*) occurs in large numbers in the organically-enriched sediments of the Cochin mangrove especially in Station 1 and it can be regarded as a tolerant species of organic pollution (Aravind *et al*., 2007). Asari (1983) studied the biology of *Victoriopisa chilkensis* and reported that they are filter feeders feeding on organic rich nutrients. They are detritivores and an important food source for fishes, invertebrates and crabs. They were observed in all stations except station 4 implying that they can withstand all the hostile nature of mangrove habitat. They were encountered from benthic epifaunal communities in the mangrove swamps of Puduvypin where they function as shredders of mangrove leaves (Aravind *et al*., 2007). However *Eriopisilla* sp. was restricted to station 3 where salinity was higher. They are grazers that feed on epiphytic macroalgae, pennate diatoms and organic matter (Wongkamhaeng, 2009).In mangroves of Cochin, *Idunella* sp. of Liljeborgiidae family attained maximum density of 40170 ind.m^{-2} among all macrobenthic species. A new species of *Idunella* (previously known as *Listriella*) was reported from Kayamkulam Lake, Kerala in association with the algal communities (Rabindranath, 1971). The members of Liljeborgiid genus *Idunella* was also seen in symbiotic relationship with polychaete worms of the family Maldanidae and Terebellidae (Bousfield 1973), and also exhibited a positive response to pectinariid mucus (Batcheler and Mills, 1965). In the mangrove, *Idunella* was observed in higher densities in station 5 and 6 (Valanthakad), where it may be associated with algae in pnuematophores and stilt roots of mangroves. Corophid *Cheiriphotis geniculata* also adds to density of macrofauna along with *Idunella* sp. together contributing to 58% of malacostraca. Recent study by Asha (2017) in Vembanad backwaters also listed the abundance *Cheiriphotis geniculata* especially in oligohaline zone, having higher organic carbon in the sediment. However in mangrove stations they were observed in Valanthakad region, a pristine mangrove zone and preferred sandy sediment with low organic matter and lower salinity.

Tanaids were represented by *Ctenapseudes chilkensis* contributed to 23% and *Pagurapseudopsis gymnophobia* to 8% among malacostracan density next to *Idunella* and *Cheiriphotis geniculata.* Tanaidaceans are smaller organisms having a worldwide distribution and a truly demersal organisms that prefer shallow brackish waters and inhabit the surface layer of the sediments, either in burrows, or by constructing tubes, or interstitially while some of the taxa are crevice dwellers, and others build tubes on algae or even on marine vertebrates (Larsen, 2016). They are opportunistic and their abundance indicate organic matter accumulation in an area (Pearson and Rosenberg, 1978).They have a short generation time, high fecundity and can be used as ideal live feed organisms for fin and shell fishes due to high protein content. Tanaids have varied preference for substrate as some preferred muddy and fine sand shell deposition for its proliferations (Priya *et al*., 2014) while some found in marine caves (Guţu and Iliffe, 2001) and some even been found in sulfurous anoxic environments (Sieg and Heard, 1985). In Cochin mangrove, these opportunistic species were present in all stations due to their tolerance to environmental variables but attained maximum density in polluted fine sediments of station 1 with higher sulphur content and organic content and even anoxic at times. They directly feed on mangrove leaves and help in nutrient recycling. According to Ates *et al*. (2014), sediment texture is the primary factor affecting the density variation of tanaids along with other abiotic factors such as temperature, tides and freshwater discharge. In station 1 decapods especially commercially valuable penaeids (*Metapenaeus affinis*, *Metapenaeus dobsoni*, *Penaeus indicus*) were observed which spend there for breeding and feeding on the juveniles of tanaids as it is a valuable live feed (Priya *et al*.,2014).

Among the molluscan fauna, Myidae represent the single dominant family among bivalves contributing to 80% of molluscan fauna represented by *Indosphenia* sp. with numerical density of 23835 ind.m^{-2} followed by *Villorita cyprinoides* (10%). The soft-shell clams, Myidae (*Indosphenia)* are suspension feeders with two fused siphons that make burrows and lead a sessile lifestyle (Graham *et al*., 2018). Siphoning activities may create water current that have a profound effect on sediment biochemistry (Hansen *et al*., 1996). The repeated withdrawals and extensions of the siphon and transport of water and oxygen from the shells are known to stimulate oxygenation, biotic enrichment, microbial activity and benthic processes in the thin sediment zone surrounding the bivalve (Reise, 1983; Forster and Zettler, 2004). *Villorita* is of great importance in fisheries and source of protein and are adapted to low to high saline conditions and thrive at salinities as high as 15 ppt (Sheeba, 2000). Their diversity seems to be high in station 5 and station 3 that may be based on salinity gradient. Molluscs are least sensitive to organic matter enrichment and H_2S accumulation (Kuk-Dzul and Dıaz-Castaneda, 2016) but may be intolerant to increased siltation that might be their absence in silty sediment of station1.

Among sporadic representatives, oligochaetes were dominant especially during first year (2010-11) followed by insects represented by Chironomidae. To date, 56 species of marine Oligochaeta have been recorded from mangroves (Erseus, 2002). Oligochaetes in mangroves mostly belong to the family Tubificidae (synonimised to Naididae) and also to Enchytraeidae (Erseus, 2002). Similarly in the present study these families were encountered and tubificid oligochaete worms were the dominant taxa in the infauna of mangrove sediments represented by *Tubificoides psuedogaster* contributed to 80% to "others" density while Enchytridae were least represented. Mangrove oligochaetes largely represent genera adapted to low salinity and organically enriched sediments, both conditions being characteristic of station 1 where they present in larger densities (12056 ind.m^{-2}). Whenever present in great numbers, they appear to be important contributors to the decomposition and remineralisation of organic material and to the production of higher trophic levels in the mangrove ecosystems (Erseus, 2002).

Species diversity is an ecologically powerful tool and a simple and useful measure of biological system that reflects the well- being of the ecosystem. When the diversity value is more than 3, the system is considered to be pristine and diverse in nature (Sanders, 1968). Higher species diversity, dominance and richness of macrofaunal species in Valanthakad region (Station 5 and 6) imply that the environmental variables were optimum for the assemblage of macrofaunal communities and was comparable to Pichavaram and Vellar mangroves (Murugesan *et al*.,2016), Kachchh mangroves (Saravankumar *et al*., 2007). Metcalfe-Smith (1994) reported that the use of diversity indices when toxicity is present causes a decrease in both number of species present and abundance; which in turn results in an increase in "evenness" as in station 4 where larger assemblage of benthic algae (Microcystis) was observed which may become toxic to benthic fauna and hence lower abundance and diversity in this station. However seasonal variations implies the diversity of macrofaunal species attained maximum during pre-monsoon during the two year period (2010-2012) and lowest in post- monsoon as reported in Kodungalloor–Azhikode estuary (Jayachandran, 2017; Jayachandran *et al*.,2019) while diversity, dominance and richness index were maximum during second year in post-monsoon. The increased abundance of macrofauna during pre-monsoon and post-monsoon season was mainly due the increased reproduction rate of macrofauna during these seasons (Harkantra and Parulekar, 1985). Moreira *et al*., 2008 also suggested that seasonal variations were due to temperature-dependent life cycle and reproductive strategies. However in mangroves of Kerala the south-west monsoonal rain also a factor of influence.

5.3.2 Benthic Community assemblage pattern

One of the general characteristics of ecological communities is that the number of species accumulates with increasing area sampled (Ugland *et al*., 2003). In mangrove ecosystem, continuous monthly sampling for two years could significantly contributed to species richness and found that, compared to first year (41 species) 7 more species were encountered by the end of second year. Hence species accumulation rate was comparatively high in mangroves and the curve reached the upper asymptote, indicating that the study area was sampled sufficiently. Perhaps the species estimators found that there were chances of more number of species, even upto 57 to 62 species according to Jacknife estimator 1 and 2 from mangrove ecosystem. However Sobs (Observed number of species) and Chao1 estimated the exact number of species sampled. Warwick and Clarke (1995) reported that chronically disturbed locations would exhibit greater variation and reduced taxonomic distinctness. Out of the six stations, station 4 and 1 exhibited lower taxonomic distinctness probably due to some stressed factors as the concept introduced by Warwick and Clarke (1995). Average taxonomic distinctness (Δ+) and Variation in Taxonomic Distinctness (Λ+) between other stations were well within the 95% confidence funnel implying a high degree of taxonomic stability as observed in Kakinada bay and adjacent mangrove channels of Godavari delta (Raut *et al*., 2005). The abundance-biomass curve (ABC curve) also depicts a similar ecological status of mangrove stations. The abundance and biomass curve lie closer and intersects with a negative W-value in station 1 whereas in station 4, W value does not have a negative value but almost closer to zero indicating stressed condition. These values imply frequently disturbed benthic community composed of individuals that are small in body size, numerically abundant and short-lived (Dauer, and Alden, 1995) as oligochaetes in station 1 and chironomids in station 4 of Cochin mangroves. Biotic indices such as BENTIX (Simboura and Zenetos, 2002) and AMBI (Borja *et al*., 2000) help to identify the ecological status of an aquatic system. According to Borja *et al.* (2000), benthic communities react to changes in environmental quality either by increase in species density, species diversity, and variation of dominant species from tolerant to sensitive to pollution. In the present study some discrepancies could be seen between both index in classifying the stations. According to BENTIX station 4 was in a bad ecological status with its value less than 2, however AMBI found this station as unpolluted with very good ecological status among all stations. BENTIX could able derive Valanthakad stations (S5 and S6) as pristine, ABC curve also gives similar results, however AMBI consider it unpolluted to slightly polluted.

The *k*-dominance plot also showed similar results on spatial scale where the curve for station 4 occupies most elevated position inferring its lowest diversity and maximum perturbation with assemblage of chironomid larve (60%) mainly. This might be due to the higher density and dominance of mangrove species *Exoecaria indica* that retain a rich tannin content and high alkaloids that may affect the benthic assemblage, density and diversity. The curve for station 1 lie just below station 4 where distinct assemblage of *Tubificoides psuedogaster* - tanaids *Ctenapsuedes chilkensis* and *Pagurapseudopsis gymnophobia* were seen. However the curve of station 6 and station 5 occupied lowest position with highest diversity characterised by distinct assemblage of *Idunella* sp - *Dendronereies aestuarina*- *Indosphenia* sp. in station 6 and *Dendronereies aestuarina*- *Cheiriphotis geniculata* -*Idunella* sp. in station 5. Annually *k*-dominance curve for first year (2010-11) lie lower inferring higher diversity and dominance due to the distinctive assemblage of *Cheiriphotis geniculata* - *Ctenapsuedes chilkensis* - *Tubificoides psuedogaster* than second year as the assemblage was by *Idunella* sp. - *Indosphenia* sp.- *Dendronereis aestuarina*. Seasonally *k*-dominance plot showed that assemblage of *Dendronereies aestuarina*- *Ctenapsuedes chilkensis*- *Indosphenia* sp.- *Cheiriphotis geniculata* - *Capitella* sp. - *Idunella* sp. caused higher dominance in monsoon season.

Macrofaunal assemblages in the mangroves were significantly separated based on the spatial distribution and diversity by hierarchial clustering and SIMPROF (HDD and LDD) and also based on species composition by similarity percentage analysis (SIMPER). The high density and diversity stations (HDD) such as station 5 and station 6 have very higher similarity between their species composition (81.4%) compared to Low diversity and density (LDD) stations such as station 1, 2 and 3 (53.4 %), while station 4 is an outlier perhaps due to their irregular assemblage pattern and lower diversity of species that was not at all comparable to other stations.

HDD stations were characterised by lower organic matter, higher redox potential and sandy texture with a pristine ecology distinct them from LDD stations with very higher organic matter, higher nutrients, silty sediment, lower dissolved oxygen. Analysis of Similarities with one way ANOSIM proved significant difference between clustered stations where R value lies away from 95% confidence limit or null distribution. The similarities or dissimilarities between the mangrove stations were due to difference in species assemblages, presence or absence of some unique species or the variation in abundance of predominant species which was verified by SIMPER analysis. *Dendronereis aestuarina* (polychaete), *Idunella* sp. and *Cheiriphotis geniculata* (amphipods), *Indosphenia* sp. (bivalve) are major species responsible for HDD group while opportunistic species such as *Ctenapsuedes chilkensis* (tanaid), *Tubificoides psuedogaster* (oligochaete), *Idunella* sp. and *Victoriopisa chilkensis* (amphipod) in LDD group. Furthermore the absence of *Indosphenia* sp. *Victoriopisa cusatensis*, *Villorita cyprinoides* in LDD and *Capitella* sp. (organic pollution indicator) in HDD also separated these clustered stations.

5.3.3 Influence of environmental variables on diversity and species assemblage

One of the main goals of benthic ecology is to understand the mechanisms regulating relationships between environmental parameters and benthic fauna (Snelgrove and Butman 1994; Aller *et al*., 2001). Most of the studies in mangroves especially Saravanakumar *et al*. (2007) in Kachchh mangroves found importance of salinity in species structure while Lui *et al*., (2002) found salinity and season in Hong Kong mangroves; Sunilkumar (1993) found salinity and substrate in Cochin mangroves; Schrijvers *et al*.,1998 found detritus availability and predation in Kenyan mangroves, while Morrisey,2003 found stand age of mangrove vegetation in New

Zealand mangroves determining species richness and assemblage. Community assemblage of benthic fauna in mangrove ecosystems of Cochin was determined mainly by sediment variables mainly particle size, organic matter, total organic carbon, pH and nutrients [Table 5.9]. The number of species in Cochin mangroves were determined by sediment particle size especially sandy texture (*r*= 0.168) perhaps a decline in species number and richness was seen in sediment with lower grain size(*r*= -0.233), higher organic matter (*r*= -0.299), and higher nutrient concentration such as total phosphorus (*r*= -0.394) and sulphur (*r*= -0.257). Sanders (1968) observed that sandy biotope supports more diversified benthic community than muddy biotope as sand possess more micro-habitats, where permanent burrowers were abundant increasing the permeability and oxygen content. Studies have shown that benthic communities are responding to increased silt/clay as a result of higher sedimentation and low benthic diversity and abundance was associated with increasing sediment mud content (Thrush *et al*., 2003; Ellis *et al*., 2004; Stokes *et al*., 2009). In muddy sediments, permeability will be lower and anoxic condition usually prevails due to action of sulphate reducing bacteria, increasing the hydrogen sulphide in sediment (Lacerda *et al*., 1993). Organic matter is the best predictor for benthic diversity, as increase in organic matter may perhaps leads to hypoxia reducing benthic faunal diversity((*r*= -0.187). Evenness in species distribution was said to be linked with organic matter content (Levin and Gage, 1997). Sensitive fauna responds to the organic matter enrichment by their migration or avoidance however opportunistic species will proliferate due to tolerance to organic enrichment thereby reducing diversity of system. Besides, mangrove litter will produce humic acids along with higher carbondioxide during organic matter decomposition that may cause acidification of mangrove habitats reducing benthic diversity (Lohrer *et al*., 2004). Nutrients especially total sulphur and total phosphorus have influence on diversity and species richness. Sulphur in anoxic sediment seems to be in reduced state and forms hydrogen sulphide and these are deleterious to benthic organisms (Sawyer & McCarty 1989). Organic matter decomposition may contain nutrients such as nitrogen and phosphorus. Organic rich sediments may act as buffer either as well as a source or sink of nutrients especially phosphorus by adsorption–desorption reactions (Krom and Berner 1980) and even cause hypoxia as in Chesapeake Bay (Hagy *et al*., 2004), hence are negatively correlated to species diversity(r= -0.311) and richness(r= -0.379). Changes in benthic assemblages also correlate with lower redox potential indicating a possible hypoxia situation (de-la-Ossa-Carretero *et al*., 2012). RDA triplot also give a possible relation of species diversity linked mainly to higher redox potential and higher sand where species richness was maximum while factors in opposite direction indicate a negative correlation to species especially to organic matter, nutrients and finer grain size. Generally most of the amphipod species are sensitive to redox changes (Dauvin and Ruellet, 2007) and occupy areas with higher redox potential, similarly the polychaetes *Dendronereis aestuarina* and bivalves are sensitive to organic pollution that was found to occur in unpolluted areas as in station 5 and 6.

Table 5.9 Pearson correlation analysis of macrofaunal diversity indices with environmental parameters in Cochin mangroves during 2010-2012 period.

Environmental variables	S	d	J'	H'	1-λ’
Water Temperature	0.083	0.113	0.148	0.15	0.154
Water pH	-0.093	-0.131	-.175*	-.167*	-.177*
Salinity	-0.055	-0.044	-0.022	-0.051	-0.031
Dissolved oxygen	0.151	0.122	0.088	0.112	0.101
Turbidity	-0.038	-0.035	-0.049	-0.012	-0.025
Sediment Temperature	0.011	0.047	0.151	0.102	0.126
Sediment pH	-0.094	-0.115	-0.09	-0.13	-0.114
Organic matter	-.299**	-.272**	-0.021	-.187*	-0.146
Sand	.168*	0.14	-.173*	0.028	-0.033
Silt	-0.137	-0.117	0.158	-0.015	0.038
Clay	-.233**	-.188*	.175*	-0.068	0.002
Sediment Eh	0.137	0.137	0.065	0.107	0.084
Total Sulphur	-.257**	-.230**	0.051	-0.13	-0.073
Total Phosphorus	-.394**	-.379**	-0.119	-.311**	-.267**
Organic carbon	-.299**	-.272**	-0.021	-.187*	-0.146

Significant correlation at a level of $p < 0.01$ (**), $p<0.05$ (*)

Chapter 6

TAXONOMY OF AMPHIPODS WITH DESCRIPTION OF A NEW SPECIES *Victoriopisa cusatensis* FROM COCHIN MANGROVES

"Taxonomy is described sometimes as a science and sometimes as an art, but really it's a battleground."

Bill Bryson

6.1 Introduction

No group of plants or animals on the planet exhibits the range of morphological diversity as seen among the crustaceans. This morphological diversity or disparity in the paleontological jargon makes the study of crustaceans so exciting (Martin and Davis, 2001). Among the crustaceans, the Amphipoda represents one of the largest orders of the Crustacea under the class Malacostraca with 228 families, 1674 genera and 10,207 species (Horton *et al*., 2019). Even though they are extremely abundant, their identification is so difficult due to their small size, morphology and fragile nature of the specimens, moreover, the taxonomy and systematics of this group was always inconsistent,confusing and under debate (Martin and Davis, 2001).

Amphipods are variously known as scuds or sideswimmers. Those amphipods that have colonised the land are often referred to as landhoppers, and beach dwellers are called sandhoppers or beach/sand fleas (Horton *et al*., 2019). The name Amphipoda means 'different feet' and refers to the different forms of legs. Amphipods are usually less than 10 mm size but range in size from a millimetre in length to 340 mm as reported in the supergiant amphipod *Alicella gigantea* from Atlantic ocean and also from a depth of 5300 metres in Pacific ocean. Amphipods occupies almost all habitats and majority of them were marine (~81%) including estuaries, deepest ocean trenches (e.g. *Hirondellea dubia*), hydrothermal vents and have also colonised freshwaters (17%) and even supralittoral or terrestrial habitats(3%).

Amphipods are primarily benthic animals but they were also seen in pelagic realm especially during their reproductive stage. They are diversified, in terms of the numbers of species, the niches occupied and are classified according to habitats as tube dwellers, nestlers, algal inhabitants, commensals and fossorial. Some pelagic constituents are demersal, infaunal tube-dwellers that enter the water column periodically or may found in the plankton (Thomas, 1993). The association of amphipods with other invertebrates (echinoderms, sponges, tunicates, hermit crabs, sea anemone) are common. They are even seen under rocks or in wood pylons and jetties (Hughes and Ahyong, 2016; Lowry and Myers,2017).

Sexes are separate in amphipods and sexual dimorphism is usually pronounced in adults, with males generally bearing larger and more developed appendages (gnathopods) and often referred as mate guarders. Unlike many other crustaceans, amphipods do not have pelagic larval stages instead the young ones are brooded in a marsupium by the female and hatch as miniature adults. The amphipods are trophically diverse and include scavengers, detritivores, herbivores, filter feeders, predators and even parasites (Hughes and Ahyong, 2016).

Amphipods are of great significance as food for fishes and for higher crustaceans (Edgar, 1997).They have a major role in trophodynamic relationship, as primary consumers, omnivores, carnivores and opportunistic feeders (Wongkamhaeng *et al*., 2009). They are litter shredders or detritus feeders especially in mangroves and even irrigate the anoxic sediment by burrowing and enhancing oxygenation and nitrification processes. They are important in the decomposition of wastes and in the cycling and outwelling of nutrients (Robertson and Mann, 1980) and thus structuring the energy requirements of benthic-pelagic region (Asha, 2017). Amphipods are considered as most sensitive group towards environmental perturbation especially sediment contamination (Dauvin, 2008) and can be used to assess the health of a biotope (Mondal *et al*., 2010).

The order amphipoda are divided into six suborders such as Amphilochidea, Colomastigidea, Hyperiidea, Hyperiopsidea, Pseudingolfiellidea, Senticaudata (Horton *et al*., 2019; Lowry and Myers, 2017). Suborder Senticaudata contains largest number of families (99), genera (908) and species (5638) of amphipods followed by Suborder Amphilochidea (88 families; 682 genera; 4,140 species); then Suborder Hyperiidea (35 families; 76 genera; 283 species); Suborder Hyperiopsidea (3 families; 4 genera; 13 species); Suborder Colomastigidea (2 families; 3 genera; 55 species) and Suborder Pseudingolfiellidea (1 families; 1 genera; 4 species).

6.1.1 Amphipod Morphology (Thomas, 1993; Chapman, 2007)

Amphipods usually have a laterally compressed, comma-shaped body wthout a carapace, and are unique in the possession of three pairs of pleopods and three pairs of uropods unlike other malacostracans.The body of an amphipod is divided into three major regions; head, pereon (thorax), and pleon (abdomen) [Figure 6.1]. **The head** bears two pairs of antennae, the first three articles of the first antenna, and the first 5 articles of the second antenna, form the peduncle. The remaining smaller articles are referred to as the flagellum. An accessory flagellum is an important taxonomic character, can be seen arising from the base of the third peduncular segment of the first antenna. Mouth parts includes upper lip, lower lip, mandibles, maxilla (first and second maxillae) and maxillipeds , which are important on a taxonomic point of view. **Pereon** (thorax) bears seven segments with 7 pairs of pereopods(walking legs), the first two pairs of which are highly modified and called gnathopods. Gnathopods are widely used for feeding and grasping the female during reproduction (amplexus). Details of the prehensile gnathopod morphology are critical in amphipod taxonomy and includes various types (chelate, subchelate, merochelate, carpochelate, transverse, simple). Commencing with the third pair of legs are pereopods 3-7. Each Pereopods bears seven segments (articles) and named as coxa, basis, ischium, merus, carpus, propodus and dactyl. Coxa in each pereopod vary in shape and is of taxonomic significance. Female amphipods bear brood plates (oostegites) basally on the medial surface of coxae 2-5. Small sac-like structure called coxal gills are found on the medial surface of coxae 2-7. **Pleon** bears 6 segments (3 pleosomes+ 3urosomes). Pleosomes bear ventrally three pairs of biramous pleopods. Pleopods are used for swimming or in respiration and generation of feeding currents in sedentary forms. The lateral margins of the pleon (side plates) are referred to as epimera 1-3. Various features of the posterior margin of epimeron 3 are used in identifying certain amphipod families.Urosomes bear 3 pairs of biramous uropods (outer and inner rami) is a prime taxonomic feature. The third uropod is different in certain families as the outer rami is again divided into two articles as in Eriopisidae and in certain case inner rami is very small as in Melitidae, Eriopisidae. The telson is a dorsal flap situated dorsal and posterior to the base of the third uropods. It is also an important taxonomic feature, depending whether it is cleft or entire/ laminar or fleshy.

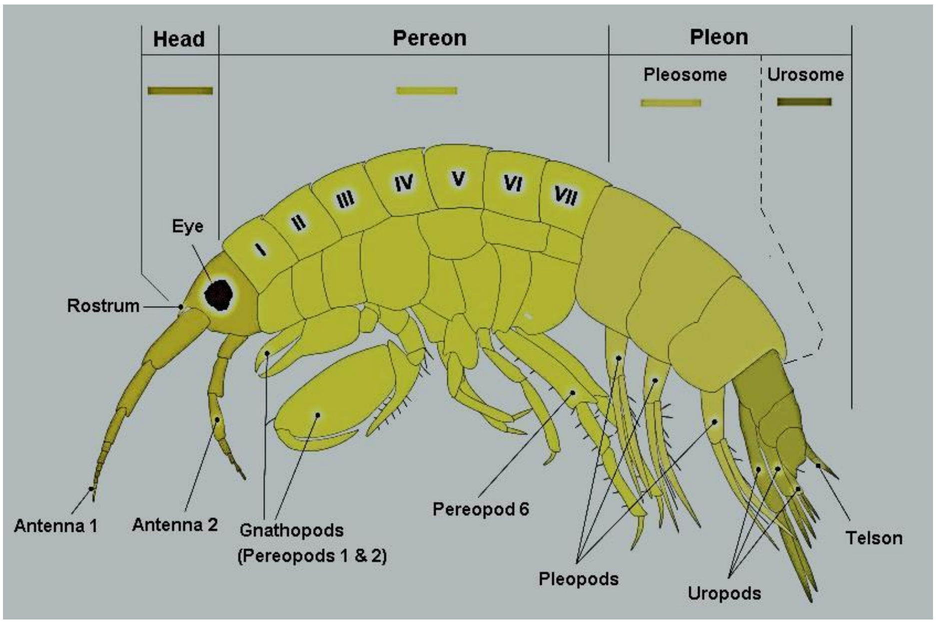

Figure 6.1 Amphipod morphology for taxonomic identification (https://en.wikipedia.org/wiki/Amphipoda)

6.1.2 Taxonomic outline and ecology of genus *Victoriopisa*

The genus *Victoriopisa* comes under the suborder Senticaudata under family Eriopisidae. Senticaudata was characterised by presence of robust setae on 1st and 2nd uropods (Lowry and Myers, 2013). The amphipod family Eriopisidae was established by Lowry and Myers (2013), and is characterized by longer first antenna, the second gnathopods which are similar between males and females and the inner ramus of uropod 3 is minute or shorter than the outer ramus, telson is deeply cleft. This family is divided into two groups, the Eriopisa group and the Eriopisella group, in the presence or absence of the extraordinarily developed second article of the outer ramus of uropod 3, respectively. The Eriopisa group includes nine genera (Lowry & Myers, 2013) of which genus *Victoriopisa* was erected by Karaman and Barnard, 1979. The taxonomic studies in Indian amphipods by Chilton (1921) was remarkable in the history of genus *Victoriopisa* as his description of the first species of genus as *Niphargus chilkensis* from Chilka Lake of India, later Schellenberg (1930) reassigned it to the genus *Eriopisa* Stebbing, 1890 and currently under the genus *Victoriopisa* Karaman and Barnard, 1979 *Victoriopisa* have 13 species so far described and the new species forms the 14 th and a major share from Asian continent (9 species including new species). This genus exhibit wide habitat preference that ranges from brackish to coastal marine environment, which includes sea grass beds (*V. tinggiensis* Lim *et al*., 2010), algal mats (*V. bruneiensis* Hossain & Hughes, 2016), sandy-muddy-tidal flats (*V. wadai* Ariyama, 2015), rock pools (*V. papiae* Asari, 1983), brackish water lagoons (V. chilkensis Chilton, 1921; V. guanarocana Ortiz & Lalana, 1989), sand flats (*V. atlantica* Stock and Platvoet, 1981), soft-bottom subtidal sediments (*V. bantenensis* Arfianti & Wongkamhaeng, 2017) and other coastal marine habitats (*V. marina* Lowry & Springthorpe, 2005 and *V. australiensis* Chilton, 1923). However, *V. multiartus* (Zhao *et al*., 2016) of China, *V. ryukyuensis* (Morino, 1991) of Japan and present specimen *V. cusatensis* sp. nov. of India were inhabiting in complex mangrove habitats.

Pioneering works in Indian amphipod taxonomy were carried out by Giles (1888, 1890), Chilton (1921), Tattershall (1923, 1925) and Barnard (1935). Later Pillai (1937), Nayar (1959, 1965), Sivaprakasam (1967-1970, 1972, 1977), Rabindranath (1971 a, b, c, 1972 a,b,1974, 1975), Rao (1972) gave detailed description on amphipods from Indian waters. Giles (1888) in his notes on the Amphipoda of Indian waters described two caprellid species, later he identified 27 species and described new species of *Grandidierella megnae*. Chilton in 1921 published a volume on fauna of Chilka Lake in Memoirs of Indian museum with special emphasis on amphipods. He was able to identify 17 species of which three species (*Idunella chilkensis, Niphargus chilkensis* and *Grandidierella gilesi*) were new to science. Later Tattersall (1923, 1925) published his valuable findings of Indian amphipods. Barnard (1935) re-examined the specimens described from Indian waters and also from regions of Cochin, Vembanad, Vishakapatanam, Tuticorin and Calcutta and identified seven new species of amphipod and an isopod and a tanaid. The new species of amphipod (newly accepted and synonymised name in parenthesis) were *Paracalliope indica* (*Indocalliope indica*), *Parorchestia notabilis* (*Cochinorchestia notabilis*), *Parhyalella indica* (*Exhyalella indica*),*Photis digitata* (*Dodophotis digitata*), *Photis geniculata* (*Cheiriphotis geniculata*) isopod *Xenanthura orientalis* and *Apsuedes gymnophobia* (*Pagurapseudopsis gymnophobia*). He also made an attempt to sort out species of *Grandidierella* in concurrence with Zoological Survey of India. Nayar (1959, 1965) dealt with the amphipods of the Madras coast and Gulf of Mannar. Sivaprakasam (1967, 1968 a,b,c; 1969a,b,c; 1970 a,b,c; 1972, 1977) contributed to our knowledge of the amphipods from east coast of India and also identified caprellids (skeleton shrimps) from Kerala coast and Tamil Nadu coast. He described new species of *Idunella demersalis* from Kerala coast and *Atylus (Kamehatylus) processicer* from Gulf of Mannar.

Rabindranath studied amphipods from west coast of India mainly from Kerala. He described species belonging to Haustoriidae family of which *Urothoe platydactyla* was new to science (Rabindranath,1971a).Same year he identified new species of *Listriella similis* (*Idunella similis*) under Liljiborgiidae family from Kerala (Rabindranath,1971b). He also identified species belonging to Ampeliscidae family (Rabindranath,1975), Amphilochidae family (Rabindranath,1972a) of which two were new species *Amphilochus tropicus* and *Gitanopsis subpusilla* and Ampithoidae family (Rabindranath,1972b) of which three of them were new to science *Ampithoe serraticauda, Ampithoe (Pleonexes) auriculata* and *Cymadusa imbroglio* collected from Gulf of Mannar and Kollam. Surya Rao (1972) gave a checklist of 132 species pertaining to 54 genera of Gammarid amphipods of the intertidal regions of the Indian coasts. Asari and Myers (1982) made taxonomic studies on the genus *Grandidierella* and redescribed five species from India, furthermore Asari (1983) described two new species of amphipods from Andamans, *Victoriopisa.papiae* and *Quadrivisio lobata*. Shyamasundari (1972) studied the fouling amphipods *Americorophium triaenonyx* of Vishakapatanam harbour. Lyla *et al*., (1998) described the amphipods of Parangipettai coast and identified new species *Natarajphotis manieni.*

Contributions of Pillai (1966), Nair and Anger (1979) and Nair *et al*.(1983) are remarkable in taxonomy and ecology of amphipods from Cochin backwaters and reported that the more important species noticed were *Corophium triaenonyx, Photis longicaudata , Perioculodes longimanus, Eriopisa chilkensis. Grandidierella* sp. and *Hyperia* sp. Geetha and Bijoy Nandan (2014) have identified six species of amphipods while Asha (2017) identified 4 species from Cochin estuary. Jayachandran (2017) identified 9 species from Kodungalloor –Azhikode estuary.

Generally studies pertaining to amphipods in mangrove ecosystem are limited not only due to difficulty in sampling strategies, but also due to ambiguites in identification of these structural and taxonomic diverse taxa. Satheeshkumar (2011) identified seven amphipods crustaceans from Pondicherry mangroves,that comprised of *Eriopsia chilkensis, Eriopisella sp., Melita dentada, Grandidierella bonnieroides, G.pathyi, Cymadusa pathyi* and *Isaei montagui*. Sunil Kumar (1993) identified only two amphipods from Cochin mangroves (*Gammarus* sp. and *Corophium triaenonyx*).

Saravanakumar (2007) recorded only *Eriopisa* species from Gulf of Kachchh mangroves. Thilagavathi (2013) reported 55 species from mangrove ecosystems of Tamil Nadu.

6.2 Results

6.2.1 Taxonomic description of amphipod species

A total of 9 species of Amphipods were identified from Cochin Mangroves belonging to 6 families, of these 8 species, that were previously described from Indian waters and one was new to science. Family Eriopisidae has 3 species- *Victoriopisa chilkensis*, *Victoriopisa cusatensis* sp.nov and *Eriopisella* sp., while Corophiidae has 2 species such as *Cheiriphotis geniculata* and *Americorophium triaenonyx,* family Aoridae includes only *Grandidierella megnae*, Liljeborgiidae only *Idunella* sp., Talitridae with *Floresorchestia* sp and Amphilochidae with *Amphilochus* sp. [Figure 6.2]

1) *Idunella* sp. Sars, 1894

Order: Amphipoda
Suborder: Amphilochidea
Family: Liljeborgiidae
Genus: *Idunella*

Taxonomic description

- Ornamentation can be seen throughout the body
- Antenna 1 is smaller than antenna 2, accessory flagellum biarticulate.
- Gnathopod 1 is larger than gnathopod 2.
- Sexual dimorphism seen in gnathopod
- Pereopods 6 and 7 longer
- Uropods 1 and 2 with apical robust setae
- Uropod 3 with smaller inner rami and broader leaf like outer rami.
- Telson cleft and laminar

2) *Amphilochus* sp. Spence Bate, 1862

Order: Amphipoda
Suborder: Amphilochidea
Family: Amphilochidae
Genus: *Amphilochus*

Taxonomic description

- Large eyes with dorsoventrally flattened body.
- Antenna 2 peduncle with brush setae
- Maxilliped palps well-developed,mandible incisors dentate
- Coxae 4 is larger and prominent
- Gnathopod 2 broad, transverse, larger than gnathopod 1, carpus subequal to propodus.
- Gnathopod 1 simple or subchelate, carpus with an anterio-distal lobe reaching half of propodus
- Uropod 2 smaller, uropod 3 inner ramus slightly longer than the outer ramus

3) *Floresorchestia* sp. Bousfield, 1984

Order: Amphipoda

Suborder: Senticaudata

Family:Talitridae

Genus: *Floresorchestia*

Taxonomic description

- Larger eyes
- Antenna 1 small and antenna 2 slender
- Maxilliped palp article 4 reduced
- Gnathopod 2 subchelate, cuspidactylate
- Characterised by autapomorphic stridulating organ in epimera 2 and 3
- Uropod 1 outer ramus with a row of 3-4 robust setae
- Telson apically incised.

4) *Grandidierella megnae* Giles, 1890

Order: Amphipoda

Suborder: Senticaudata

Family: Aoridae

Genus: *Grandidierella*

Taxonomic description

- Ventral spine in pereon segment 1 and 2.
- Gnathopod 1 is larger than gnathopod 2.
- A strong apical spine on the carpus of gnathopod1 and a small spine in palm.
- Sexual dimorphism seen in gnathopod
- Coxae 1 of gnathopod 1 and coxae 2 of gnathopod 2 are widely placed.

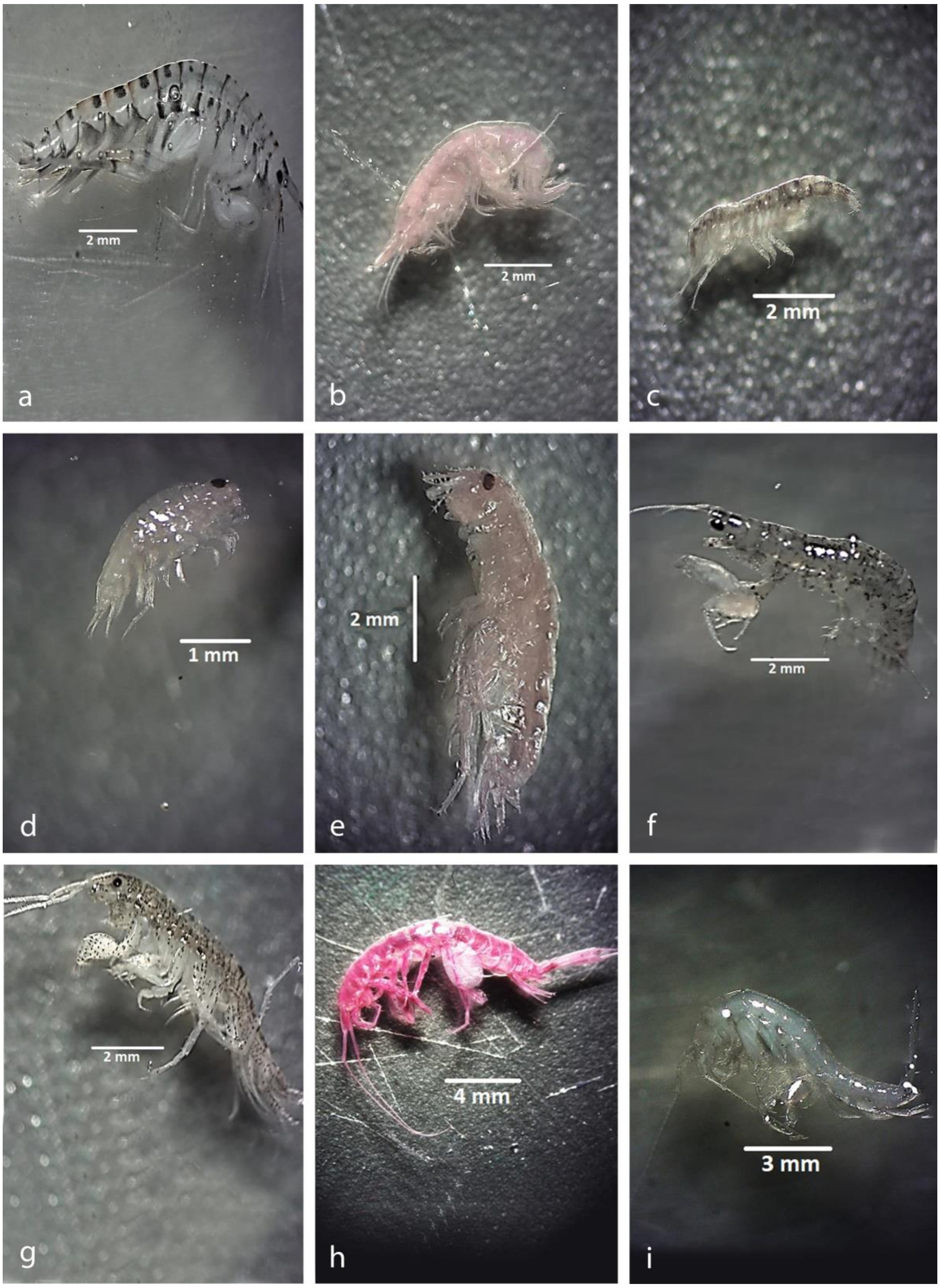

Figure 6.2 Amphipods identified from Cochin mangroves during 2010-2012 period a) Idunella sp. b) Eriopisella sp. c) Americorophium triaenonyx d) Amphilochus sp. e) Floresorchestia sp. f) Cheiriphotis geniculata g) Grandidierella megnae h) Victoriopisa chilkensis i) Victoriopisa cusatensis

5) *Americorophium triaenonyx* Stebbing, 1904

Order: Amphipoda
Suborder: Senticaudata
Family: Corophiidae
Genus: *Americorophium*

Taxonomic description

- Large prominent second antenna
- Head with a triangular rostrum
- Gnathopod 2 dactylus with 3 spines(tridentate), carpus highly setose
- Uropod 1 peduncle outer margin with 10 to 12 spines, uropod 2 peduncle with 3 to 5 dorsal spines
- Telson broad, round

6) *Cheiriphotis geniculata* Barnard, 1916

Order: Amphipoda
Suborder: Senticaudata
Family: Corophiidae
Genus: *Cheiriphotis*

Taxonomic description

- Ocular lobe well developed with large protruded eyes
- Antenna 2 longcr, stouter than antenna 1, flagellum 7-jointed,
- Sexual dimorphism seen in gnathopod
- Gnathopod 2 of male large and prominent while simple in female.
- Gnathopod 2 in male with spine at apex of palm and a small spine in middle
- Dactylus of pereopod 7 is curved
- Coxa 1 largest

7) *Eriopisella* sp. Chevreux, 1920

Order: Amphipoda
Suborder: Senticaudata
Family: Eriopisidae
Genus: *Eriopisella*

Taxonomic description

- Antenna 2 flagellum not fused
- Accessory flagellum uniarticulate
- Maxilla 1 innerplate with 2 or 3 setae apically
- Maxilla 2 lacks oblique row of setae.

- Uropod 3 outer rami second article is very small.
- Inner rami scale like

8) *Victoriopisa chilkensis* Chilton, 1921

Order: Amphipoda
Suborder: Senticaudata
Family: Eriopisidae
Genus: *Victoriopisa*

Taxonomic description

- Maxilla 1 with triangular inner plate
- Maxilla 2 inner plate has oblique rows of 8 setae
- Inner plate of maxilla 1 triangular with 10 setae
- Gnathopod 2 with1 excavation and 1 prominence in propodus
- Dactylus of gnathopod 2 with a prominence
- Uropod 3 - outer rami with 2 articles and inner rami scale
- Telson with 1 apical spine and no lateral spine

9) *Victoriopisa cusatensis* sp.nov

Order: Amphipoda
Suborder: Senticaudata
Family: Eriopisidae
Genus: *Victoriopisa*

6.2.2 Morpho-taxonomy of a new species *Victoriopisa cusatensis*

Etymology-The species name ‘cusatensis’ refers to Cochin University of Science and Technology (CUSAT), a premium institution in India considering its contribution in the field of Marine Sciences.

Habitat- Brackish, mangrove fringed area of Valanthakad Island in Vembanad backwater, Kochi, Kerala, 9°55’10.24” N and 76°20’ 01.23”.

Material examined- Holotype: male 8.6 mm, Paratypes: 1 male 8.4 mm; 2 females (7.6 mm, 6.7mm) [Figure 6.3; 6.4; 6.5; 6.6; 6.7; 6.8 and 6.9]. Taxonomic and morphological study based on standard literature (Chapman, 2007) and monographs. Holotype specimen along with paratypes was submitted to Zoological Survey of India (ZSI), Kolkata. The following abbreviations are used on the figures: A, antenna; AF, accessory flagellum; D, dactylus; EP, epimera; G, gnathopod; H, head;

I, inner lobe; LL, lower lip; MD, mandible; MP, maxilliped; MX, maxilla; O, outer lobe; P, pereopod; PA, palp; PL, pleopod; T, telson; U, uropod; UL, upper lip; R, right; L, left; ♂, male habitus; ♀, female habitus.

Diagnosis- Body slender, laterally compressed. Head with eyes and lateral cephalic lobe. Antenna 1 large with expanded peduncle article 1, larger than head; peduncle article 2 seems to be projected dorsolaterally; accessory flagellum 2-articulate, not reaching the first flagellar article. Gnathopod 2 palm smooth. Epimeral plates with posteroventral tooth. Pereopod 7 basis and merus largely expanded. Pleopods with more than 20 articles in outer rami. Urosomites separate; Uropod 3, outer rami 2-articulate, inner rami scale like. Telson with one subapical spine and two lateral spines on each lobe.

Description of male (Holotype, 8.6mm)

Head. Eyes small, rounded; lateral cephalic lobe large and triangular, anteroventral sinus indistinct. Antenna 1 half times body length; peduncular articles length ratio from 1-3 is 1.0:0.6:0.2; peduncular article 1 well developed, without setae along posterior margin, 14 transverse ridges in posteroproximal angle; peduncular article 2 geniculate, dorsolateral margin seems to be projected; primary flagellum with 33 articles on right and 30 articles on left with distal setae, aesthetasc begins from article 8; accessory flagellum with 2 articles shorter than article 1 of primary flagellum. Antenna 2 shorter, about a third length of antenna 1; peduncular article 2 cone gland not reaching the end of peduncular article 3, peduncular article 4 and 5 subequal (1.8:1.7); flagellum highly setose, with two fused long articles and three short articles. Upper lip wider than deep and semicircular with row of fine setae. Lower lip inner lobes well-developed; outer lobes with apical setae. Mandible palp 3-articulate with length ratio 1:3.7:3.1, article 3 shorter than article 2; left incisors with 6 teeth and right with 5 teeth; lacinia mobilis with 4 teeth on both side; accessory setal row with 10 serrated setae; molar large and triturative. Maxilla 1 inner plate rectangular, with 6 plumose setae on left maxilla and 5 on right; outer plate with 9 serrated apical spines; palp 2- articulate, left palp article 2 with 2 stout spines, 4–5 robust setae and 5 simple setae on apical margin, right palp with 8 robust setae and 5 simple setae. Maxilla 2 inner plate armed with 7 plumose setae in oblique row and simple setae on apical margin. Maxilliped inner plate with 3 stout apical spines on right maxilliped and 4 on left, 6 robust setae on apical margin and few sub apical plumose setae; outer plate with 6 robust setae and many simple setae on apical and lateral margin; palp 4-articulate, article 2 long, highly setose on lateral margin, article 3 with many long apical setae and three subapical setae, article 4 claw-like with few setae at the dorsoventral margin.

Pereon. Gnathopod 1 coxa anteroventrally produced; basis with 4 setae on posterior margin and 4–5 setae on posterodistal corner; merus with 6–8 simple setae distally; carpus ovoid, highly setose along the posteroventral margin, larger than propodus; propodus palm transverse and broad distally, palm with 4 short spines on posterodistal corner accompanied by 5 simple setae, 10–12 sparse setae along the entire margin; dactylus smooth, curved with 7 sparse setae on inner margin and one simple setae on outer margin. Gnathopod 2 coxa ovoid, convex anteroventrally; basis with 6 long setae along posterior and distal margins respectively; carpus with transverse row of marginal setae; propodus broad, palm smooth with 3 stout spines, 10–12 sparse setae in palmar margin; dactylus closing along palm, inner margin smooth, armed with 14 sparse setae, outer margin with 1 medial seta. Pereopod 3 coxa broad, ovoid; basis with 10 long setae at the posterior margin, fine setae on anterior margin, 5 setae distally; merus slightly enlarged distally; carpus ovoid, subequal to propodus; propodus setose marginally, a robust setae on posterodistal corner; dactylus curved, with a medial setae. Pereopod 4 coxa rectangular; basis linear with 8 long setae at posterior margin, fine setae at anterior margin; merus, carpus, propodus and dactylus similar to pereopod 3. Pereopod 5 short, stout; coxa partially lobate; basis oblong; merus with 2 anterior robust setae and few posterior simple setae; carpus setose, armed with 8–9 robust setae; propodus with 5 robust setae; dactylus simple armed with 2 simple setae at posteroproximal margin and 2 sub-distal setae. Pereopod 6 coxa shallow; basis oblong, with minute castellation; merus and carpus with similar setal armature as that of pereopod 5; propodus with 8 robust setae, 3 at posterior margin, 2 posterodistally and 3 anterodistally. Pereopod 7 coxa small, rectangular; basis broadly expanded, castelloserrate, basilar width ratio of pereopod 5, 6, 7 follows the order 1:1.4:2.4 respectively; merus broadly expanded, anterior margin with 5 robust setae, posterior margin with 3–4 groups of long setae; carpus with 4 robust setae accompanied by simple setae; propodus with 6 robust setae, 4 at posterior margin and 2 distally.

Pleon. Epimera 1–3 with small acute tooth at posteroventral corner, epimera 2 with a row of 8 plumose setae, epimera 3 with 3 small acute spine ventrally. Pleopods peduncle nearly quadrate, with paired retinacula on inner margins and plumose setae on outer margins. Pleopod 1 peduncle with 8 plumose setae, outer rami with 26 articles and inner rami with 18 articles; pleopod 2 peduncle with 6 plumose setae, outer rami with 23 articles and inner rami with 17 articles; pleopod 3 peduncle without plumose setae, outer rami with 23 articles and inner rami with 17 articles. Urosomites not fused, uropod 1 peduncle with 2 robust setae and a spine distally, outer rami subequal to inner rami, outer rami with 3 robust setae in inner margin and 5 robust setae distally; inner rami with 2 robust setae in the inner margin and 5 robust setae distally. Uropod 2 peduncle with 3 robust setae; outer rami smaller, outer and inner rami with 3 robust setae in the inner margin and 5 robust setae distally. Uropod 3 parviramous, inner rami scale like, 0.15 times that of proximal article of outer rami; outer rami much enlarged with 2 articles, longer and broader proximal article and smaller distal article, proximal article with three robust setae on outer margin, 2–3 robust setae and simple setae distally, distal article with fine setae, three on inner and two on outer margins and tuft of long setae apically. Telson deeply cleft, each lobe with one subapical long robust setae and two marginal small robust setae, right apex is tooth like and left apex smooth with simple setae.

Description of female (Paratype, 7.6 mm)

Antenna 1: peduncle article 1 is dilated as in male specimens; article 2, dorso-lateral margin without projection, right flagellum with 20 articles, left flagellum with 18 articles. Maxilla 1: inner plate of first maxilla bears 5 plumose setae on right and left side, palp is similar in both.

Oostegites: long ovoid with simple setae along the margins, present in gnathopod 2 and in pereopods 3, 4 and 5, absent in male.

Gnathopod 2: similar in both sexes, with smooth palmar margin.

Pleopods: peduncle with paired retinacula in inner margin, pleopod 1 peduncle with 8 plumose setae in outer margin, pleopod 2 with 4 plumose setae and pleopod 3 with 1 plumose setae; pleopods 1–3 bears 18 articles in outer rami and 13 articles in inner rami.

Telson: with only two robust setae on either half, one subapically and one laterally.

6.3 Discussion

The coastal wetlands (backwaters) along the Western Ghats are “hot-spots” of biological diversity of the world. The Vembanad-Kol Wetland ecosystem (Ramsar site), lying parallel to Lakshadweep Sea on the westcoast is a highly potential system that has introduced many new species to the world (Subhash Babu and Bijoy Nandan, 2010; Peter *et al*., 2017; Oliver *et al*., 2018). Oliver *et al*. (2016) found taxonomic ambiguities in description of many Indian species. In the case of amphipods since taxonomic diversity was higher there may be chance for misrepresentation of many species. However molecular systematics will enable us to resolve the morpho-taxonomic disparities in the classification and species status.

A corophid *Cheiriphotis geniculata*, one of the most abundant species collected in my sample from mangroves of Cochin was previously under the genus *Photis*. Barnard (1935) described the species *Photis geniculata* as new species collected from Alappuzha, Kerala. In WoRMS,2018 as well as Barnard and Karaman (1991) cited that *C. geniculata* was described in 1916 by K.H. Barnard, but this seems to be mistake as K.H. Barnard (1916) only described *C. durbanensis* (Krapp-Schickel and Myers, 2006). Eventhough it was misidentified the present specimen, and shares all the features as that of Barnard’s *Photis geniculata.* Another corophid *Corophium triaenonyx* synonimised to *Americorophium triaenonyx* is the opportunistic and fouling amphipod (Shyamasundari, 1972) found commonly in

Cochin backwaters (Jayachandran *et al*., 2017). It was described by Stebbing (1904) from Ceylon. Chilton (1921) found same specimen from oyster shells in Chilka Lake. Now it is one of the predominant amphipod in estuaries and backwaters of Kerala due to its salinity tolerance. In mangroves they are comparatively least represented.

In the present study amphipods under genus *Grandidierella* matches with the features described as that of *Grandidierella bonnieri* Stebbing 1908 rather than that of *Grandidierella megnae* Giles 1890 as reported by Barnard in 1935. But as per World Register of Marine Species (WoRMS) *G. bonnieri* has been synonymised and accepted as *Grandidierella megnae* (Barnard, 1955).The morphological variation might be due to different stage of developments of amphipods where there may be slight variation from the mature specimen. Barnard (1935) studied the variations between *Grandidierella* species and proposed, the key for the identification. He collected *G. bonnieri* and *G.gilesi* from Cochin and other areas of Kerala and even described new species of *G.gravipes* from Vembanad Lake. Later Asari and Myers (1982) redescribed the species in the genus *Grandidierella* from Indian waters.

Similarly Talitrid amphipod *Floresorchestia* sp. was previously under genus *Orchestia* and it was the only species (*Orchestia floresiana*) under the genus *Floresorchestia* identified from salt lakes of Lower Bengal and Andaman Islands, India. This genus was characterised by a small stridulatory structures on its epimera 2 and 3 especially in case of males to produce some sounds to attract females (Bousfield, 1984).A similar feature was also observed in my specimen, but sufficient specimens were lacking for further definitive species level identification. *Floresorchestia* species was terrestrial or littoral form and usually seen in mangrove, but its presence was not reported yet after Barnard (1935) in Indian waters.

Idunella species was the most abundant amphipod species from Cochin Mangroves. They belongs to family Liljeborgiidae characterised by smaller endopod (inner rami) than exopod(outer rami). From India, three new species of *Idunella* has been reported.They were *Idunella chilkensis* (Chilton,1921) from Chilka lake, *Idunella demersalis* (Sivaprakasam,1972) from Cochin and *Idunella similis* from Kayamkulam lake, Kerala (Rabindranth, 1971). *Idunella similis* was previously under genus *Listriella* and now reassigned to *Idunella*. But, specimen from the present study do not match with *I. chilkensis* in gnathopod structure but show similarty with *I. demersalis* however species was not confirmed due to certain morphological disparities.

Very few number of *Amphilochus* species were encountered in the present study so it was not possible to study it, at species level and couldn't even compare with the species previously reported from Kerala *Amphilochus tropicus* (Rabindranath, 1971) and from Chika Lake *Amphilochus brunneus* (Chilton, 1921).

Eriopisella sp. was restricted to only one of the study site especially in Vypin region where salinity was higher. This species share features similar to *Victoriopisa* collected during the study. Literature has clarified that both genus comes under family Eriopisidae that includes two groups, Eriopisella group and Eriopisa group. *Eriopisella* sp. of present study comes under Eriopisella group and *Victoriopisa* comes under Eriopisa group even though families were same (Lowry and Myers, 2013). Eriopisella group differentiate from Eriopisa group by extraordinarily well developed second article of the outer ramus of uropod 3 in the Eriopisella group (Lowry and Myers,2013), inner plate of maxilla 1 with 2-3 setae at apex only, inner plate of maxilla 2 narrow and without setae on inner margin (Barnard,1935).

Victoriopisa chilkensis was the first species of genus *Victoriopisa* described from Chilka Lake, India by Chilton (1921).Subsequently *V.papiae* were described from Andamans by Asari, 1983. Chilton referred the species, under genus *Niphargus* later Schellenberg(1930) reassigned them into genus *Eriopisa* and now again reassigned to *Victoriopisa* by Karaman and Barnard(1979). Currently two species of genus *Victoriopisa* was recorded from Vembanad lake, the dominant species *V. chilkensis* and the new species *V. cusatensis* sp. nov. *V.chilkensis* was common in all amphipod collections in Vembanad and was reported as *Eriopisa chilkensis* from several studies even after revision by Karaman and Barnard (1979).

Victoriopisa cusatensis sp. nov differs from the other Indian species: *V. chilkensis* and *V. papiae* in having following characters (features of *V. chilkensis* and *V. papiae* in parentheses): (1) smooth palm of gnathopod 2 (1 excavation and 1 prominence in *V.chilkensis* and 3 prominences in *V. papiae*); (2) smooth dactylus (a prominence in V. *chilkensis* and *V. papiae*); (3) peduncular article 2 of antenna 1 projected dorsolaterally (smooth in *V. chilkensis* and *V. papiae*); (4) inner plate of maxilliped with 3 spine on right and 4 on left (3 in *V. chilkensis* and *V. papiae*); (5) epimeral plate 2 with 8 plumose setae (9 setae in *V. chilkensis*, 10 in *V. papiae*); (6) inner plate of maxilla 1 rectangular with 5 plumose setae on right and 6 on left (triangular with 10 setae in *V. chilkensis*, rectangular with 7 setae in *V. papiae*); (7) telson with 1 apical and 2 lateral spines (1 apical spine and no lateral spines in *V. chilkensis*,1 subapical spine and 2 apical spine in *V. papiae*). Three Indian species were similar in presence of eyes, broader basis and merus of peropod 7, smaller gnathopod 1 compared to gnathopod 2. *Victoriopisa cusatensis* sp. nov. differ from other Asian species in having smooth palm and dactylus of gnathopod 2; while *V. wadai* and *V. multiartus* have excavated palm and smooth dactylus; whereas *V. ryukyuensis* and *V. bruneiensis* have prominences in the palm and excavation on dactylus, *V. tinggiensis* and *V. bantenensis* presents smooth palm and dactylus as the new species, but differs from it by having a deep cephalic notch, *V. cusatensis* sp.nov. also differs from *V. atlantica, V. australiensis, V. guanarocana, V. epistomata*, *V. marina*, by the presence of eyes.

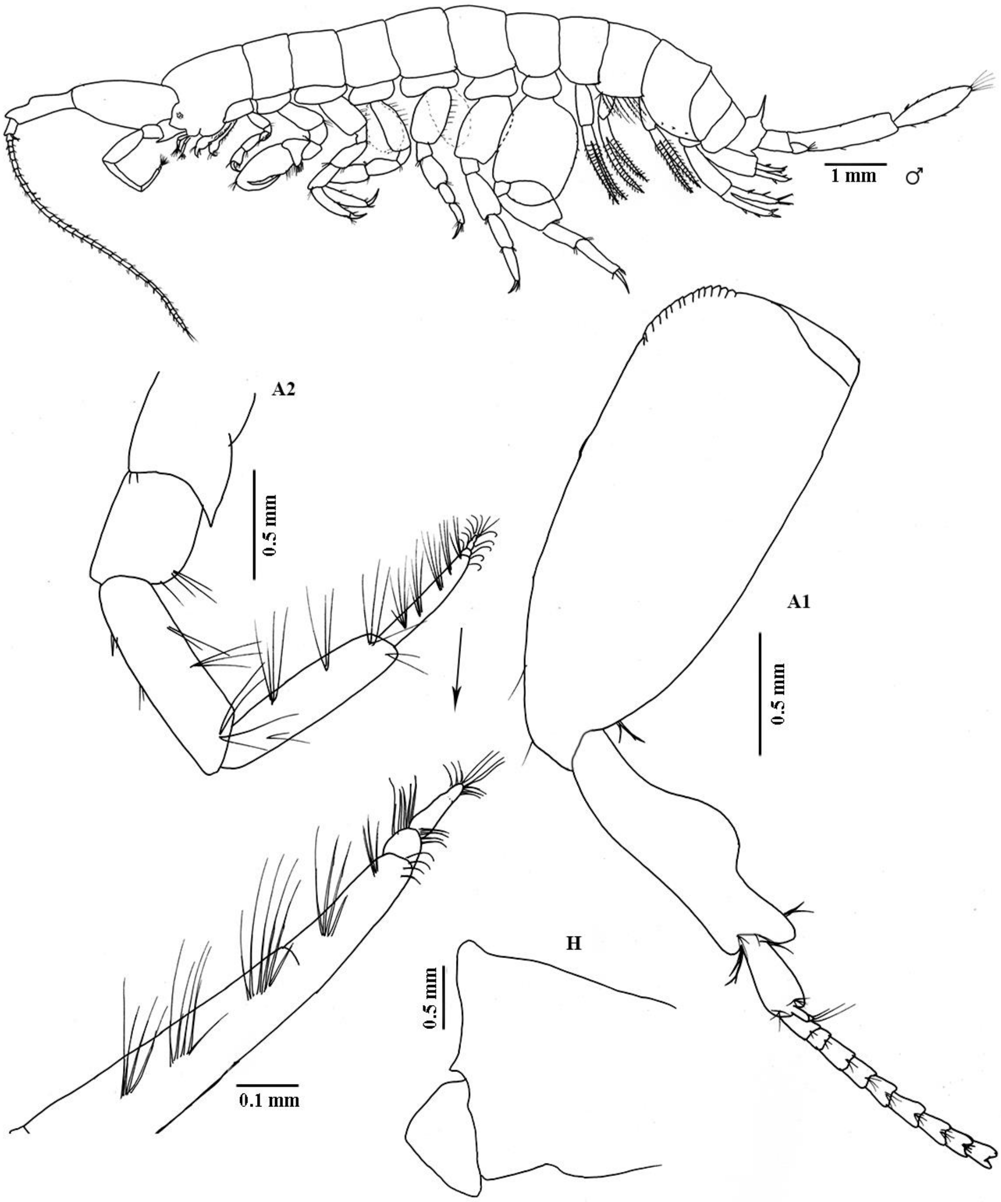

Figure 6.3 *Victoriopisa cusatensis* sp. nov., holotype, male habitus (8.6 mm), scales: habitus male (♂), 1 mm; A1, A2, H, 0.5 mm [A1-antenna 1, A2-antenna 2, H-head].

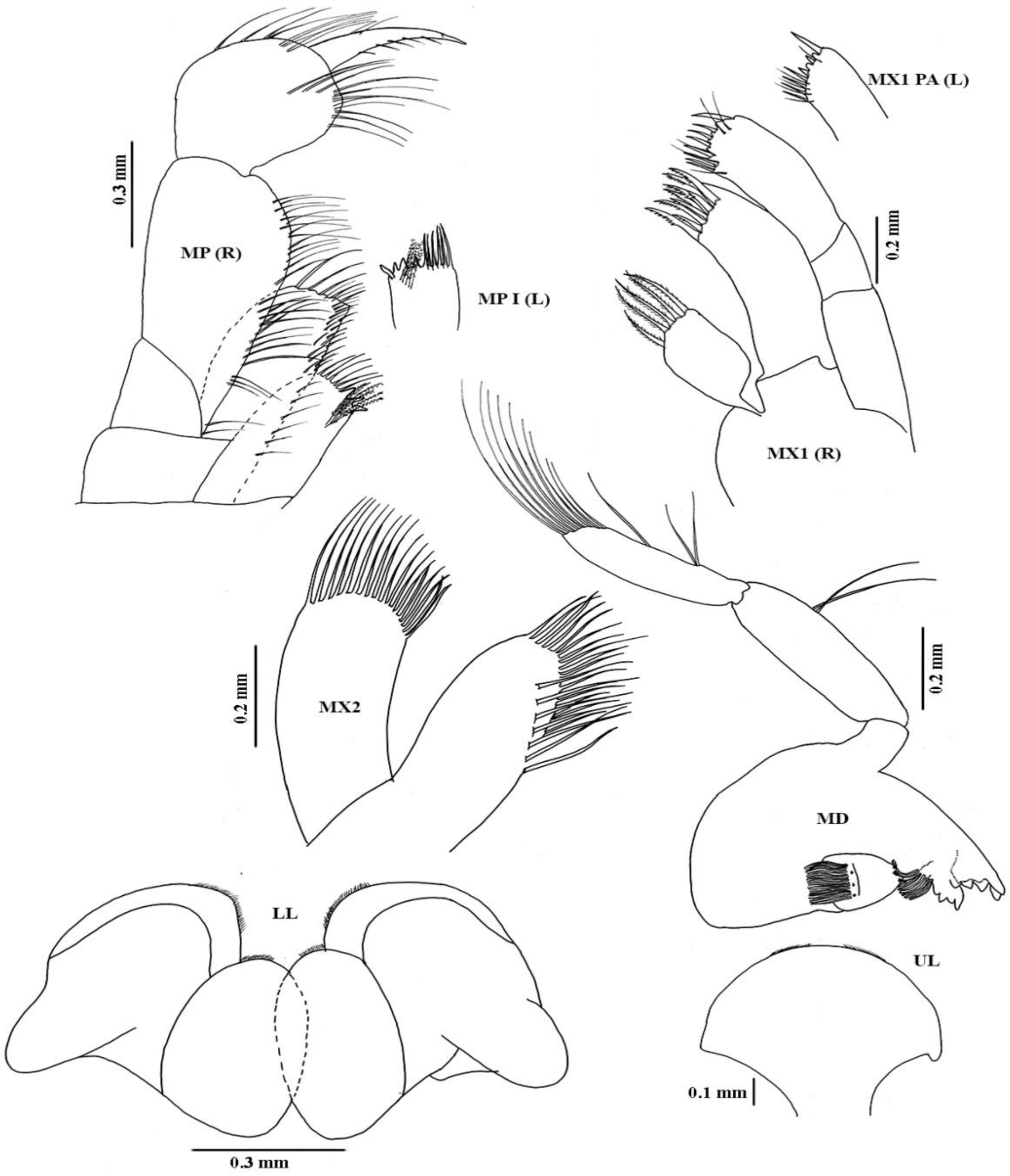

Figure 6.4 *Victoriopisa cusatensis* sp. nov., holotype, male habitus (8.6 mm), Mouth parts scales: MP, LL, 0.3mm; MX1, MX2, MD, 0.2mm; UL, 0.1mm [MP-maxilliped, MX1-maxilla 1, MX2-maxilla 2, MD-mandible, LL-lower lip, UP-upper lip]

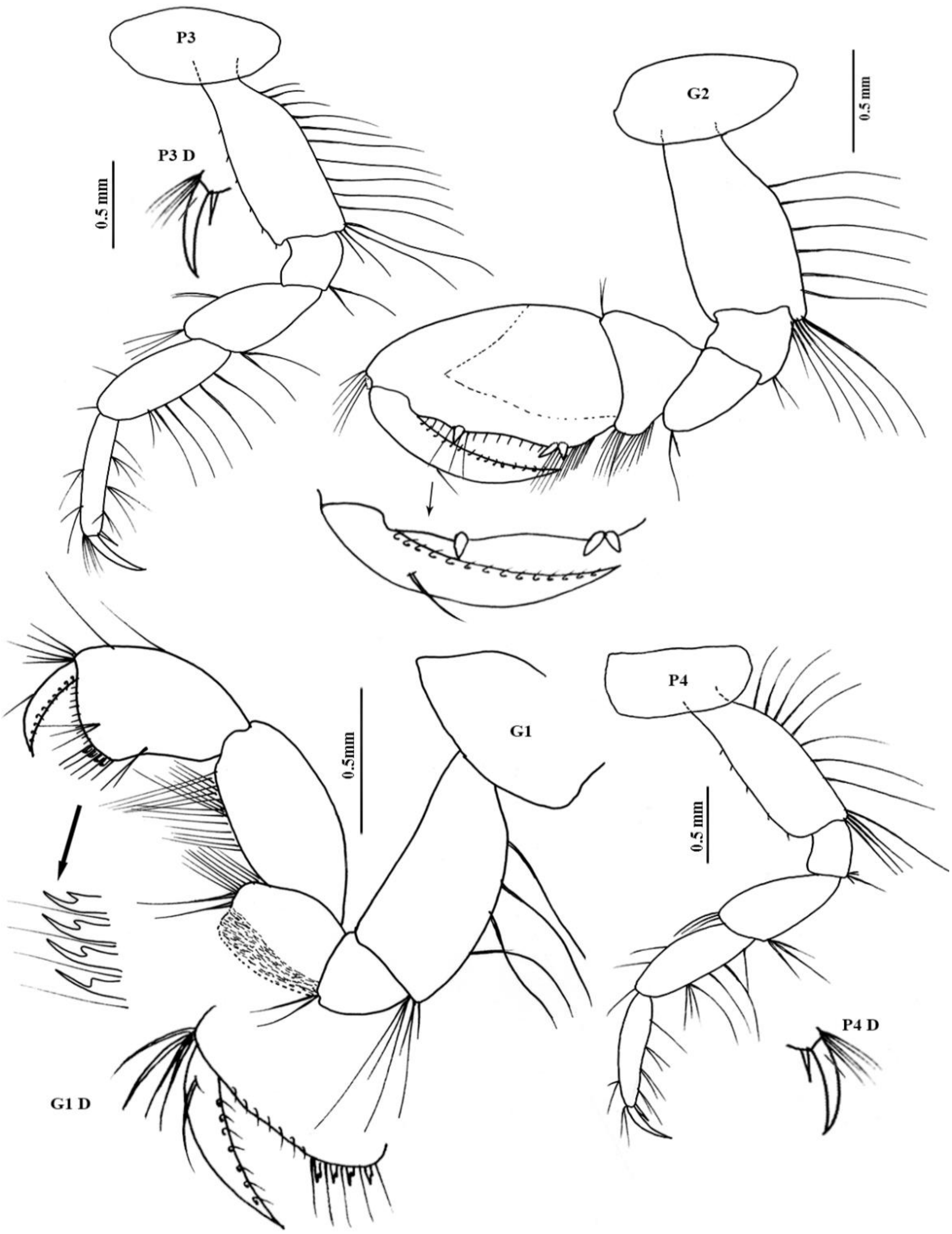

Figure 6.5 *Victoriopisa cusatensis* sp.nov., holotype, male habitus (8.6 mm), all scales: 0.5 mm [G1-gnathopod 1, G2-gnathopod 2, P3-pereopod 3, P4- pereopod 4]

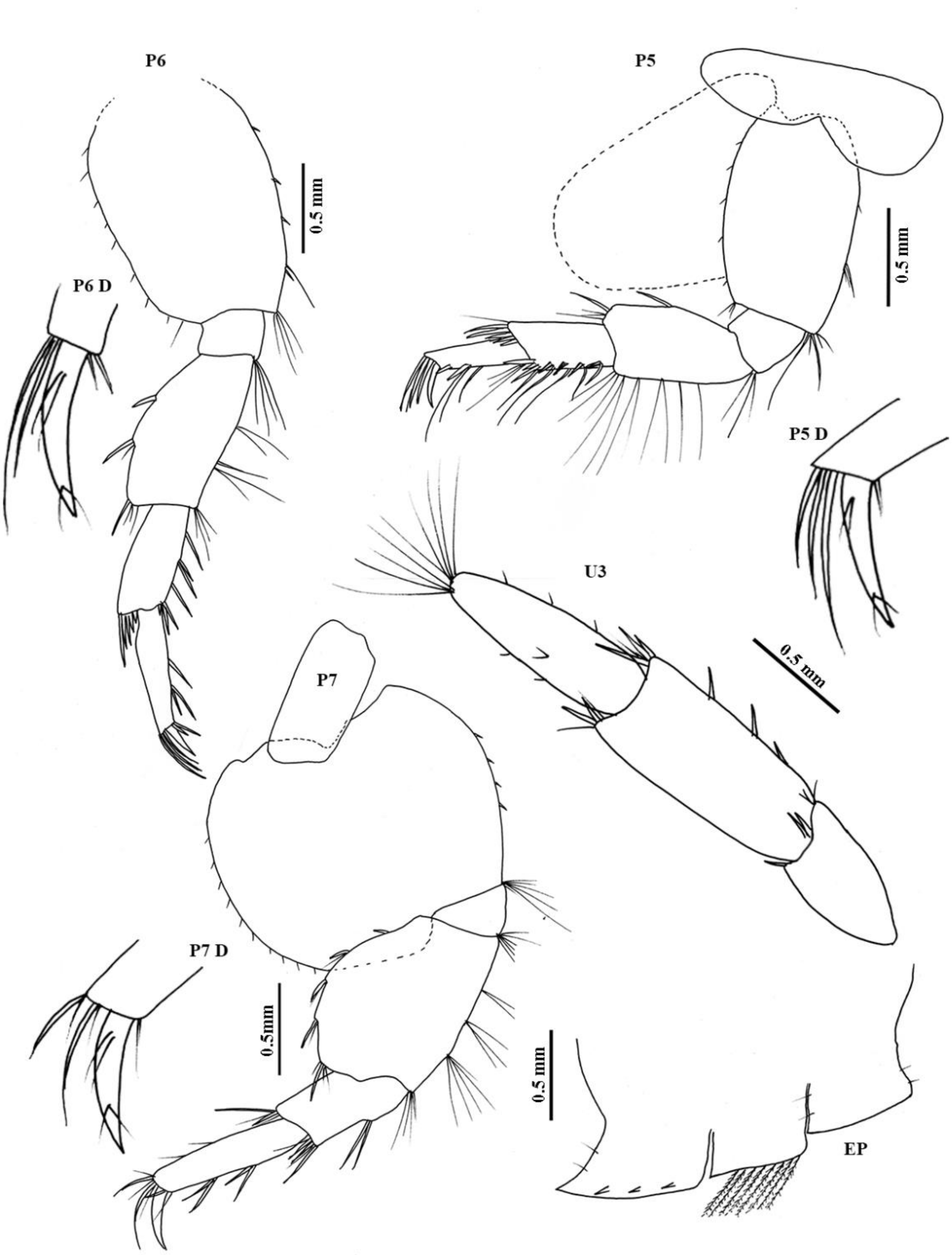

Figure 6.6 *Victoriopisa cusatensis* sp.nov., holotype, male habitus (8.6 mm), all scales:0.5 mm [P5-pereopod 5, P6-pereopod 6, P7- pereopod 7, U3-Uropod 3, EP-Epimera]

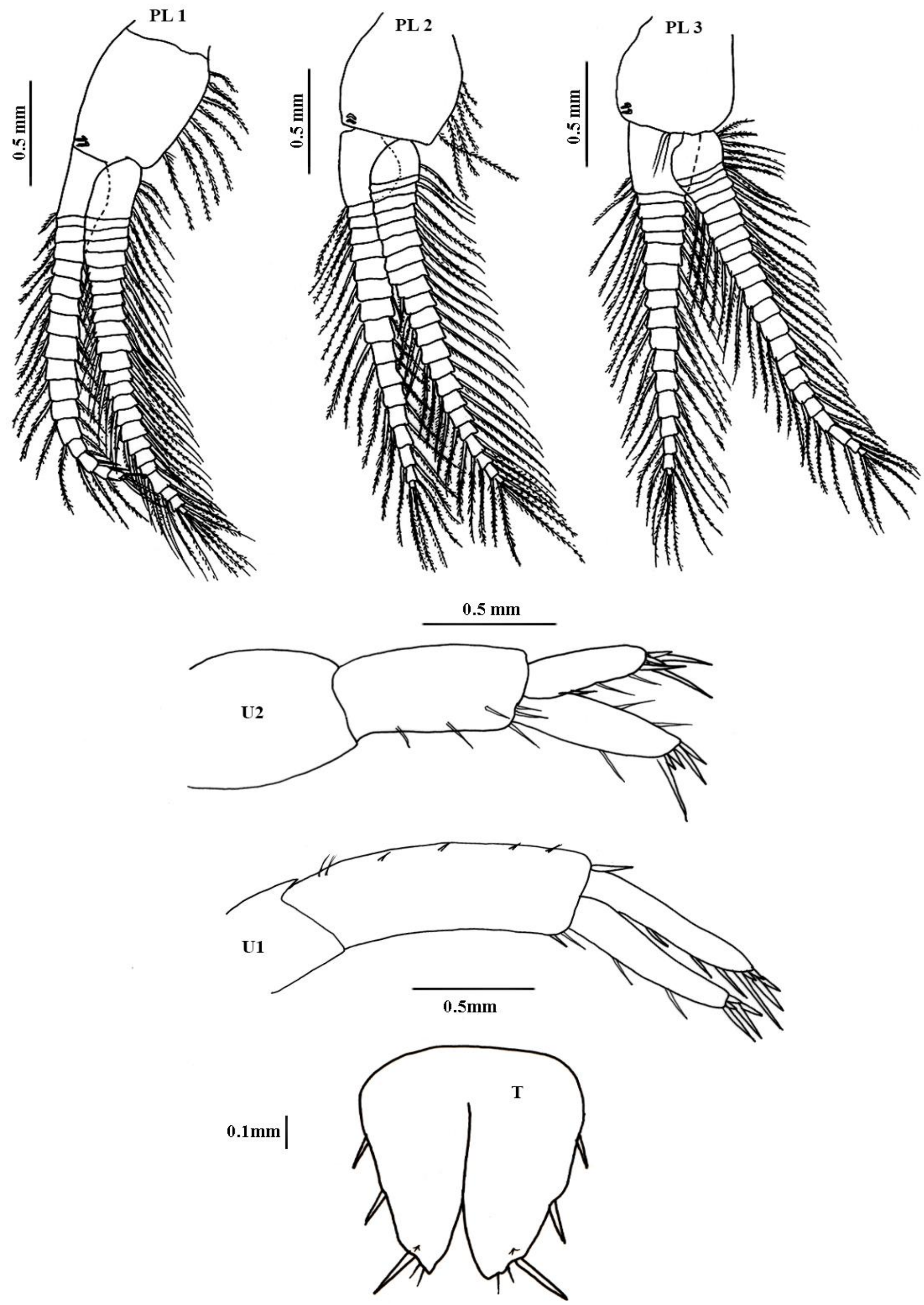

Figure 6.7 *Victoriopisa cusatensis* sp. nov., holotype, male habitus (8.6 mm scales: PL1,PL2,PL3,U1,U2, 0.5mm; T, 0.1mm [PL1-pleopod 1, PL2-pleopod 2, PL3-pleopod 3, U1-uropod 1, U2-uropod 2, T-telson]

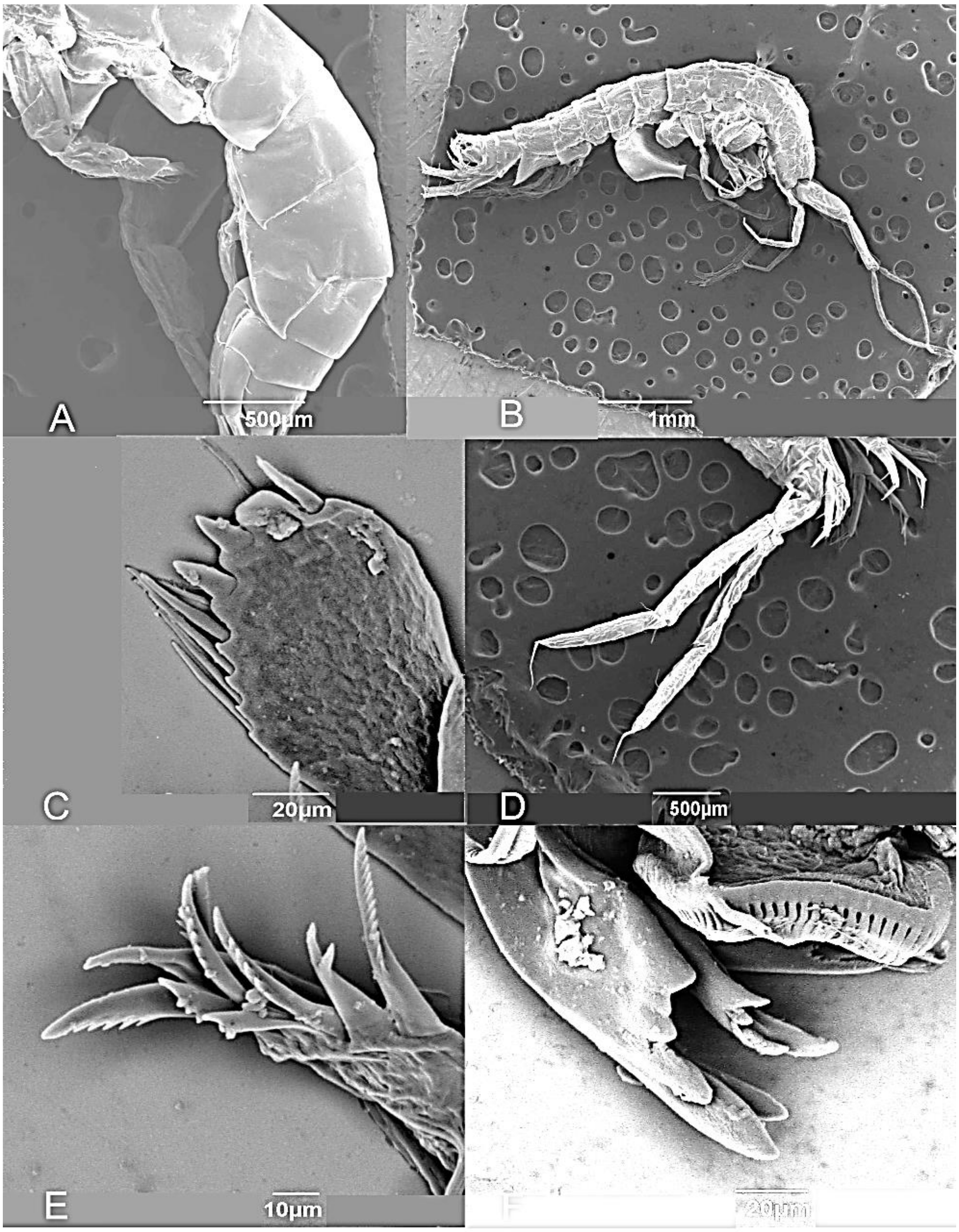

Figure 6.8 *Victoriopisa cusatensis* sp. nov., SEM images, male habitus (8.4 mm), female habitus,♀(6.7mm), scales: habitus female (♀), 1 mm; EP, U3, 500µm; MX1 PA, MD, 20 µm; MX1 O, 10 µm.

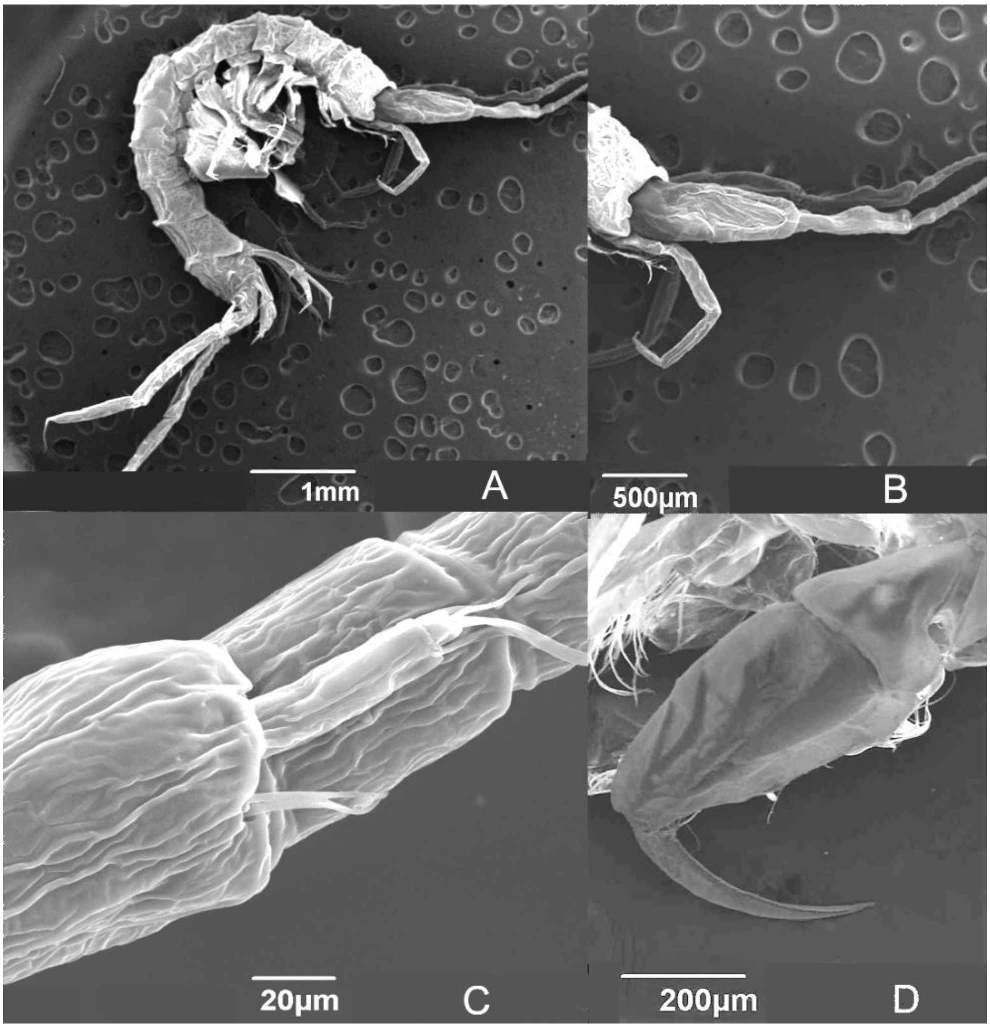

Figure 6.9 *Victoriopisa cusatensis* sp. nov., SEM images, male habitus (8.4 mm), Scales : habitus male (♂), 1mm; A1, 500μm; AF, 20 μm; G2, 200 μm.

Chapter 7

HEAVY METAL DISTRIBUTION, ENRICHMENT IN MANGROVE SEDIMENTS AND THEIR BIOACCUMULATION IN MACROFAUNA

7.1 Introduction

From prehistoric times, the coastal areas are of prime centres of India's heritage and thriving trade between the Mediterranean worlds (Landstrom, 1964). Human's eagerness to improve the standard of living with respect to production of food, energy and other requirements has led to the introduction of hazardous, non-degradable, chemical pollutants to our water bodies. These pollutants get enriched in bed sediments and accumulate over time. Heavy metals are one such persistent, non-degradable, chemical pollutant having densities higher than 5 g cm^{-3} (Jarup, 2003). Approximately 91 out of the 118 occurring elements are metals and exact number is debatable, and many of these, such as Fe, Cu, Co, Ni, Mn, and Zn are essential micronutrients and their deficiency leads to clinical abnormalities, but can become toxic at higher doses. Other heavy metals, such as Cd, Hg, Ag and Pb have no known function in living organisms, and are toxic even at mild concentrations (Caussy, 2003; Baird and Cann, 2012). Heavy metals said to have a natural origin from earth's crust. Their environmental release might be attributed to natural events such as weathering of rocks, volcanic activity and erosion or by anthropogenic activities such as mining, smelting, industrial uses, urbanisation, application of fertilizers, pesticides, fossil fuel combustion etc. (Shibu, 1992). Once released these pollutants find their way to aquatic ecosystems. Due to the physical adsorption and chemical bonds that occur between the metals and sediment, sediments often remain as a sink or source of metals (Giere, 1993). In elevated concentrations these metals impart adverse environmental impacts, including acute or chronic toxicity, sublethal behavioural or mutagenic changes, changes in the density, diversity or taxonomic composition of aquatic fauna or by bioaccumulation in their tissues causing health risk to higher predators and for human consumers (Mac Donald *et al*., 2000).

Rise in industrialisation, urbanisation, population pressure and unmanageable anthropogenic actions have declined the tropical vegetative mangrove habitats. The nature's response in the form of tsunamis, hurricanes, flood and storm has necessitated coastal communities to protect mangroves for their sustenance and scientific communities to study the geomorphology and sediment quality status of these fragile ecosystems for the near future. Tropical habitats were evaluated for metal pollution World-wide. Studies in Hong Kong mangroves (Tam and Wong, 1995; 1996; 2000; Ong Che,1999; Tam and Yao,1999), mangroves of China (Zhou *et al*., 2010; Deng *et al*., 2015; Feng *et al*., 2017), Brazilian mangroves (Miola *et al*., 2016; Machado, 2002; Silva *et al*., 2003; Harris and Santos, 2000.); Panama mangroves (Defew *et al*., 2005), Australian mangroves (MacFarlane and Burchett, 2002; Preda and Cox, 2002), Carribean mangroves (Ellison and Fansworth, 1996), New Zealand mangroves (Mac Farlane, 2003), Tanzanian mangroves (Mremi and Machiwa, 2003), Malaysian mangroves (Yunus *et al*., 2011) recorded polluted status, however Australian mangroves, Brazilian mangroves and Hong Kong mangroves were deemed unpolluted and "clean" mangrove (Preda and Cox, 2002; Tam and Wong,2000; Harris and Santos, 2000).

Indian mangrove forests such as Pichavaram (Ramanathan *et al*., 1999; Ranjan *et al*., 2008), and Muthupet mangroves (Ashokkumar, 2006) of Tamil Nadu, Mandovi mangroves of Goa (Attri and Kerkar, 2011), Godavari mangroves in Andhra Pradesh (Ray *et al*., 2006), Bhitarkanika mangroves of Orissa (Saranghi *et al*., 2002), Sunderbans of West Bengal (Chowdhury *et al*., 2017; Kader and Sinha, 2018), Pondicherry mangroves (Satheeshkumar & Senthilkumar, 2011), Thane creek, Mumbai (Fernandez *et al*., 2012) were found to be polluted by metals.

Kerala mangroves were extensively studied by Badarudeen (1997) on Kannur, Thiruvananthapurm (Veli) and Cochin mangroves, while Thomas and

Fernandez (1997) on Kottayam (Kumarakom), Kollam and Thiruvananthapuram (Veli) mangroves and Sarika and Chandramohanakumar (2008) on Thrissur (Chettuva), Kollam (Ayiramthengu), Ernakulam (Nettoor, Mangalavanam, Vypin) and reported pollution of mangroves due to heavy metals such as cadmium, copper etc. Ratheesh Kumar *et al*. (2010) compared Cochin mangroves with Cochin estuary and reported severe enrichment and pollution of cadmium, lead and zinc in estuaries however unpolluted to moderately polluted status of mangroves by anthropogenic activities. The severe polluted status of Cochin estuary was attributed to industrial discharges (Anu *et al*., 2014; Martin *et al*., 2012; Salas *et al*., 2017 ; Ciji and Bijoy Nandan, 2014; Selvam *et al*., 2012; Deepulal *et al*., 2012). A comprehensive assessment carried out by Central Pollution Control Board (CPCB) in association with Indian Institute of Technology (IIT), ranked Cochin as the 24th among the critically polluted areas (CPA) in India with a Comprehensive Environmental Pollution Index (CEPI) of 75.08. Out of the 83 red category industries in Cochin, 95% fall within the Eloor- Edayar area, largest industrial belt in Kerala along the Cochin estuarine coast (Kerala State Pollution Control Board, KSPCB, 2010) which was considered a toxic hotspot by Greenpeace (2003). Other than industrial sources, Cochin estuary and the adjoining coast receives municipal solid wastes, biomedical wastes, e-wastes and domestic wastes which find their way to the estuary and mangrove zones (Central Pollution Control Board, CPCB, 1996). The Cochin shipping port activities and dredging activities discharge large quantities of stratified metals to estuary. The persistent stress imposed by increasing heavy metal contamination in Cochin estuarine-mangrove system has affected the biotic entities resulted in about 40% depletion in mangrove vegetation (Sateeshkumar *et al*., 2011) along with gradual shift in benthic community structure (Saraladevi and Venugopal, 1989).

Even though, heavy metal contamination in Cochin estuary and adjoining areas has been reported, the mangrove habitats have not been comprehensively evaluated for decades, over and above bioaccumulation and trophic transfer of heavy metal contaminants are affecting in an ecological fall out on the biota and the humans. Off late, in India health cases pertaining to physical, muscular, and neurological degenerative diseases that resemble Alzheimer's, Parkinson's disease, muscular dystrophy, multiple sclerosis and renal diseases are on a rise that attribute to metallic pollution. Hence it is imperative to study the sediment quality, pollution status and probable bioaccumulation on benthic fauna to devise long-term management and conservation plans of the ecologically significant mangrove forests with a focus on sustainable livelihood.

7.1.1 Mangrove sediments –The sink and source of heavy metals

Tropical mangrove forests act as biogeochemical barriers or natural filters between Land- Sea interphase retaining various organic and inorganic pollutants. Their dynamic physico-chemical and biogeochemical properties such as anoxic, highly reduced, sulphidic and organic rich sediment makes it an efficient medium to trap the pollutants (Lacerda *et al*., 1998; Tam and Wong, 2000). Among the various pollutants reaching the mangrove, heavy metals pose higher risk to mangrove habitat (Chai *et al*., 2015) due to their bio-accumulative properties, severe toxicity and non-biodegradability (MacFarlane and Burchett, 2002). Concentration of heavy metals in sediments usually exceed twice the magnitude than those of the overlying water. From the sediment-water interface, metals can be transferred into mangrove plants (MacFarlane *et al*., 2003) and benthic organisms (Saha *et al*., 2006). Subsequently, they are accumulated into higher trophic levels of animals in the food webs (Jara-Marini *et al*., 2009). Therefore, the mangrove sediments may shift from sink to source of trace elements in the coastal waters (Harbison, 1986).

There are several dynamic factors responsible for metal retension, adsorption and transport within the mangrove ecosystem and to the neighbouring coastal zone. Mangrove plants exhibit differential accumulation of metals that depends on their structural attributes, complexity of roots, and their litter biomass, that bind and retain metals in the sediment (Marchand *et al*., 2006). These metals were then translocated from roots to stem, then to leaf thus reducing metal mobilisation to water column. The mangrove litter, algae, microbial mats and suspended matter contributes to organic carbon in mangrove sediment (Wooller *et al*., 2003; Kristensen, 2008). This organic rich mangrove detritus bind the metals in fine sediment. The humic acids, a major part of organic matter produced by biological and chemical degradation of mangrove plants, animals and microbes, because of their negatively charged organic ion, acts as chelating agents and form complexes with positively charged metals and reduce their bioavailability (Bettina, 2001). Mangrove sediments with low redox potential also act as a sink of metal. In anoxic sediment, sulphate reducing bacteria produce H_2S that may precipitate metals as metal sulphides (Lacerda *et al*., 1993). Sediment granularity is another important factor regulating metal concentrations. The silt and clay fraction have higher affinity to metal than sand fraction in mangrove sediment. The fine particles and organic matter have high specific surface area and can efficiently trap heavy metals from overlying water (Tam and Wong, 2000; Marchand *et al*., 2006). Metal distribution is also linked to tidal action. Tides influence the transport of metal rich effluents discharged from various industrial outlets and deposit in the flow restricted mangrove habitats, and from there to coastal waters (Mackey and Hodgkinson, 1995).

7.1.2 Bioaccumulation of metals in macrobenthic fauna

Bioaccumulation assessment is important for scientific evaluation of risk associated with metals and other chemicals to human health and environment with a focus on regulatory effort. (Arnot and Gobas, 2006). The contaminated sediments are direct source of toxicity to aquatic organisms. Toxicity of a pollutant specifically metals depends mainly on their chemical nature, their speciation and bioavailability. Metals reaching aquatic systems have intrinsic affinity to bind with sediments. The diagenetic process cause stratification of metals in sediment profiles (Du Laing *et al*., 2009). These stratified metals will be made bioavailable by active bioturbation processes such as construction of biogenic structures, irrigation of burrows, sediment mixing and production of faecal pellets of benthic fauna, crabs, polychaetes, clams along with other chemical reactions and natural events (Kristensen, 2000). The resuspended metals probably get accumulated in mangrove plants and animals through trophic transfer causing hazardous effects to aquatic organisms, fishes and to humans (Environmental Protection Agency, 2004) by binding to vital cellular components such as structural proteins, enzymes and nucleic acids and interact with their functioning.

Benthic fauna due to its ubiquitous distribution, sedentary nature, long life cycles are prone to metal accumulation and can be efficiently used in biomonitoring studies. Furthermore the pollutant concentrations in the organism indicate the result of the past as well as the present pollution level of the environment in which the organism lives (Ravera *et al*., 2003). Benthic invertebrates can take up heavy metals in three principal ways: (1) by direct contact of the body surface with contaminated sediment particles, (2) from the interstitial water, and (3) from sediment particles being ingested and digested in the intestine (Garnier-Laplace *et al*., 1992). Bioaccumulation of metals can cause change in community composition, species structure, and even biodiversity loss and ecosystem imbalance. It was also evident that tolerant or opportunistic species will dominate and occupy the niche replacing the less tolerant species which are sensitive to pollution (Pearson and Rosenberg, 1978). Mussels and oysters by their feeding activities on sediment detritus, directly intake metal pollutants and has reported higher concentration of Zn, Hg, Cu, Mn, Fe in their tissues that ultimately reaches human consumers (Franco *et al*., 2002, Kamaruzzaman *et al*., 2011; Lias *et al*., 2013). Metal accumulation in amphipods (Barak and Mason, 1989; Xu and Pascoe, 1994), isopods (van Hattum *et al*., 1989), decapods (Anderson *et al*., 1978), insects (Hare and Campbell, 1992), Chironomids (Chapman, 1985) were studied from different aquatic systems. In Indian context commercially important species especially shrimps, fishes, clams were extensively studied from mangrove and estuarine habitats (Mitra *et al*., 2012; Swaileh, and Adelung, 1995; Mitra and Choudhury, 1992; Joseph and Srivastava,1992; Barua *et al*.,2011). From Indian sunderbans, five species of commercially important shrimps (*Penaeus monodon, Penaeus indicus, Penaeus semisulcatus, Penaeus marguensis and Metapenaeus brevicornis*) were studied for bioaccumulation of metals such as Zn, Cu, Pb, Cd and observed considerable bioaccumulation in tissues (Mitra *et* *al.*,2012). The Cochin mangrove-estuarine region, downstream of Periyar river receives 260 million litres of hazardous industrial effluents from Kochi industrial belt (Green Peace, 2003) and several studies have carried out on metal bioaccumulation in commercially important benthic and pelagic fauna of Cochin estuary. The bioaccumulation studies in bivalves and gastropods especially *Perna viridis*, *Villorita cyprinoides*, *Crassostrea madrasensis*, *Sunetta scripta* (George et al.,2013;Ragi *et al*., 2017; Ouseph *et al*., 1987; Lakshman *et al*.,1989; Pillai and Valsala,1995; Rajendran and Kurian,1986), penaids (Kaladharan *et al*., 2005; George *et al*.,2011) and fishes especially *Puntius parrah*, *Oreochromis mossambicus* (Bijoy Nandan *et al*., 2013; Ciji and Bijoy Nandan, 2014) were carried out with toxic metals such as Cr, Cd, Pb, Zn and Cu and found higher concentration of zinc in mussels and fishes (Renjitha *et al*., 2011 Ramani, 1979); Rajamani *et al*., 1994).

7.2 Results

7.2.1 Distribution of metals in mangrove sediments of Cochin

In Cochin mangrove habitats, concentration of seventeen metals was analysed from the sediment. The concentration (mg kg^{-1}) of the selected metals ranged as follows in decreasing order of Al(3524-57375), Fe (2975.4-47629.4), Mn(6.8-187.8), Cr (5.5-202), Li (3.94-212.7), Zn (6.73-129.8), Sr (4.69-92.85), Ba (0.97-72.38), Ni (0.06-64.5), Cu (0.89- 40.68), B(0.8-40.76), Pb (0 -18.11), Co (0-11.71), As (0-4.79), Ag (0-4.68), Cd (0-1.34), Hg (0-0.68). Average concentration and spatial variability of metals in mangrove zones were depicted in Table 7.1.Concentration of Li, Cd, Hg, Zn, Fe, Cr and Ag was considerably above the expected natural background levels (Turekian and Wedepohl, 1961). Ag was observed to increase by sixtyfold (4.6g/kg vs 0.07 g/kg background value) than its background value. Range concentration of other metals exhibited less than fivefold increase from the background value in average shale (Turekian and Wedepohl, 1961). ANOVA revealed that all the heavy metals exhibited strong spatial variation (F (5, 72), p<0.05) except Hg (F (5, 72), p=0.604) and no seasonal variation except boron (F (5, 72), p=0.003). Since year wise variation was not significant for most of the metals, the data is pooled and presented. Aroor zone (station 1) was characterised by higher concentration of all the metals especially those of terrestrial origin such as Al, Fe, Cu, Cr, Mn, Ni, Pb, Zn and Li. Highly industrialised Puthuvype zone station 3, nearer to sea was found to contain an elevated concentration of Ag and Li while lower concentration of other metals however station 4 closer to the Arabian Sea was characterised by higher Cd concentration (0-1.34). Metals like As, Ag and Cd was below detectable level (BDL) in Valanthakad zone (S5 and S6) whereas other metals were in lower concentration. Mercury (Hg), a toxic, global pollutant was found in higher concentration in station 5 occasionally. The mean, range and quartile deviation of metal concentration is represented in Figure 7.1, Figure 7.2 and Figure 7.3.

Table 7.1 Spatial variation in mean concentration of heavy metals (mg kg^{-1}) in mangrove sediments of Cochin during 2010-2012 period.

Metals	S1	S2	S3	S4	S5	S6	Background value
As	1.8±1.3	0.63±1.1	1.2±0.5	0.395±1.3	BDL	BDL	13
Cr	122±24	53.8±31.5	58±44.6	38.9±18.8	15.1±5.1	26.8±4.2	90
Cu	32±7.06	13.1±7.7	15±11.6	10.1±4.2	2.6±1.1	5.4±0.9	45
Fe (%)	3.64± 0	1.9 ±0.86	1.72±1.41	1.43±0.63	0.59±0.2	1±0.17	4.72
Zn	84.9±20	47±25.3	44.2±29.5	46.2±19.8	13±5.3	20±5.04	95
Mn	123±24	72.8±47.3	66.8±42.3	75.3±30.7	20.5±8.0	32±11.9	850
Ni	41±8.2	18.3±11.2	19.7±14.8	12.3±6.2	3.7±1.7	7.47±1.6	68
Pb	13.9±2.9	6.7±4.1	6.9±4.9	3.8±1.8	3.6±4.17	4.1±3.7	20
Cd	0.18±0.2	0.01±0.02	0.1±0.09	0.1±0.3	BDL	BDL	0.3
Ag	1.02±1.4	0.2±0.6	0.8±0.5	0.7±0.7	BDL	BDL	0.07
Co	7.4±1.7	3.3±2.5	3.8±2.5	4.1±2.1	0.5±0.4	1.6±0.4	19
Hg	BDL	0.01±0.05	0.01±0.02	0.05±0.1	0.08±0.2	0.03±0.1	0.4
Al (%)	4.58±0.7	2.61±1.13	2.26±1.74	1.53±0.62	0.70±0.2	1.19±0.1	8
B	16.3±7.6	10.2±7.4	10.4±4.1	11.08±6.3	3.1±1.1	5.6±1.8	100
Ba	48.17±12	26.8±16.5	25.9±15.9	39.2±14.0	6.2±2.9	13.03±4.	580
Sr	51.7±9.6	29.5±16.1	26.7±18.6	31.3±13.7	10.4±2.8	15.4±2.7	300
Li	105.5±28	50.2±34.8	54.5±35.2	36.6±23.1	12.1±4.6	23.06±5	66

Metal with concentration above background value is represented in bold ,
BDL- Below detectable level *(Background values from Turekian and Wedepohl, 1961)*

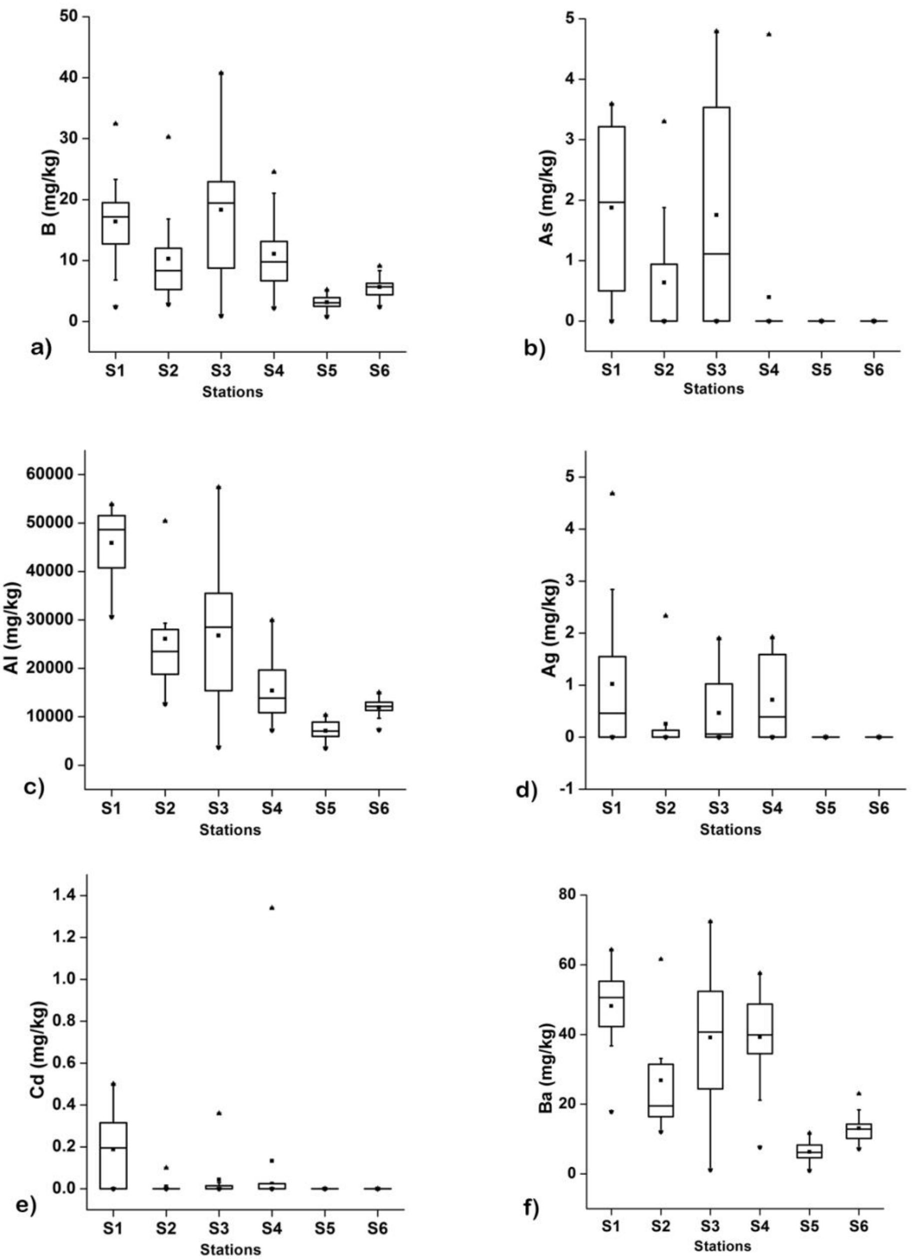

Figure 7.1 (a-f). Box plot representing metal concentration (B, As, Al, Ag, Cd, Ba) in mangrove sediments of Cochin during 2010-2012 period (whisker: range, box: interquartile range, square: mean).

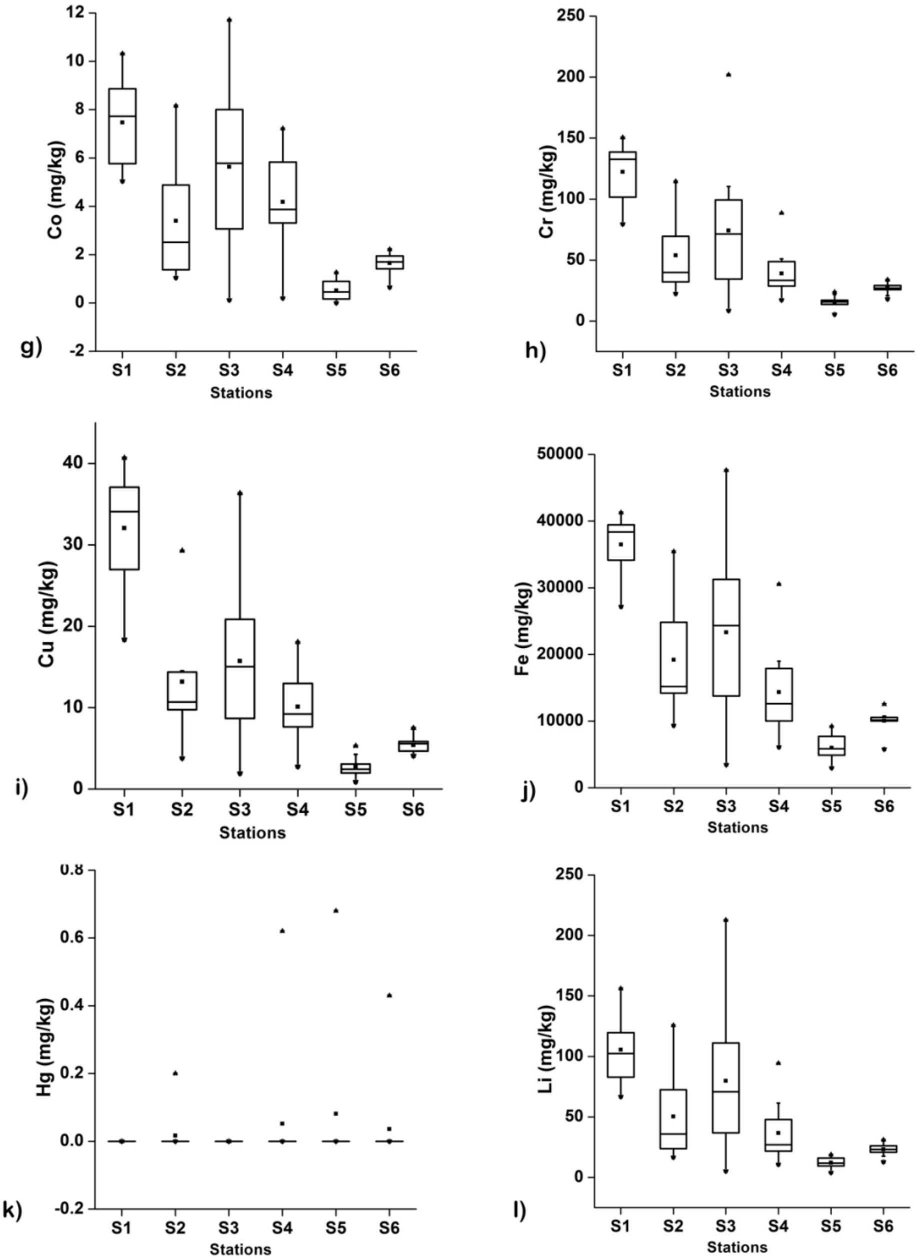

Figure 7.2(g-l). Box plot representing metal concentration (Co, Cr, Cu, Fe, Hg, Li) in mangrove sediments of Cochin during 2010-2012 period (whisker: range, box: interquartile range, square: mean)

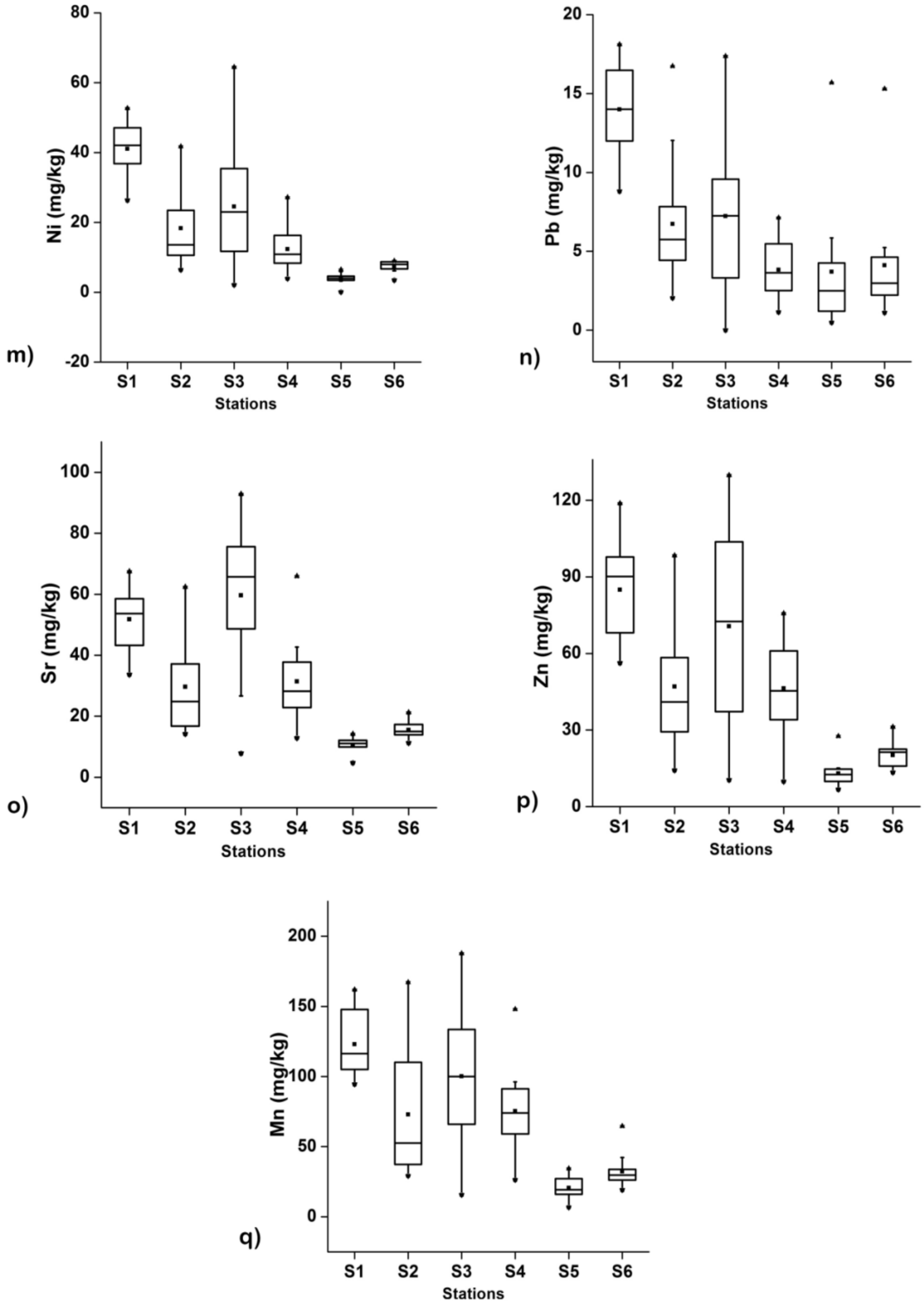

Figure 7.3 (m-q). Box plot representing metal concentration (Ni, Pb, Sr, Zn, Mn) in mangrove sediments of Cochin during 2010-2012 period (whisker: range, box: interquartile range, square: mean

7.2.2 Assessment of metal contamination based on sediment quality guidelines (SQG) and pollution indices

Sediment quality analysis was carried out using standard NOAA SQuiRTs (Screening Quick Reference Tables) (Buchman, 2008). Metals such as Cr (79.5-150.5 mg kg^{-1}) and Cu (18.3-40.6 mg kg^{-1}) were above NOAA Effect Range Low (ERL), while Ni (26.3-52.6 mg kg^{-1}) and silver (0- 4.68 mg kg^{-1}) were above NOAA Effect Range Medium (ERM) in station 1 of Aroor zone. Whereas, in station 2 of Aroor only Ni, Ag and Cr were affecting sediment quality and were above ERL, other toxic metals were below the effect range. Station 3 in Vypin also hosts substantially elevated concentration of all the toxic metals particularly Cr (8.5-202 mg kg^{-1}) and Ni (2-64.5 mg kg^{-1}) at this zone. Sediment screening standards of Ag, Ni, Cr and Cu were similar to that of Aroor (S1). Station 4 of Vypin notably had higher toxic concentration of most toxic metals such as Cd and Hg in a range just above ERL. Valanthakad zone characterised by sand dominated texture (>85%), low organic carbon (>1%) have lower metal concentration in sediment and were below NOAA ERL indicating lower risk to aquatic fauna in this Island mangroves. The Ag and Cd were below detectable level (BDL) in this zone however mercury (0-0.68 mg kg^{-1}) was infrequently observed and usually above ERL. Metal concentration in sediments compared to NOAA standards are given in Table 7.2

Table 7.2. NOAA sediment quality guideline values for selected metals (SQuiRTs)

SQG	As	Cr	Cd	Cu	Pb	Hg	Ni	Ag	Zn
ERL	**8.2**	**81**	**1.2**	**34**	**47**	**0.15**	**21**	**1.0**	**150**
ERM	**70**	**370**	**9.6**	**270**	**220**	**0.71**	**52**	**3.7**	**410**
*** Minimum**	**0**	**5.5**	**0**	**0.8**	**0**	**0**	**0.06**	**0**	**6.7**
*** Maximum**	**4.79**	**201.9**	**1.34**	**40.6**	**18.1**	**0.68**	**64.5**	**4.68**	**129.8**

Metal concentration in present study

Enrichment factor and PCA analysis helps to identify the source (anthropogenic or natural) of metal pollution in the sediment. Enrichment factor analysis revealed anthropogenic source of Ag, Cr, Pb, Zn, Cd, Hg, Li, Fe, Co with enrichment in mangrove sediments of Cochin (Table 7.4). Silver (0-133.7) exhibited extremely severe enrichment (EF>50), while severe enrichment of Hg (0-18.8), Cd (0-17), Pb (0-17.8) was observed in mangroves of Cochin. Enrichment factor of Li (1.2- 4.4), Cr (1.1-3.1) and Zn (0.9-3.8) implies minor to moderate enrichment whereas Co and Fe with minor enrichment. The extremely severe enrichment of Ag was notable in four mangrove stations S1, S2, S3 and S4, while Hg, Pb causes severe enrichment (EF=10-25) in S5 and moderately severe(EF=5-10) in other stations. Cd enrichment was severe in S4 and minor in other sites. Lithium enrichment was moderate in all sites except in S5and S6. EF values of Ni, As, Mn, Cu, Sr, B, Ba were below 1(EF<1), hence have no enrichment indicating that these metals in sediment were not from human activities but by natural weathering.

In **Principal component analysis** two components with eigen value greater than one was considered, the first principal component (PC1) exhibited 72.9 % of total variance and second principal component (PC2) with 5.9 % variance [Table 7.3 and Figure 7.4]. PC1 correlates well with variables such as Al, Co, Ni, Mn, Zn, Fe, Cu, Cr, Li with higher positive loadings (> 0.9) indicating their natural origin by weathering. PC2 exhibited higher positive loading for Ag and Cd and negative loading for Hg. Since Ag, Cd and Hg are geologically rare metals with a natural background concentration < 1 mg kg^{-1}, PC2 can be considered entirely anthropogenic, and their sources were attributed to industries in the vicinity of Cochin.

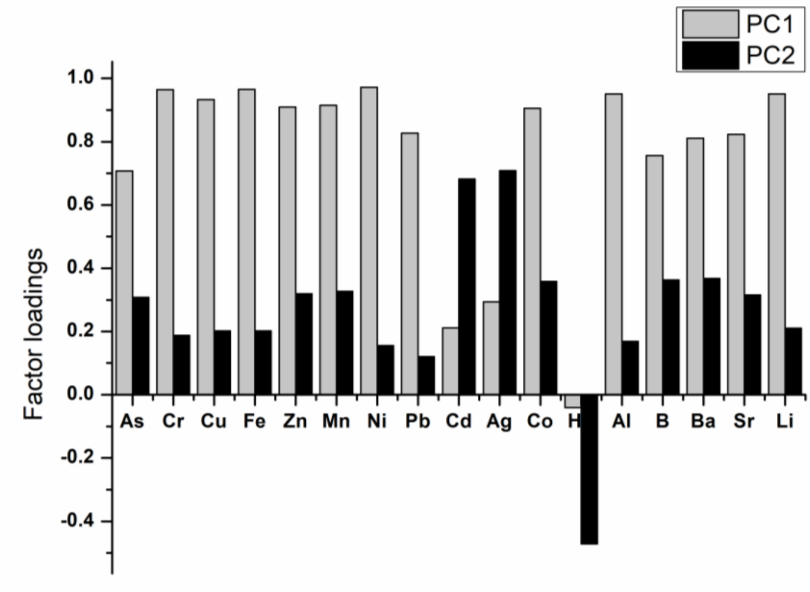

Figure 7.4 Factor loadings for PC1 and PC2 (eigen value >1) in mangrove sediments of Cochin during 2010-2012 period.

Table 7.3 Total variance explained by PCA analysis in mangrove sediments of Cochin during 2010-2012 period.

	Initial Eigen values					
Component	**Total**	**% of Variance**	**Cumulative %**	**Metal**	**PC1**	**PC2**
1	12.406	72.976	72.976	As	0.708	0.308
2	1.005	5.911	78.887	Cr	0.964	0.188
3	0.965	5.674	84.561	Cu	0.933	0.202
4	0.759	4.465	89.026	Fe	0.965	0.202
5	0.663	3.901	92.927	Zn	0.909	0.32
6	0.454	2.673	95.6	Mn	0.915	0.327
7	0.249	1.464	97.065	Ni	0.972	0.156
8	0.179	1.056	98.121	Pb	0.827	0.121
9	0.117	0.687	98.808	Cd	0.212	0.682
10	0.078	0.461	99.269	Ag	0.294	0.709
11	0.042	0.248	99.517	Co	0.906	0.358
12	0.032	0.189	99.706	Hg	-0.041	-0.471
13	0.019	0.109	99.815	Al	0.951	0.169
14	0.016	0.092	99.907	B	0.756	0.363
15	0.007	0.04	99.947	Ba	0.811	0.368
16	0.006	0.036	99.983	Sr	0.823	0.316
17	0.003	0.017	100	Li	0.951	0.211

Pollution and contamination of mangrove sediments were assessed by Contamination factor (CF), Geoaccumulation Index (I_{geo}) and Pollution load index (PLI) and summarised in Table 7.4.

Contamination factor (CF) of metals such as Ag (0.42-66.85), As (0.07-0.36), Cr (0.06-2.24), Cu (0.01-0.9), Co (0.006-0.6), Cd (0.06-4.4), Fe (0.06-1), Mn (0.008-0.22), Pb (0.04-0.9), Ni (0.0008-0.9), Hg (0.5-1.7), Zn (0.07-1.36), Al (0.04-0.7), B (0.008-0.4),Ba (0.001-0.12), Sr (0.01-0.3), Li (0.05-3.2) were calculated. Among these metals Ag, Cd, Li, Cr, Zn, Hg were found to cause contamination in mangrove sediments. Ag causes very higher contamination (CF>6), followed by cadmium and lithium with considerable contamination ($3 \leq CF \geq 6$). However metals like Cr, Zn, Hg causes moderate contamination (CF<3) in mangroves. Other metals cause lower contamination in mangrove sediments. Ag cause very higher contamination in S1, moderate to higher contamination in S3 and S4, considerable to very high contamination in S2 and probably not in a contamination range in S5 and S6. Cd contamination was considerable in S4 while moderate in S1 and S3. Zn and Cr cause moderate contamination in S1 and S3. As, Cu, Co, Ni, Pb, Fe, Al, Ba, B, Ca, Mg, Sr causes lesser contamination in mangrove sediments.

A negative to a positive range of **geoaccumulation index** (I_{geo}) was exhibited by Ag, Li, Hg, Cd, Cr indicating pollution of the system by these toxic metals while other metals exhibited a negative I_{geo} index. Among the different metals, Ag exhibited highest I_{geo} index value that varies spatially. It was found extremely polluted in S1, strongly to extremely polluted in S2, S3 and S4 and unpolluted in S5 and S6. Mercury was found to cause unpolluted to a moderately polluted condition in S4 and S5, while practically unpolluted ($I_{geo}<0$) in other stations. Cd causes moderate pollution (S5) while Zn in unpolluted range. Lithium and chromium cause moderate pollution in mangrove sediments notably in S3 with and practically unpolluted in other sites.

Table 7.4 Enrichment factor, Geo-accumulation index, Contamination factor, and Pollution load index of heavy metals in mangrove sediments of Cochin during 2010-2012.

Pollution indices: Enrichment factor (EF)

EF	S1	S2	S3	S4	S5	S6	Status
Li	**1.6-3.7**	**1.2-3.2**	**1.6-4.4**	**1.7-3.8**	**1.3-2.4**	**2-2.9**	Moderate enrichment
Cr	**1.9-2.6**	**1.1-2.2**	**1.9-3.1**	**2-2.6**	**1.2-2.1**	**1.8-2.1**	Moderate enrichment
Ag	**0-104.4**	**0-57.5**	**0-77.7**	**0-133.7**	0	0	Extremely severe enrichment
Zn	**0.9-2**	**0.8-1.8**	**1.6-3.8**	**1.1-3**	**0.9-2.2**	**0.8-1.7**	Moderate enrichment
Pb	0.9-1.5	0.4-1.3	0-1.2	**0.4-2.2**	**0.2-17.8**	**0.4-8.3**	Severe enrichment
Hg	0	**0-2.3**	0	**0-8.2**	**0-18.8**	**0-6.9**	Severe enrichment
Cd	**0-2.7**	0-0.5	**0-2.5**	**0-17**	0	0	Severe enrichment
Fe	1.2-1.5	1-1.5	**1.4-1.6**	**1.4-1.7**	1.2-1.5	1.3-1.5	Minor enrichment
Co	0.4-0.8	0.2-0.7	0.13-1.1	**0.1-1.6**	0.1-0.5	0.3-0.6	Minor enrichment

Pollution indices: Geo-accumulation index (Igeo)

I_{geo}	S1	S2	S3	S4	S5	S6	Status
Ag	**-1.8-5.4**	**0-4.4**	**0-4.1**	**-0.07-4.1**	0	0	Extremely polluted
Li	-0.56-0.65	-2.5-0.34	**-4.2-1.1**	-3.2--0.06	-4.6--2.3	-2.9--1.6	Moderately polluted
Cr	-0.76-0.15	-2.5--0.2	-3.9-0.5	-2.9--0.6	-4.6--2.5	-2.9--1.9	Unpolluted - moderately
Hg	0	-1.5-0	0	0-0.047	-1.04-0.18	-0.48-0	Unpolluted - moderately
Cd	-1.24-0.15	-4.4-0	-3.9-0	**-4.4-1.57**	0	0	Moderately polluted

Pollution indices: Contamination factor (CF)

CF	S1	S2	S3	S4	S5	S6	Status
Li	**1.01-2.3**	**0.2-1.9**	**0.07-3.2**	**0.1-1.4**	0.05-0.28	0.1-0.4	Considerable contamination
Cr	**0.8-1.6**	**0.2-1.2**	**0.09-2.2**	0.19-0.98	0.06-0.26	0.2-0.3	Moderate contamination
Ag	**0-66.8**	**0-33.2**	**0-27.1**	**0-27.4**	0	0	Very high contamination
Zn	**0.5-1.2**	**0.14-1.03**	**0.1-1.3**	0.1-0.7	0.07-0.2	0.1-0.3	Moderate contamination
Hg	0	0-0.5	0	**0-1.5**	**0-1.7**	**0-1.07**	Moderate contamination
Cd	**0-1.6**	0-0.3	**0-1.2**	**0-4.4**	0	0	Considerable contamination

Pollution indices: Pollution load index (PLI)

PLI	S1	S2	S3	S4	S5	S6	Status
	0.45-0.62	0.22-0.49	0.33-0.6	0.23-0.41	0.05-0.09	0.10-0.14	Presence of contaminants causing pollution

Metals with EF> 1.5, Igeo >0, CF>1 are only represented and values given in bold

Pollution Load Index (PLI) ranged between 0.02-0.6 in mangroves of Cochin. Pollution load index value was comparatively higher in S1 (0.2-0.6). Mostly other sites experienced a moderate level of pollution with PLI that ranged between 0.09-0.49 in S2, 0.03-0.60 in S3, 0.06-0.41 in S4 indicating the presence of contaminants in mangrove zones. Remarkably lower PLI was in S5 (0.02-0.09) and S6 (0.07-0.14) indicating very low pollution status [Figure 7.5]

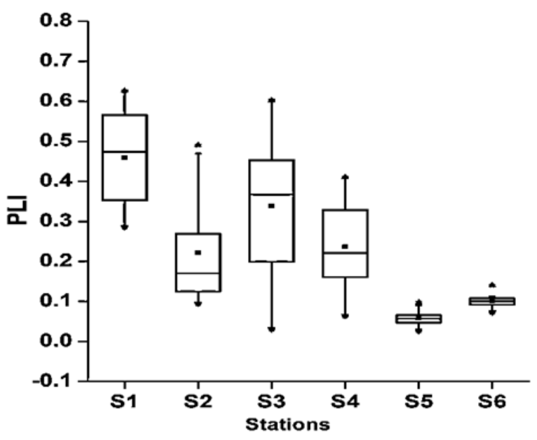

Figure 7.5 Spatial variation in Pollution load index in mangrove habitats of Cochin during 2010-2012 period.

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7.2.3 Bioaccumulation of metals in macrobenthic fauna

Heavy metal concentrations in the five benthic invertebrates are given in Table 7.5.The metal concentration generally followed as Fe>Cr>Zn>Pb>Ag>Li>Cd and their concentrations are expressed in mg kg^{-1} dry wt. Fe had in highest concentration in all fauna as that of sediment while Cd was in least concentration. Fe concentrations ranged from 504.1 to 2085.1 mg $kg^{-1}$and lowest value was recorded in amphipods (504.1 mg kg^{-1}) and higher values in tanaids (2085.1 mg kg^{-1}) and polychaetes (2072.3 mg kg^{-1}). Chromium accumulation in macrofauna was observed in higher value in crustaceans especially in decapods (25.05 mg kg^{-1}) followed by polychaetes and bivalves. Tanaids (5.7 mg kg^{-1}) and polychaetes (3.5 mg kg^{-1}) were the major accumulator of zinc in mangrove sediments. Lead accumulation was observed in polychaetes (1 mg/kg) and bivalves (0.47 mg kg^{-1}) mainly and was below detectable limit in others. Accumulation rate of lithium was lower in all selected fauna. Silver and cadmium accumulation concentration was in a lower range and comparatively higher in tanaids and was 0.32 and 0.20 mg kg^{-1} respectively. Cd concentration in tanaids and Pb concentration in bivalves and Fe concentration in all selected fauna seems to be slightly above the permissible value as given by FAO/WHO (1992).

Bioaccumulation factor was calculated to analyse the transfer rate of metals from sediments. Very low rate of metal was said to be accumulated in tissues of benthos. Polychaetes seems to bioaccumulate mostly all metals except Ag and Cd. Cr seems to be most bioaccumulated metal by polychaetes with a BAF of 0.62 followed by Fe and Zn. Eventhough Fe and Zn concentration were higher in tanaids, the bioavailability was lower with low BAF of 0.06 and 0.07 respectively. Cd and Ag accumulation was highest in tanaids and decapods. Biaoccumulation of metals by amphipods were comparatively lower. Lithium was not bioavailable for benthic fauna in mangroves. Thus polychaetes may be considered as basic bioaccumulator of metals followed by tanaids [Table 7.5 and Figure 7.6].

Table 7.5 Total concentration (TC) (mg kg^{-1}) of heavy metal and bioaccumulation factor (BAF) in benthic fauna in mangrove habitats of Cochin during 2010-2012 period.

Organism	Iron	Chromium	Zinc	Lead	Lithium	Silver	Cadmium
Total concentration							
Polychaetes	2072.3	9.30	3.55	1	0.47	0	0
Bivalves	1077.8	6.10	1.27	0.47	0.01	0	0
Amphipods	504.1	4.15	0.65	0	0.08	0.09	0.03
Decapods	845.3	25.05	1.02	0	0.10	0.17	0.06
Tanaids	2085.1	3.93	5.77	0	0	0.32	0.20
Bioaccumulation Factor							
Polychaetes	0.35	0.62	0.16	0.28	0.04	0.00	0.00
Bivalves	0.18	0.40	0.06	0.13	0.00	0.00	0.00
Amphipods	0.01	0.03	0.01	0.00	0.00	0.09	0.14
Decapods	0.02	0.21	0.01	0.00	0.00	0.17	0.25
Tanaids	0.06	0.03	0.07	0.00	0.00	0.31	0.77

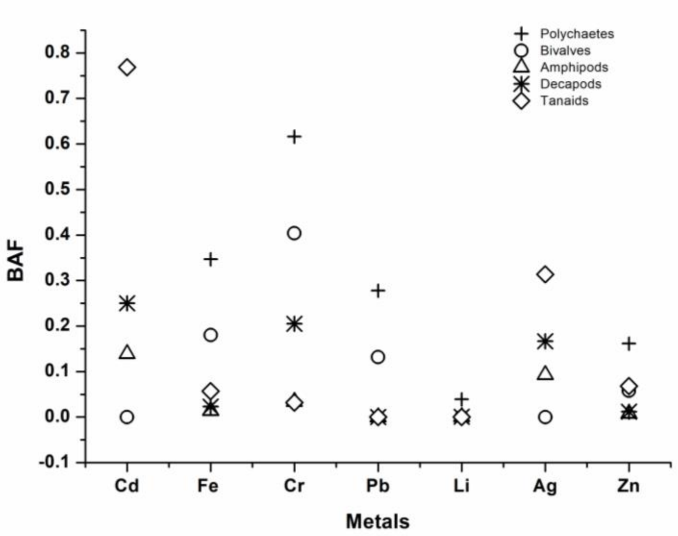

Figure 7.6 BAF of metals in benthic fauna of mangrove ecosystem of Cochin during 2010-2012 periods.

7.3 Discussion

7.3.1 Heavy metal accumulation in sediments

Cochin mangroves turn to be a source rather than sink of different metals derived both from anthropogenic and natural origin. Seventeen metals were screened from Cochin mangrove stand. As in any natural ecosystem Al and Fe has maximum concentration in Cochin which were considered to have increased background concentration. Higher concentration of Fe in mangrove sediment might be due to the permanently reducing conditions of sediment organic matter, textural and mineralogical characteristics (Ramanathan *et al*., 1999; Abdo and Sayed, 2009). In reducing sediments, iron precipitates with sulphidic compounds and form iron sulphides that act as a source for metal binding in sediment (Howarth, 1979).The metals, Hg, Cd, Ag, Li, Zn, Fe and Cr were found to be considerably above the background value in the average shale, and notably silver (Ag) exhibited sixty-fold increase in their concentration from background concentration while other metals exhibited less than fivefold increase. The concentration of Ag reached up to 5 mg/kg dry weight or above in sediments is usually associated with widespread anthropogenic disturbance (Bryan *et al*., 1985). In marine, coastal and estuarine sediments silver was bioavailable and underwent bioaccumulation (Luoma *et al*., 1995). Ag, Hg, Cd are non-essential metals and even in lower values they were considered as serious environmental toxins having no essential role in biological functions and its bioaccumulation in tissues causes toxic effects to plants and animals (Nogueirol and Alleoni, 2013). Comparison with other studies (Salas *et al*.,2017; Defew *et al*., 2005; Liu *et al*.,2017; Chowdhury *et al*.,2017; Liu *et al*.,2015 Wu *et al*.,2017) lower metal concentration and accumulation was observed in mangrove sediments of Cochin however Ag and Hg level were found in a higher range [Table 7.6]. Spatial variation was observed in distribution and concentration level of metals which might be attributed to geomorphological changes such as the textural properties, organic content and other intrinsic factors in the system (Horowitz and Elrick, 1987). Station 1 with the fine sediment grain size complexed by mangrove leaf litters and organic matter retained a higher concentration of all the metals such as Al, Fe, Cu, Cr, Mn, Ni, Pb, Zn, Ag and Li due to run off from terrestrial and estuarine sediments with increased discharge of effluents from industries, agricultural, construction wastes and domestic sewage (Anu *et al*., 2014). The dominant vegetation of *Avicennia* trees and their root structure may also favour metal deposition in station 1. The metal tolerance and accumulative properties of *Avicennia* trees were reported in mangrove sediments (Chowdhury *et al*., 2017; MacFarlane, 2007; MacFarlane and Burchett, 2002). Sediment quality analysis revealed that metals such as Cr, Cu, Cd, Hg, Ag and Ni were above the sediment quality criteria by NOAA SQuiRTs. In station 1 and station 3, Ag and Ni concentration was above effect range medium (ERM) that implies a frequent incidence of adverse biological effects to mangrove fauna and sediment should be considered toxic if atleast one metal exceeds ERM (Long *et al*., 1995). Ratte (1999) reviewed bioaccumulation and toxicity of silver and opined that silver bioaccumulation is lower in sediments. However other metals were above effect range low (ERL) causing occasional incidence of toxicity to aquatic fauna. ERL level of Hg was infrequently observed in S5 and S4. The source of these metals mostly correspond to anthropogenic factors as determined by enrichment factor analysis except nickel that may be crustal in origin whose EF were below 1.5 in all stations. In mangrove sediments the major source of metals are from industrial discharges (Fernandez–Cadena *et al*., 2014; Xin *et al*., 2013), aquaculture activities, fertilizers and other agricultural inputs (Behera *et al*., 2013), and mangrove exploitation (Bodin *et al*., 2013).

The industrial activity that make a range of chemicals, fertilizers, pharmaceuticals, pesticides, petrochemical products, rare-earth elements and leather products in Cochin industrial area are the point source of metals, as emphasised in many studies (Ciji and Bijoy Nandan 2014; George *et al*., 2016). An extremely severe enrichment of Ag (EF>50) was notable in all stations except Valanthakad zone. Higher Ag enrichment was due to the reduced natural Ag sources from coastal and estuarine waters implying its anthropogenic inputs (Sanudo-Willhelmy & Flegal, 1992). Approximately 2,500 tonnes of silver is released to the environment from industrial wastes and emissions annually, 150 tonnes gets into the sludge of wastewater treatment plants and 80 tonnes is released into surface waters (Smith and Carson, 1977; Petering, 1984). Silver immobilisation in soil is linked predominantly with soil organic matter (Jacobson *et al*., 2005) and its cation exchange capacity (Hou *et al*., 2006). The production and refining process of zinc also contributed to Ag, Pb, Cd (TERI report 2014). Zinc production and refining plant of Binani Zinc Limited in Cochin industrial area are core in production of value added products such as cadmium, zinc alloys, zinc ingots and planned to extract in lead, copper, gold, silver from the ore (BZL report, 2013).The effluent discharged from the industries and leached out ore may be the silver and cadmium source in Cochin mangroves. Cd enrichment as previously reported was mainly from fertilisers, pesticides and by industrial effluents from Eloor industrial belt (Martin *et al*., 2012; Salas *et al*., 2017). The source for occasional release of Hg in Valanthakad might be from biomedical wastes especially from nearby hospital complex or by industrial output reaching the island by riverine flux. Fossil fuel combustion, industrial effluents, fertilisers, pesticides and sewage were the common anthropogenic source of Ni in aquatic sediments (Gimeno-García *et al*., 1996), however enrichment factor implies a crustal origin of nickel in mangrove sediments. In PCA analysis,72.9% of variance were observed that correlates with majority of metals, of these Al, Fe, Li, Mn are naturally abundant metals and association of aluminium with clay minerals (aluminosilicate) and interaction of Fe and Mn suggest geogenic origin (Mico *et al*., 2006),but presence of Cr, Cu suggest diagenetic origin (Gan *et al*., 2014). PC2 exhibited higher negative loading for Hg and higher positive loading for Ag and Cd, implying common origin, and similar reaction with chloride forming chloro-complexes (Lee & Fisher 1992). Since Hg, Ag and Cd are geologically rare metals with a natural background concentration < 1mg kg^{-1}, PC2 can be considered entirely anthropogenic, and their sources is attributed to industries in the vicinity of Cochin.

The biodiversity rich Cochin mangrove habitats are in imminent danger of pollution due to metal rich effluents discharged from the industries in the vicinity of Cochin estuary. The metals that pollutes Cochin mangrove sediments were Ag, Cd, Li that pose higher contamination and pollution and their contamination factor was above the contamination criteria(CF>6) (Hakanson, 1980). Ag pose very high contamination (CF=66.8) and extremely polluted range of geoaccumulation index (I_{geo}>5) at Aroor (S1) and strongly to extremely polluted range (I_{geo}=4-5) in other zones (S2,S3 and S4). The biocidal application in medical field, antimicrobials, skin ointments, food processing industries, textile industries, biocidal plastics and nano-technological applications (WHO,2018) release silver to aquatic systems. Very high contamination of cadmium (CF=92.5) with a strongly polluted condition (I_{geo}=3-4) was reported to be in Cochin estuary (Martin *et al*., 2012, Ratheesh Kumar *et al*., 2010; Deepulal *et al*., 2012), but considerable (CF=3-6) and moderate ((I_{geo}=1-2) in Cochin mangroves. Li contamination was moderate to considerable in most of sites and practically unpolluted in other sites. Li release was attributed to its widespread use in ceramics, glass and aluminium production, pharmaceuticals, lubricants, batteries, nuclear reactant cooler (Ober, 2001).Pollution load index ranged between 0.02-0.6 which was lower compared to PLI reported from Vembanad Lake and Cochin estuarine system (Selvam *et al*., 2012; Salas *et al*., 2017). Generally mangroves are considered as safer locations compared to other aquatic systems. But in mangroves metal accumulation is purely linked to organic matter, particle size, salinity and plant structural attributes such as root modifications and complexity. However studies have proved beyond doubt that mangrove habitats and their ecologically diverse complexities can be repositories for various contaminants like heavy metals.

7.3.2 Influence of environmental factors and mangrove plants on metal accumulation.

Distribution, sequestration and concentration of heavy metal in aquatic sediments are determined by varying physico-chemical parameters such as temperature, salinity, dissolved oxygen, pH (Li *et al*., 2013; Fritioff *et al*., 2005; Atkinson *et al*., 2007), organic carbon (Machado *et al*., 2008), sediment grain size or redox potential (Morgan *et al*., 2012) supply of nutrients, sulfide concentrations (Nickerson and Thibodeau, 1985). These varying physico-chemical factors in geochemically different mangrove sediments are in turn attributed to the physical configuration of mangrove tree species (McKee, 1993). Spatial variability of metals was due to these varying environmental parameters. Sediment pH exhibited an alkaline trend in mangrove ecosystems of Cochin but an acidic condition was seen in S1 Aroor zone. The spatial variation may be linked to the differences in carbonate nature of sediment (Chuan *et al*., 1996; Thornton, 1996) or due to hydrolysis of tannins especially in litter rich sediments (Liao, 1990). The increased acidity of soil favour trapping of metals (Simpson *et al*., 2004) as in S1, where concentration of all metals was mostly higher. Varying salinity regimes have direct influence on mobility of metals, but metal mobilisation is linked to higher salinity (Du Laing *et al*., 2007). Due to proximity to Arabian Sea and Cochin City, station 3 exhibited higher salinity accompanied by heavy pollution and deforestation. Nevertheless the concentration of metals was comparatively lower. Lower values might be due to salinity induced metal mobilisation to water column rather than retaining in sediments, consequently in a more bioavailable form to aquatic fauna. Salinity was significantly correlated to Ag (r=0.30), As (r=0.25) and T.potassium (r=0.24) in sediments. Previous studies have shown that heavy metal concentrations are positively correlated with silty sediments and to organic matter (Gomes *et al*., 2009; Gan *et al*., 2013). In the present study, TOC, silt and clay were significantly related to heavy metal content. TOC was positively correlated to silt and clay and also to metals. Litter from mangrove plants associated with finer sediment texture formed the major organic composition in mangrove sediment and was always higher than estuaries (Rani *et al*., 2016 b; Jennerjahn and Ittekkot, 2002). The terrigenous contribution of silt and clay (Lacerda *et al*., 1993) was higher in mangrove sediments compared to estuaries. Sediment texture along with organic matter determines the diagenetic reactions of metals, in mangrove sediments (Emerson and Hedges, 2006). Higher TOC and silt composition also favours metal retension in Aroor (S1). Sand exhibited strong negative correlation with TOC, silt and all metals. The metals which are said to be associated with the finer sediment fraction (Rodríguez-Barroso *et al*., 2010) exhibited significant positive correlation with silt, clay and associated TOC (Table 5) while significant negative correlation to sand prevailed ($p<0.05$). This was obvious in sand dominated sediment of Valanthakad (S5 and S6), where the metal concentration was lower. The reduced soil with lower Eh can stabilise the heavy metals there by reducing their bioavailability. Nutrients such as total phosphorus, total potassium, total sulphur are proper indicators of nutrient status in a system exhibiting highly significant positive correlation with all the metals ($p<0.05$) which was higher in Aroor (S1). Furthermore total sulphur was significantly correlated to TOC($r=0.930$) as reported by Goldhaber and Kaplan (1975) where sulphides are formed by sulphate reduction using organic matter by microbes in anoxic conditions. The high sulphur content in mangrove sediment reduces the metal fraction and fixes it in sediment by sulphate reducers (Alongi *et al*., 2001). That is when sulphate is reduced and organic matter is oxidised, the sediment contains a proportional amount of sulphide and residual carbon. A highly significant correlation of TOC and total phosphorus with metals such as Cu, Cr, Fe, Ni, Mn, Zn, and Li were notable. Mostly all the environmental parameters showed positive correlation to all the metals except sand which was negatively correlated [Table 7.7].

Mangrove plants have strong adaptability to metal pollution by excluding the non-essential metals (Ong Che 1999; Machado *et al*., 2002).The complexity of physical structure of mangrove vegetation along with organic input, change of soil pH determines the differential distribution and retension of metals within mangrove sediments (MacFarlane and Burchett, 2000). The mangrove stand by their complex root structures, pneumatophores and also differential zonation showed differential accumulation of fine-grained sediment particle and organic matter content (Zhou *et al*., 2010) under each stand. In station 1 of Aroor zone the metal concentration were observed to be higher where *Avicennia officinalis* was predominant in density (2080 ind.ha^{-1}) and was found significantly correlated (p<0.05) to majority of metals (Al, Pb, Cr, Cu, Fe, Zn, Ni, Zn, Mn, Sr and Li) along with *Bruguiera sexangula* [Table 7.8]. Previous studies has reported the higher litter fall rate (Rani *et al*.,2016 b) and complex pnuematophores of *Avicenna* trees in binding sediment and accumulation of the metals (Chowdhury *et al*., 2017; MacFarlane 2007). The microbial decomposition of mangrove litter and oxidation of ferrous compounds and the secretion of root exudates (Zhou *et al*., 2010), may results in acidification of sediments beneath each stands and increase bioavailability of metals (Liu *et al*., 2014). *Acanthus ilicifolius* was the dense vegetation of S2 (9066 ind.ha^{-1}), S5 (12500 ind.ha^{-1}) and S6 (50000 ind.ha^{-1}) where the metal concentration was lower, which may attributed to low litter production and weak roots of this shrub mangrove which make them less potential accumulator of metals. Lower accumulation ability of *Acanthus* was reported by Thomas and Fernandez (1997) in Kerala mangroves. *Acrostichum aureum* was seen in higher density next to most dense *Acanthus ilicifolius* in S5 and S6 where Ag was below detection level that corresponds to some accumulating properties of *Acrostichum* that reduce the Ag(r= -0.842) and Mn (r= -0.832) concentration by selective adsorption, so that a significant negative correlation was seen that implies an inverse relation between plant density and metal concentration. *Rhizophora apiculata* also showed similar negative trend in relation to metals especially to Ag(r= -0.870). The significant correlation of *Exoecaria agallocha*, one of the dominant vegetation of station 4, 5 and 6 with Hg(r=916), implies that mangrove plants have differential retension pattern for metals with the help of their roots. Chakraborty *et al*. (2014) reported the higher bioaccumulative properties of *Exoecaria agallocha* in Sunderbans mangroves. Li *et al*. (2015) reported higher concentration of Cu, Zn, Cr, Pb and Ni in surface sediments of the *Avicennia marina* community of Futian mangrove and Zn, Pb, Cu, Ni, and Mn in *Laguncularia racemosa* in Guanabara Bay, Brazil (Machado *et al*., 2002) where metal bioavailability to water column was low. The determination of metal concentrations in mangrove plants and litter may be used to evaluate the potential of metal loss from the forest through detritus export.

7.3.3 Bioaccumulation of heavy metals in macrobenthic fauna.

Benthic fauna can be considered as potential indicators of sediment quality (Macfarlane, 2002).The toxic effects of pollutants can be monitored using benthic organisms. Aquatic invertebrates receive metals directly via pore water or by direct contact with sediment particles. The direct interaction of fauna with pollutants and its bioaccumulation may reduce diversity and alter community structure of benthic invertebrates (Clements, 1994). The concentration of heavy metals is largely governed by the biological, chemical, and physical characteristics of the surrounding environment. Biological factors especially benthic fauna enhance metal bioavailability by their bioturbation activities modifying the biogeochemistry of sediments. Bioturbation by crabs and other benthic fauna can cause oxidation and dissolution of sulphide, which is an important trace metal sink (Machado *et al*., 2014) and also affect the trace metal behaviour increasing their bioavailability and environmental impacts(Júnior *et al*., 2016). Physical factors such as light intensity, nutrients and nitrogen are some factors influencing bioaccumulation of Cd and Ni (Lee and Wang, 2001). Bioaccumulation in benthos directly depends on metal concentration in sediments. Goodyear and McNeill (1999) found significant relationships between concentrations of metals (Zn, Pb, Cd) in sediment and animal. In this study bioaccumulation of metals such as Fe, Pb, Ag, Cd, Li, Cr, Zn in benthic fauna was observed in Cochin mangrove and Fe seems to be most concentrated as reported by Gawade *et al*.(2013) in Mandovi estuary. In the present study tanaids have higher concentration of metals such as Cd, Fe, Ag, Zn however Cr seems to be highly concentrated in amphipod, Pb and Li in polychaetes. The accumulation rates of these metals were higher in polychaetes as revealed by bioaccumulation factor (BAF). Davydkova *et al*. (2005) reported polychaetes as potential bioaccumulator of Fe, Zn, Cr in Zolotoi Rog bay, Japan. Furthermore the body wall and gut of polychaete tissues have the greatest concentration of metals (Dange and Manoj, 2015). Pollutants enter fin and shell fishes through five main routes: via food or non-food particles, gills, oral consumption of water and the skin. In Sunderbans, mangrove forest mudskippers were the major bioaccumulator and gastropods the least bioaccumulator of metals (Ahmed *et al*., 2010). The adverse impact of industrialization and urbanization has accumulated metals in the order Zn > Cu> Pb> Cd on the edible crustaceans (shrimp species) of Sunderbans (Mitra *et al*., 2012). The Fisher and Ali (2005) reported higher concentration of heavy metals (Fe, Zn, Mn, Ni, Cu, Co, Pb, Cr, Cd) in Mollusca and Crustacea especially barnacles followed by annelida. Tanaids seems to accumulate Ag and Cd in their tissues in this study, on the contrary Moreno *et al*. (2008) pointed out that tanaids are very sensitive to heavy pollution and may disappear from the site. Cd is a highly toxic environmental pollutant and potent cell poison that causes different types of damage including changes in cell morphology and affects cell aggregation leading to cell death (Chiarelli and Roccheri, 2014). Ag bioaccumulation was reported in amphipods *Gammarus* and *Hyalella* sp. (Hirsch, 1998; Ewell *et al*., 1993), in bivalve *Mytilus* sp. (Calabrese *et al*., 1984), in gastropod *Crepidula* sp. (Nelson *et al*., 1983).The formation of stable chloro-complexes with chlorine favour the distribution and accumulation of silver in benthic organisms. Silver accumulation might be considered indications of physiological damage, which can lead to premature release of germ cells, reduction in number of offspring, reduced storage of glycogen for egg production and reduced growth (Martoja *et al*., 1988; Nelson *et al*., 1983; Calabrese *et al*., 1984). Other biological effects of metals includes respiratory and cardiovascular depressions, immunotoxicity, reduced rates of oxygen consumption, bradycardia, imbalance of Ca^{2+} signaling pathway, retarded growth etc. (Burlando *et al*., 2004; Scott and Major,1972 Gagnaire *et al*., 2004). Studies carried out by Bijoy Nandan *et al*.(2013); Ciji and Bijoy Nandan (2014) observed sublethal effects in aquatic fauna including degenerative and necrotic changes in renal tubules and aggregation of inflammatory cells, decrease in erythrocyte count, haemoglobin, haematocrit and mean corpuscular haemoglobin with a marked decline in finfishes and shell fishes and even a shift in benthic community structure in Cochin estuary (Remani et al., 1983; Saraladevi and Venugopal, 1989).However in the present study, Since the BAF of selected metals were lower in mangrove macrofauna, the probability of metal pollutant effects were minimal.

Table 7.6 Heavy metal concentration(mg/kg) in mangrove and estuarine sediments around the world.

Location	Fe(%)	Pb	Cd	Co	Ni	Mn	Cr	Cu	Zn	Ag	Hg	Reference
Punta Mala Bay,Panama	0.98	78.2	<10		27.3	295	23.3	56.3	105	-	-	Defew *et al.*,2005
Leizhou Peninsula, China	-	23.4	0.18	-	15.4	-	33.8	11.5	59.4	-	-	Liu *et al.*,2017
Sunderban mangrove,India	4.14	52.9	0.48	12.7	47.4	1197.5	41.8	60.6	88.3	-	0.24	Chowdhury *et al.*,2017
Zhangjiang estuary, China	-	66.5	0.28	-	-	-	71	25.3	83.9	-	0.14	Wu *et al.*,2017
Estero Salado,Ecuador	-	81.3	1.9	20.8	82.2	469.6	94.5	253.8	678.3	3.33	-	Fernández-Cadena *et al.*,2014
Veli mangrove,India	0.56-1.90	16-103	1-2	11-55	-	27-388	-	20-81	22-86	-	-	Badarudeen,1997
Kannur mangrove,India	2.30-5.40	17-39	1-6	20-70	-	26-334	-	19-77	48-87	-	-	Badarudeen,1997
Cochin mangrove,India	3.75-86.26	0.74-58.21	BDL-12.82	BDL-60.28	-	12.4–325.98	1.91-244.01	0.13-39.95	14.02-238.4	-	-	Sarika,2005
Cochin mangrove,India	0.33-5.21	19.5-39.5	0.06-0.22	12.8-23	30.6-69.5	210-315	53.3-90.2	23.9-39.1	101.3-455.6	-	-	Ratheesh,2010
Cochin estuary, India	0.27–7.45	0-34.5	0-11	3.9-21.5	2-58.2	14.7-252.9	0.15-89.3	0.28-41.8	51.9-741.9	-	-	Ratheesh, 2010
Cochin estuary, India	0.27–7.45	0.2–95.6	0.1–64.4	0.4–30.1	3.1–74.2	45.5–921.2	10.3–681.25	1.35–146.60	3.4–4655	-	-	Salas *et al.*,2017
Cochin mangroves,India	**0.30-4.76**	**0-18.1**	**0-1.34**	**0-11.71**	**0.06-64.5**	**6.8-187.8**	**5.5-201.9**	**0.8-40.6**	**6.7-129.8**	**0-4.68**	**0-0.68**	**Present study**

Table 7.7 Pearson correlation analysis matrix for metals and environmental variables in mangrove habitats of Cochin during 2010-2012 period.

	Li	**Hg**	**Ag**	**Co**	**Cd**	**Pb**	**Ni**	**Mn**	**Zn**	**Fe**	**Cr**	**Cu**	**As**	**TP**	**TS**	**clay**	**Silt**	**TOC**	**sand**	**Salin**
Li	1																			
Hg	-0.16	1																		
Ag	**0.36**	-0.12	1																	
Co	**0.94**	-0.15	**0.50**	1																
Cd	**0.38**	-0.08	**0.31**	**0.44**	1															
Pb	**0.79**	-0.15	0.**38**	0.**74**	0.**30**	1														
Ni	**0.96**	-0.16	**0.38**	0.**92**	**0.34**	**0.83**	1													
Mn	**0.94**	-0.17	**0.47**	**0.97**	**0.38**	**0.73**	**0.92**	1												
Zn	**0.94**	-0.15	**0.44**	**0.95**	**0.44**	**0.75**	**0.92**	**0.95**	1											
Fe	**0.94**	-0.18	**0.43**	**0.93**	**0.34**	**0.82**	**0.98**	**0.93**	**0.92**	**1**										
Cr	**0.96**	-0.17	**0.42**	**0.92**	**0.35**	**0.84**	**0.99**	**0.92**	**0.91**	**0.98**	**1**									
Cu	**0.90**	-0.16	**0.45**	**0.89**	**0.37**	**0.85**	**0.97**	**0.87**	**0.88**	**0.97**	**0.96**	**1**								
As	**0.73**	-0.14	**0.44**	**0.73**	**0.28**	**0.60**	**0.69**	**0.75**	**0.71**	**0.71**	**0.70**	**0.65**	**1**							
TP	**0.89**	-0.19	**0.37**	**0.86**	**0.29**	**0.69**	**0.86**	**0.87**	**0.88**	**0.87**	**0.88**	**0.83**	**0.69**	**1**						
TS	**0.74**	-0.15	**0.52**	**0.79**	**0.47**	**0.68**	**0.79**	**0.76**	**0.77**	**0.82**	**0.79**	**0.84**	**0.58**	**0.67**	**1**					
Clay	**0.56**	-0.13	**0.24**	**0.54**	**0.18**	**0.54**	**0.60**	**0.55**	**0.56**	**0.62**	**0.58**	**0.64**	**0.44**	**0.50**	**0.62**	**1**				
Silt	**0.62**	-0.13	**0.44**	**0.64**	**0.44**	**0.66**	**0.73**	**0.60**	**0.62**	**0.74**	**0.71**	**0.78**	**0.45**	**0.51**	**0.83**	**0.65**	**1**			
TOC	**0.81**	-0.16	**0.55**	**0.85**	**0.49**	**0.73**	**0.84**	**0.82**	**0.83**	**0.86**	**0.84**	**0.88**	**0.58**	**0.73**	**0.93**	**0.61**	**0.80**	**1**		
Sand	**-0.64**	0.141	**-0.42**	**-0.66**	**-0.41**	**-0.67**	**-0.74**	**-0.62**	**-0.65**	**-0.76**	**-0.73**	**-0.80**	**-0.47**	**-0.54**	**-0.83**	**-0.75**	**-0.99**	**-0.81**	1	
Salinity	0.09	-0.11	**0.30**	0.15	0.12	-0.01	0.03	0.14	0.15	0.07	0.05	-0.01	**0.25**	0.12	0.07	-0.19	0.006	0.08	0.03	1

Table 7.8 Correlation of mangrove plants with metals in mangrove sediments of Cochin during 2010-2012 period.

Metals	*A.officinalis*	*A.aureum*	*E.agallocha*	*R.apiculata*	*B.Sexangula*
As	0.784	-0.762	-.845*	-0.625	0.628
Cr	.891*	-0.672	-0.778	-0.495	0.803
Cu	.881*	-0.699	-0.777	-0.531	0.784
Fe	.905*	-0.691	-0.779	-0.499	0.789
Zn	.847*	-0.806	-0.753	-0.654	0.682
Mn	.819*	-.832*	-0.739	-0.692	0.641
Ni	.892*	-0.698	-0.802	-0.516	0.776
Pb	.920**	-0.56	-0.762	-0.338	.836*
Cd	0.538	-0.714	-0.442	-0.765	0.561
Ag	0.531	-.842*	-0.621	-.870*	0.432
Co	0.78	-0.79	-0.703	-0.698	0.692
Hg	-0.629	0.652	.916*	0.546	-0.547
Al	.919**	-0.694	-.833*	-0.474	0.759
B	0.754	-.855*	-0.752	-0.759	0.601
Ba	0.664	-.828*	-0.579	-0.781	0.541
Ca	0.45	-0.788	-0.342	-0.803	0.292
Mg	0.797	-0.803	-0.679	-0.667	0.629
Sr	.832*	-0.788	-0.706	-0.65	0.691
Li	.879*	-0.718	-0.81	-0.545	0.762

Significant correlation at a level of $p < 0.01$ (**), $p<0.05$ (*)

Chapter 8

SUMMARY AND CONCLUSION

The thesis entitled **"Benthic biocoenosis in the tropical mangrove stands of Kerala"** embodies the results of investigation on the mangroves of Cochin over a period of two years, to evolve and establish the ecology, community structure and taxonomy of the macro and meio benthic fauna in relation to the environmemtal parameters and floristic structure. It also provides insights on the heavy metal contamination in the mangrove sediments and bioaccumulation in macrobenthos from industrial and other anthropogenic activity in the Cochin region Macrobenthic composition in mangroves of different districts of Kerala is also highlighted in this study.

Floristic diversity revealed 13 true mangroves in Cochin with higher density of *Acanthus ilicifolius*, *Exoecaria agallocha* and *Acrostichum aureum.* The Rhizophoraceae family represented maximum number of species (6 spp.). Station 6 (68400 ind.ha^{-1}) and station 5 (31100 ind.ha^{-1}) represented maximum density with higher abundance of *Acanthus ilicifolius* while station 1(7840 ind.ha^{-1}) represented least density. Eventhough Station 1 has lowest density; species diversity was maximum with 11 species of which *Avicennia officinalis* was the dominant vegetation. Station 3 and 4 have only seven species of mangroves and station 3 is unique in having *Avicennia marina* and *Sonneratia alba* in Cochin and most densest species was *Bruguiera cylindrica*, however in station 4 *Excoecaria agallocha* was predominant in terms of density.

Kerala experiences a typical climatic condition receiving South-west monsoonal rains during June to September. Hence rainfall was maximum during monsoon and minimum during pre-monsoon season. The average temperature of water (29°C) and sediment (30°C) showed significant temporal variation with higher values in pre-monsoon and lower in post-monsoon. The study area experienced alkaline pH for water (7.2) and sediment (7.3) in almost all stations but sediment of station 1 showed slightly acidic nature. Salinity was mixo-mesohaline (8.17 ± 7.19 PSU) in nature, with significant variation spatio-temporally. Mean salinity was higher in second year (10.8 PSU) period and was seasonally higher in pre-monsoon. The station 3 (Puthuvypin) being closer to Arabian sea, experiences higher salinity (14 PSU) whereas lower values were observed in S5 and S1.The mean turbidity was 4.5 NTU in mangrove stations but station 1 experiences maximum turbidity of 39 NTU. The dissolved oxygen level was moderate in mangrove stations with a mean value of 3.8±1.2 mg/L. Redox potential (Eh) exhibited highly reduced condition in mangrove sediments with significant spatial variations and was higher in S5 and S6 and lower in S4 and S1. Sediment texture was sand dominated (75%) almost in all stations except at station 1, where it is dominated by silt fraction. Organic matter showed a mean value of 31.8 ± 23.09 $g{\cdot}kg^{-1}$and organic carbon 18.5 ± 13.4 gkg^{-1}in mangrove stations of Cochin. Out of the six stations, station 1(Aroor) showed higher organic content due to higher litterfall in this region and low flushing due to its closed nature. Nutrients such as total sulphur (6502.47±5187.62 mg/kg) and phosphorus (581.88±387.40 mg/kg) were higher in organic rich sediments of Aroor (S1) and lower in Valanthakad. Pearson correlation analysis revealed highly significant positive correlation that existed between sediment variables such as organic matter, organic carbon, silt, clay, phosphorus, sulphur, turbidity whereas it was significantly negatively correlated to sand. PCA analysis revealed that edaphic factors (sediment factors) play crucial role in differentiating the mangrove zones and also in structuring the benthic community.

The distribution, seasonal variation and standing stock of benthic fauna in Cochin mangrove habitats and Kerala mangroves were studied. Macrofaunal communities in Cochin were represented by 4 groups with 11 classes represented by malacostraca, polychaeta, mollusca (bivalvia and gastropoda) and Others (sporadic representatives of Clitellata, Insecta, Collembola, Turbellaria, Nemertea, Nematoda and Actinopterigii). The macrobenthic density ranged between 0 to 11223 ind. m^{-2}

with a mean density 1628 ± 2283 ind.m^{-2}. ANOVA showed significant spatiotemporal variation with maximum density observed during second year and seasonally during post-monsoon. A total of 8437 organisms were collected in the grab samples, of which, 4629 (55 %) were malacostracan crustaceans, the dominant group during the entire study, 1955 were polychaetes (23 %), 1085 were molluscs (13 %) and 768 belonged to 'others' (9%). Macrobenthic biomass showed a mean value of 20.85 ± 44.70 g.m^{-2} with higher biomass in second year especially in monsoon season during study period. Density and biomass was higher in station 5 and lower in station 4. Maximum biomass was contributed by molluscs (64%), followed by polychaetes(19%), malacostracans(15%) and others(2%) in mangrove ecosystem.

Abundance – biomass curve(ABC) of entire mangrove stands showed a positive W-value 0.096 where biomass curve lies above abundance curve but much closer indicating overall good condition with moderate stress to the benthic fauna. Density and biomass positively correlated to sand and negatively correlated to organic matter, organic carbon, silt, clay, sulphur and phosphorus. Pearson correlation analysis carried out between macrobenthic density and biomass with mangrove plant density revealed significant positive correlation between mangrove plants especially *Acrostichum aureum* and *Rhizophora apiculata* to benthic density and biomass.

The mean numerical density of macrobenthic fauna in Kerala mangrove habitats was 279±300 ind.m^{-2}, where malacostraca dominates with 48% (32% of amphipods, 9% decapods and 7% tanaids) followed by polychaetes with 27%, molluscs 22%(bivalves 18% and gastropods 4%) and others 3% (2% oligochaetes and 1% benthic fishes). Among the 10 districts, mean density was maximum in Kannur (512± 364 ind.m^{-2}), where dense healthy mangroves were observed and minimum in Thiruvananthapuram (21±27 ind.m^{-2}). Crustaceans were the principal fauna in mangrove ecosystem with a mean density of 537±392 ind.m^{-2} and its predominance were seen in districts such as Ernakulam, Alappuzha, Kannur and

Kasargod. Polychaetes formed the second dominant fauna with a mean density of 302±218 ind.m^{-2}, however it was the predominant fauna of Kottayam and Kozhikode districts. Molluscs exhibited a mean density of 244±206 ind.m^{-2} and dominance was observed in Malappuram district. Bivalves were present in mostly all sites while gastropods were limited to Kasargod, Kannur, Ernakulam, Alappuzha and Kollam. The "other" groups such as oligochaetes, fishes exhibit a mean density of 33±52 ind.m^{-2},whereas fishes and oligochaetes were sporadically observed in few numbers in Kasargod, Ernakulam and Kollam.

The meiofauna collected seasonally from Cochin mangroves were identified up to group level and the mean numerical density recorded was 539 ± 1439 ind.10 cm^{-2}. Of these, 72.31 % were nematodes, forming the dominant group, followed by foraminiferans (25.14 %), harpacticoid copepods (1.70%) and "other" organisms (0.85%). 'Others' include tanaids, ostracods, polychaete larvae and few unidentified fauna. Monsoon season showed maximum numerical density (963 ind.10 cm^{-2}) followed by post-monsoon (715 ind.10 cm^{-2}) and pre-monsoon (478 ind.10 cm^{-2}). Foraminiferans were the dominant fauna in monsoon while nematodes in other seasons. Maximum density of meiofauna was observed in Puthuvype station (S3) 2438± 2994 ind.10 cm^{-2} and least in Aroor (S1) 40±42 ind.10 cm^{-2}.Correlation with plant density revealed a significant relationship exists between meiofauna and mangrove plants such as *A.marina* (r = 0.985), *B.cylindrica* (r = 0.864) and *S.alba* (r =0.985). *Avicennia marina* plant with their high initial nitrogen content, low C:N ratio and low hydrolyzable tannin concentration favour meiobenthic fauna in station 3. Benthic standing stock in Cochin mangrove was comparable to estuarine system but diversity was hampered due to severe pollution stress.

Benthic community structure and species assemblage in mangrove ecosystems in Cochin mangroves consist of a total of 48 species in 45 genera belonging to 38 families. Among the 48 species of macrofauna, Class Malacostraca (Crustacea) formed the dominant group with 17 species belonging to 4 orders. Class Polychaeta constituted second position with 11 species, Class Bivalvia (5 spp.) and

Gastropoda (4 spp.) in the Phylum Mollusca formed third position (9 spp.).The sporadic representatives were pooled together as ‘others’ with 11 species. Annually a total of 41 species were encountered during first year (2010-11) and 40 species in second year (2011-12). Nearly 8 species encountered during first year were not observed in second year and 7 species were added in second year together contributing to overall species diversity. Spatially, station 5 and 6 have maximum species diversity with 26 species each followed by station 3(25 spp.), then station 2 (22 spp.), station 1(15 spp.) and station 4 (10 spp.). Seasonally maximum species diversity was seen in pre-monsoon (37 spp.) and monsoon (34 spp.), while least in post-monsoon (32 spp.). Mean diversity indices such as Margalef richness (0.84), Shannon diversity (2.01), Simpson dominance (0.66) were higher in S6 while Pielou evenness index in S4 (0.94).

Among the macrofaunal groups, Malacostraca (Crustaceans) formed the most dominant fauna in terms of species structure. These were represented by 17 species in 11 families and 4 orders. The numerically dominant malacostracan species in the study area were amphipods such as *Idunella* sp., *Cheiriphotis geniculata*, and tanaids such as *Ctenapseudes chilkensis*, *Pagurapseudopsis gymnophobia*. Polychaetes formed the second dominant fauna in the community structure. These were represented by 11 species in 7 families and 4 orders. The numerically dominant polychaete species in the study area were *Dendronereis aestuarina* (71%) *and Capitella capitata (13%)*. Molluscs were represented by total of 9 species in 9 families. The numerically dominant molluscs were *Indosphenia* sp. (79 %), *Villorita cyprioides* (10 %). “Others” were represented by 11 species of 11 families. It includes oligochaete were the most represented group followed by insects, nemerteans, nematodes, turbellarians and benthic fishes.An oligochaete, *Tubificoides pseudogaster* (79%) and chironomid (18%) together contributed to 97 % density in “others” category.

Community structure analysis was carried out using various univariate and multivariate techniques. Species-accumulation curves reached the upper asymptote, indicating that the study area was sampled sufficiently and in first year period of monthly sampling, 41 species obtained, and during the second year period, 7 species were added, indicating sufficient sampling by second year period. Among the species estimators the minimum estimate was given by MM (Michaelis-Menten),45 spp. which is less than the number of species in sample (48 spp.). The maximum rating was given by Jacknife 2 (62 spp.). The funnel plot(TAXD) for Average taxonomic Distinctness (Δ+) and Variation in Taxonomic Distinctness (Λ+) depicted wider taxonomic spread (higher taxonomic distinctness) in species for stations such as S2,S3,S5 and S6 that lies within the expected limit of 95% confidence funnel. Hence these stations can be considered as pristine. However stations 1 and 4 are mostly out of the confidence funnel or on the border indicating less species spread (lower taxonomic distinctness) and most impacted of mangrove stations. The *k*-dominance plot indicated higher species dominance and diversity in first year (2010-2011) than second year. *Cheiriphotis geniculate*, *Ctenapsuedes chilkensis* and *Tubificoides psuedogaster* together contributed to 50% of species dominance in first year. In second year *Idunella* sp., *Dendronereis aestuarina*, *Indosphenia* sp., accounted for 50% of dominance. The *k*-dominance curve of species abundance data pooled for each station and station 4 is at the most elevated position that indicated lowest species diversity and station 5 and 6 represented lowest of all curves indicating high species diversity. The *k*-dominance plot indicated higher species dominance and diversity during pre-monsoon and lowest during post-monsoon.

Bray Curtis hierarchial clustering and SIMPROF test gave two distinct cluster patterns. First cluster formed of stations with high diversity and density (HDD) (S5 and S6) having 81.4% similarity while second cluster formed of stations with low diversity and density (LDD) (S1 ,S2 and S3) with 53.4% similarity and station 4 is an outlier. ANOSIM showed significant differences between clustered stations where R value lies away from 95% confidence limit or null distribution. SIMPER analysis revealed that the similarities or dissimilarities between the clustered mangrove stations might be due to differences in species assemblages, presence or absence of some unique species or the variation in abundance of predominant species. Species responsible for discrimination were abundance of *D.aestuarina, Idunella spp., C.geniculata and absence of C.capitata* in HDD stations while abundance of *T.psuedogaster, C.chilkensis* and absence of *Indosphenia* sp., *V.cusatensis*, *V.cyprinoides* in LDD stations. RDA triplot clearly demarcated spatial variations in environmental parameters and also represented how they influenced the macrobenthic communities. AMBI and BENTIX also separated the stations as moderately to heavily disturbed especially station 1 and 2 while undisturbed to moderately disturbed station 3 and 4 and undisturbed station 5 and 6 as per AMBI. Bentix showed bad ecological conditions for station 4,while moderate for station 1,2,3 and pristine for station 5 and 6.

In contrast to earlier studies by Sunil Kumar (1993) in Cochin mangroves, a significant decline in species diversity from 54 to 48 species in the present study could be seen, where polychaetes notably reduced from 33 to 11 species. A community shift was noticeable comparing with the Sunil Kumar (1993) where the dominance of polychaetes were replaced by malacostracan crustaceans in terms of density and molluscs in terms of biomass in the present study due to the destructive actions on mangrove vegetation and constructive actions for large scale developmental projects hampering the entire mangrove ecosystem.

Amphipods belonging to the class malacostraca are extremely abundant group of crustaceans but seems to be less studied, as their identification is so difficult due to their small size, morphology and fragile nature of the specimens, moreover, the taxonomy and systematics of this group was always inconsistent, confusing and under debate. In Cochin estuarine and mangrove systems, the taxonomic studies of these scuds or side swimmers were scanty. The present study described 9 species of amphipods, of which one was new to science. Out of six families, Eriopisidae contributes 3 species under 2 genus-*Victoriopisa* and *Eriopisella*. The most abundant species were *Idunella* sp. and *Cheiriphotis geniculata*. Taxonomic descriptions of these 9 species of amphipod including the new species *Victoriopisa cusatensis* sp.nov were given. The new species of amphipod under genus *Victoriopisa* (

family:Eriopisidae) was discovered from the Valanthakad mangrove island of Vembanad Lake. The species named "*cusatensis"* refers to the Cochin University of Science and Technology (CUSAT). The new species forms the 14th of the world under genus *Victoriopisa*, 9th from Asia and third from India. Currently two species of genus *Victoriopisa* was recorded from Vembanad lake, *V.chilkensis* and *V. cusatensis* sp. nov.

Holotype described was a male (8.6mm). *Victoriopisa cusatensis* sp. nov differs from other species of *Victoriopisa* by presenting: (1) a characteristic projection at dorsolateral margin of peduncle article 2 of antenna 1 in male while smooth in female; (2) broad, triangular lateral cephalic lobe; (3) a posteroventral tooth in epimeral plates; (4) presence of lateral and subapical spines in telson (5) smooth palm of gnathopod 2 without any excavations. Males and females generally similar and sexual dimorphism is not evident in gnathopod. Certain differences noted in females were smooth peduncle of antenna 1, less number of antennal flagellar articles, setal structure of pleopods and presence of oostegites. Due to difficulty in sampling, mangroves are least attracted for diversity studies, but there is 1:10 chance of newer species in this complex dynamic system.

Among the various pollutants reaching the mangrove, heavy metals pose higher risk to mangrove habitat especially in Cochin mangroves due to the vicinity of various industrial complex in and around Cochin estuarine–mangrove region. Concentrations of heavy metals in sediments usually exceed twice the magnitude than those of the overlying water. By considering the increased chance in metal bioaccumulation in mangrove plants and benthic organisms and subsequently into higher trophic levels of animals in the food webs, metal concentration studies were carried out. The concentration of 17 metals in mangrove sediments of Cochin were analysed,of which concentration of Li, Cd, Hg, Zn, Fe, Cr and Ag was considerably above the expected natural background levels. Silver which exhibit as a free metal or as silver sulphide in the reduced soil of mangrove ecosystem was observed to be increased by sixtyfold (4.6g/kg vs 0.07 g/kg background value) than its background value. ANOVA revealed that all the heavy metals exhibited strong spatial variation (F (5, 72), p<0.05). Station 1 with the fine sediment grain size complexed by mangrove leaf litters and organic matter was observed to retain a higher concentration of all the metals especially those of terrestrial origin such as Al, Fe, Cu, Cr, Mn, Ni, Pb, Zn and Li. Highly industrialised mangrove zone, Station 3, contain an elevated concentration of Ag and Li while lower concentration of the other metals. In S5 and S6, metals like As, Ag and Cd was below detectable level (BDL) and the other metals were in lower concentration.

Sediment quality analysis was carried out using standard NOAA SQuiRTs (Screening Quick Reference Tables) and metals such as Cr, Cu, Cd,Hg were above NOAA Effect Range Low (ERL), while Ni and Ag were above Effect Range Medium (ERM) in most of the stations.However Valanthakad zone (station 5 and 6) characterised by sand dominated texture and low organic carbon have lower metal concentration in sediment and were below NOAA ERL indicating lower risk to aquatic fauna in this island mangroves. The Ag and Cd were below detectable level (BDL) in this zone however mercury (0-0.68 mg kg-1) was infrequently observed and usually above ERL. The concentration of selected metals were compared with the Enrichment factor of 17 metals were analysed, of these 9 metals Ag, Cr, Pb, Zn, Cd, Hg, Li, Fe, Co showed enrichment in mangrove sediments. The metal, Ag exhibited extremely severe enrichment while Hg, Cd and Pb showed severe enrichment in the mangrove sediment. EF values of Ni, As, Mn, Cu, Sr, B, Ba were below one(EF< 1) indicating that these metals in sediment were not from human activities but by natural weathering. A negative to a positive range of Igeo index value was exhibited by Ag, Li, Hg, Cd, Cr indicating pollution of the system by these toxic metals while other metals exhibited a negative Igeo index indicating the lower contribution of individual metals to pollution problems in mangroves. Among the different metals, Ag exhibited highest Igeo index value that varied spatially. Contamination factor analysis revealed that metals like Ag, Cd, Li, Cr, Zn, Hg cause contamination in mangrove sediments. Ag causes very high contamination (CF>6), followed by cadmium and lithium, with considerable contamination. While metals like Cr, Zn, Hg causes moderate contamination (CF<3) in mangroves. Pollution load index value varied spatially, and it was comparatively higher in S1 (0.2-0.6) due to higher organic loading and relatively lower grain size that favour metal flocculation and adsorption. Lower PLI in S5 and S6 indicated very low pollution status.

In PCA analyses, the first principal component (PC1) exhibited 72.9 % of total variance and second principal component (PC2) with 5.9 % variance. PC1 correlates well with variables such as Al, Co, Ni, Mn, Zn, Fe, Cu, Cr, Li with higher positive loadings (above 0.9) indicating their natural origin by weathering. PC2 exhibited higher loading for Ag and Cd implying a common origin and similar reaction with chloride forming chloro-complexes, Since Ag and Cd are geologically rare metals with a natural background concentration < 1 $mg.kg^{-1}$, PC2 can be considered entirely anthropogenic, and their sources were attributed to industries in the vicinity of Cochin.

Interaction with environmental parameters showed a significant positive correlation of metals with silt, clay and organic carbon while significant negative correlation to sand ($p<0.05$). Salinity correlates well with arsenic, strontium and silver. Mangrove plant density also showed significant correlation with metals. *Avicennia officinalis*, the dominant mangrove of S1 showed significant correlation with mostly all metals except Ag, Cd, Co while *B.sexangula* correlates positively to Pb. *A.aureum, E.agallocha* correlates negatively to metals.

Bioaccumulation studies of toxic metals were carried out on benthic invertebrates such as polychaetes, amphipods, tanaids, molluscs and prawns from mangrove sites. Range concentration of metals in benthic fauna are as follows, cadmium (0-0.2075 mg/Kg), silver (0-0.32 mg/Kg), iron (504.1-2085.1 mg/Kg), lead (0-1 mg/Kg), lithium (0-0.473 mg/Kg), zinc (3.2-28.8 mg/Kg) and chromium (12.3-111). Higher concentration Fe, Cd, Zn and Ag were observed in tanaids whereas Pb, Li concentration was higher in polychaetes and Cr in prawn. Bioaccumulation factor (BAF) revealed that tanaids accumulate more Ag and Cd than prawn and amphipods whereas other metals accumulated more in polychaetes. AMBI index also revealed that tanaids were tolerant groups belonging to ecological group 3. Even though Pb was present in all fauna, bioaccumulated fraction was seen only in polychaetes and bivalves with reference to the sediment concentration, similarly Li in polychaetes only. Fe, Zn, Cr bioaccumulated in all selected fauna.

Mangroves are among the most productive marginal marine ecosystem, providing the right kind of provisioning and cultural services as well as for livelihood sustainability. But exploitation and encroachment of mangrove habitat has resulted in declining standing stock, reducing their ecological services especially disaster mitigation, sediment stabilisation ending up in serious ecological consequences.

Thus, this PhD work has been able to explore and document the benthic faunal community structure *vis-a-vis* their community shifts from the mangrove habitats of Kerala, in the context of the current environmental status and pollution problems mainly from heavy metal contamination. Since benthic fauna occupies all the micro and macro niche including the soft sediment, stilt roots, pnuematophores, tree trunks, leaves and crevices as grazers, tube dwellers, deposit feeders, shredders, scavengers and predators of mangrove habitat, the study has proved that the macroinvertebrate fauna are suitable monitoring tool of mangrove habitat as a whole.

The study has also reinforced our knowledge that due to large scale destruction of mangrove habitats especially in Cochin, severe community level changes could be documented, where predominantly the polychaete community was replaced by crustaceans, that were tolerant and opportunistic to organic pollution.Moreover heavy metal contamination and bioaccumulation problems is also a serious matter of concern in the mangrove habitats.

Therefore, based on the study, the future course of actions that can be implemented for the management and rejuvenation of the mangroves of Kerala are given below.

- The study has recognized that, the community structure of benthic fauna has been seriously affected in the mangrove habitats of Kerala. So, there is an urgent need in conserving the depleting mangroves of the state where over 40% of the habitat has been lost due to various developmental projects, especially in Puthuvype zone of Cochin. Mangroves are the oasis of diverse macro and micro invertebrates; the taxonomic and ecological significance of which are in conformity with CBD guidelines of the United Nations. Thus, these extremely unique, endemic benthic fauna and its resources are ideal treasures of biodiversity that are mostly endangered or vulnerable or threatened which needs to be explored and catalogued for our deeper understanding of the coastal ecosystem and its ecological integrity.

- Benthic macroinvertebrates are useful biomonitoring tool due to its ubiquitous, sedentary nature with wide spectrum of responses to environmental change. Some of the fauna like oligochaete *Tubificoides pseudogaster* and the tanaid species *Ctenapseudes chilkensis* and *Pagurapseudopsis gymnophobia*, indicate pollution stress in the present study that can alter the food web character and ecological niche in mangrove habitats. Thus, to ensure ecological well-being of mangroves, an integrated BENTHIC MONITORING AND MANAGEMENT PROGRAM is to be formulated for the state.
- Most of the mangroves are dumping yards of constructional, sewage and chemical wastes from industrial activity. This PhD work has been unique to document that silver, cadmium, chromium, lead and zinc has portended bioaccumulation in benthic fauna and trophic transfer tendencies in mangrove habitats. Moreover, the complex mangrove roots traversing the habitat, accumulate, absorb and also transfer the heavy metals and other contaminants from the sediment to different biotic components, that are associated to the plant, will in turn affect common man depending on the livelihood values of mangroves. So, collective efforts by governmental and non–governmental agencies should be initiated to curb intense and unscientific industrial activity for the proper habitat preferable conservation and preservation actions.

- Coastal regulation zone (CRZ) notification released in 2018 by the Ministry of Environment, Forests and Climate Change (MoEFCC) could trigger a wave of constructions across the state's coastal belt. This has lifted up the tourism sector and construction can be permitted 50 m away from buffer zone. The ecologically sensitive areas and the geomorphological features which play a role in maintaining the integrity of the coast especially mangroves categorised under CRZ-I A. This CRZ rule which give due importance to tourism will question the sustenance of mangrove habitats. The concerned authorities should initiate eco-friendly tourism without affecting the greenery of our coast.
- Mangrove habitats on the east and west coast of India are facing serious degradation and vulnerability issues from habitat modification, land use changes and climate variabilities. The remote sensing and high resolution GIS mapping can be employed for the identification and mapping of distinct mangrove ecosystem on a regular basis for the micro or macro level management plans of the habitats for long term conservation.
- Therefore, the overall protection of the mangrove habitats of Kerala with due importance to Cochin, and Kannur mangroves are urgently required for halting their wanton destruction and severe loss. Benthic faunal surveillance will be very much effective in the degrading and declining mangrove forest to check the healthy status and for proper rejuvenation measures to conserve the existing mangroves. Such initiatives can improve and balance the blue carbon economy, thereby maintaining the climate variabilities of the region. Since Kerala is a coastal state, and their economy is dependent on fishery, services of mangrove flora and mangrove fauna to ecosystem functions will propel the benefits to the growing economy to large sections of the population.

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6/25/2018

Home Cities Kochi

New species of amphipoda found in Vembanad lake

Researchers from the School of Marine Sciences at Cusat have reported the discovery of a new species of Victoriopisa (amphipoda) from the Valanthakad mangrove in Vembanad backwaters.

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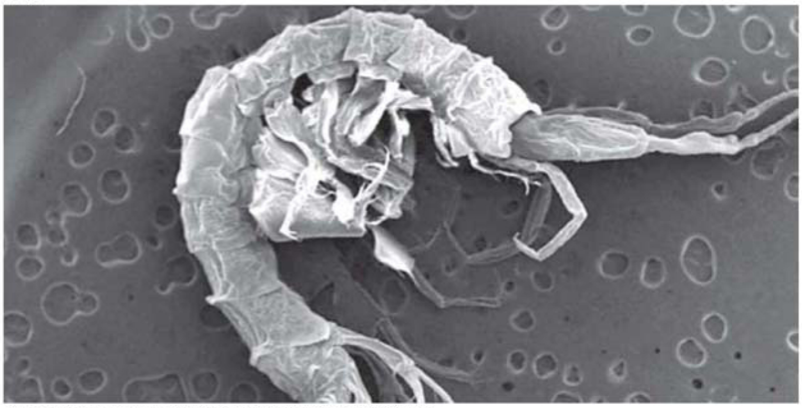

New species of Victoriopisa (Crustacea: Amphipoda: Eriopisidae) found in Vembanad backwaters

By Manoj Viswanathan

Express News Service

KOCHI:Researchers from the School of Marine Sciences at Cusat have reported the discovery of a new species of Victoriopisa (amphipoda) from the Valanthakad mangrove in Vembanad backwaters. During a study on mangroves and its associated fauna, the research team comprising Cusat School of Marine Biology head S Bijoy Nandan, Philomina

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6/25/2018

Joseph and P R Jayachandran discovered the new species at the Valanthakad Mangrove Island of Vembanad-Kol Wetland ecosystem and it has been named Victoriopisa cusatensis. This is the first time a species is named after Cusat.

The male amphipoda discovered by the team was 8.4 mm long, while the two females measured 7.6 mm and 6.7 mm. The species has five features that make them distinct from other species. They have a characteristic projection at dorsolateral margin of peduncle article 2 of antenna 1 in male which is smooth in the female. The species has broad, triangular lateral cephalic lobe and a posteroventral tooth in epimeral plates. The presence of lateral and subapical spines in telson and smooth palm of gnathopod 2 without any excavations are the other features.

"The discovery underscores the need to conserve our mangroves. Kerala had 14,000 hectares of mangroves a few decades ago which is fast shrinking due to construction activities. According to a recent report of the Forest Survey of India, the mangroves in Kerala has shrunken to around 600 hectares. The mangroves and wetlands in Kerala house many benthic organisms which are yet to be explored. We need good taxonomists to explore the rich biodiversity of our wetlands. Taxonomy is an integral component of biodiversity assessment and conservation. Our researchers are more focused on high-end research like molecular studies and disease management. Taxonomy is a vital tool for conservation at a time of habitat degradation," said Bijoy Nandan.

TAGS **New species** **amphipoda** **Valanthakad mangrove** **Vembanad backwaters**

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Printed from
THE TIMES OF INDIA

New amphipod species named after Cusat

TNN | Jun 17, 2018, 12.05 PM IST

KOCHI: A new species of amphipods that look like shrimps but very small in size has been identified in the Valanthakkad mangrove area. The species has been named Victoriopisa 'cusat'ensis after Cochin University of Science and Technology (Cusat).

This is the first time that a species is being named after Cochin University, said S Bijoy Nandan, head, department of marine biology, microbiology and biochemistry, Cusat.

"They are the ecosystem engineers which play an important role in the food chain in the area and belong to the wider group comprising shrimps, prawns and crustaceans," said Nandan.

These amphipods, live in the soil as well as in the waters and are very small — about 5 mm in size. "Lots of such species are there in the region and much needs to be discovered. As far as this species in concerned we are yet to know about its presence in numbers," he said. They live and play a vital role in the mangrove ecosystem. However, mangrove depletion has become a cause for concern. From the 14,0000 hectares of mangroves that were there in the state, it has come down to about 600 hectares.

കുസാറ്റിന്റെ പേരിൽ പുതിയ ജീവി

വളന്തക്കാട് ദ്വീപിൽനിന്നാണ് ആംഫിപോഡ് വർഗത്തിൽപ്പെട്ട ജീവിയെ കണ്ടെത്തിയത്

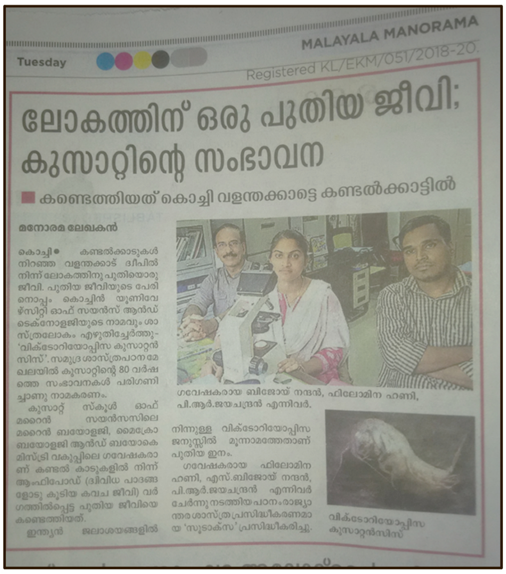
വളന്തക്കാട് ദ്വീപിൽ കണ്ടെത്തിയ പുതിയ ജീവി

കൊച്ചി
കൊച്ചിൻ യൂണിവേഴ്സിറ്റി ഓഫ് സയൻസ് ആൻഡ് ടെക്നോളജി (കുസാറ്റ്) യുടെ പേരിൽ കണ്ടൽക്കാടുകളിൽ നിന്ന് ഒരു പുതിയ ജീവി. കുസാറ്റ് സ്കൂൾ ഓഫ് മറൈൻ സയൻസസിലെ മറൈൻ ബയോളജി, മൈക്രോബയോളജി ആൻഡ് ബയോ കെമിസ്ട്രി വകുപ്പിലെ ഗവേഷകരാണ് കണ്ടൽക്കാടുകളിൽനിന്ന് ആംഫിപോഡ് വർഗത്തിൽപ്പെട്ട ജീവിയെ കണ്ടെത്തിയത്. മറൈൻ സയൻസ് മേഖലയിൽ കുസാറ്റ് നൽകിയ 80 സംഭാവനകളെ പരിഗണിച്ച് പുതിയ ജീവിക്ക് 'വിക്ടോറിയോപ്പിസ കുസാറ്റൻസിസ്' എന്ന് നാമകരണംചെയ്തു.

കൊച്ചിയിലെ വളന്തക്കാട് ദ്വീപിൽനിന്നാണ് വിക്ടോറിയോപ്പിസ് ജനുസ്സിൽപ്പെട്ട ജീവിയെ കണ്ടെത്തിയത്. ഇന്ത്യൻ ജലാശയങ്ങളിൽനിന്നുള്ള വിക്ടോറിയോപ്പിസ് ജനുസ്സിൽ മൂന്നാമത്തേതാണ് പുതിയ ഇനം. ഗവേഷകരായ ഫിലോമിനഹണി, എസ് ബിജോയ് നന്ദൻ, പി ആർ ജയചന്ദ്രൻ എന്നിവർ ചേർന്നു നടത്തിയ പഠനം അന്താരാഷ്ട്ര ജേർണലായ 'സൂടാക്സ്' പ്രസിദ്ധീകരിച്ചു.

കൊച്ചിയിലെ കണ്ടലുകളുടെ ആവാസവ്യവസ്ഥയെക്കുറിച്ചു നടത്തിയ പഠനങ്ങളിൽ ഏറ്റവും ജൈവവൈവിധ്യം നിറഞ്ഞ മേഖലയാണ് വളന്തക്കാട് പ്രദേശമെന്ന് ഈ പഠനങ്ങളിൽ തെളിഞ്ഞു.

നമ്മുടെ കായലിന്റെയും കണ്ടൽ വനങ്ങളുടെയും ജൈവവൈവിധ്യം നിലനിർത്താൻ ഇത്തരം ആവാസ വ്യവസ്ഥയുടെ സംരക്ഷണം ഉറപ്പാക്കേണ്ടതിലേക്കാണ് കണ്ടുപിടിത്തം വിരൽചൂണ്ടുന്നതെന്ന് മറൈൻ ബയോളജി, മൈക്രോ ബയോളജി ആൻഡ് ബയോ കെമിസ്ട്രി വകുപ്പ് മേധാവി പ്രൊഫസർ എസ് ബിജോയ് നന്ദൻ പറഞ്ഞു.



Tuesday — MALAYALA MANORAMA — Registered KL/EKM/051/2018-20.

ലോകത്തിന് ഒരു പുതിയ ജീവി; കുസാറ്റിന്റെ സംഭാവന

■ കണ്ടെത്തിയത് കൊച്ചി വളന്തക്കാട്ടെ കണ്ടൽക്കാട്ടിൽ

മനോരമ ലേഖകൻ

കൊച്ചി ● കണ്ടൽക്കാടുകൾ നിറഞ്ഞ വളന്തക്കാട് ദ്വീപിൽ നിന്ന് ലോകത്തിനു പുതിയൊരു ജീവി. പുതിയ ജീവിയുടെ പേരിനൊപ്പം കൊച്ചിൻ യൂണിവേഴ്സിറ്റി ഓഫ് സയൻസ് ആൻഡ് ടെക്നോളജിയുടെ നാമവും ശാസ്ത്രലോകം എഴുതിച്ചേർത്തു- 'വിക്ടോറിയോപ്പിസ കുസാറ്റൻസിസ്'. സമുദ്ര ശാസ്ത്രപഠന മേഖലയിൽ കുസാറ്റിന്റെ 80 വർഷത്തെ സംഭാവനകൾ പരിഗണിച്ചാണു നാമകരണം.

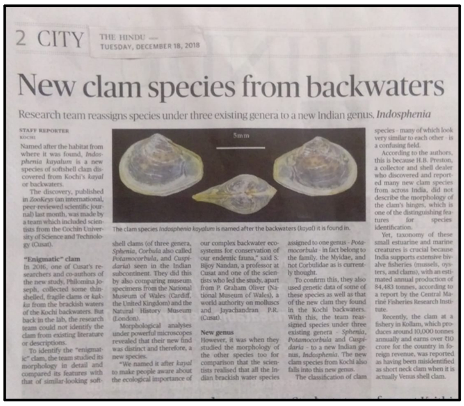
കുസാറ്റ് സ്കൂൾ ഓഫ് മറൈൻ സയൻസസിലെ മറൈൻ ബയോളജി, മൈക്രോ ബയോളജി ആൻഡ് ബയോകെമിസ്ട്രി വകുപ്പിലെ ഗവേഷകരാണ് കണ്ടൽ കാടുകളിൽ നിന്ന് ആംഫിപോഡ് (ദ്വിവിധ പാദങ്ങളോടു കൂടിയ കവച ജീവി) വർഗത്തിൽപ്പെട്ട പുതിയ ജീവിയെ കണ്ടെത്തിയത്.

ഇന്ത്യൻ ജലാശയങ്ങളിൽ നിന്നുള്ള വിക്ടോറിയോപ്പിസ ജനുസ്സിൽ മൂന്നാമത്തേതാണ് പുതിയ ഇനം.

ഗവേഷകരായ ഫിലോമിന ഹണി, എസ്.ബിജോയ് നന്ദൻ, പി.ആർ.ജയചന്ദ്രൻ എന്നിവർ ചേർന്നു നടത്തിയ പഠനം രാജ്യാന്തര ശാസ്ത്ര പ്രസിദ്ധീകരണമായ 'സൂടാക്സ്' പ്രസിദ്ധീകരിച്ചു.

ഗവേഷകരായ ബിജോയ് നന്ദൻ, ഫിലോമിന ഹണി, പി.ആർ.ജയചന്ദ്രൻ എന്നിവർ.

വിക്ടോറിയോപ്പിസ കുസാറ്റൻസിസ്



2 CITY — THE HINDU — TUESDAY, DECEMBER 18, 2018

New clam species from backwaters

Research team reassigns species under three existing genera to a new Indian genus, *Indosphenia*

STAFF REPORTER
KOCHI

Named after the habitat from where it was found, *Indosphenia kayalum* is a new species of softshell clam discovered from Kochi's *kayal* or backwaters.

The discovery, published in *ZooKeys* (an international, peer-reviewed scientific journal) last month, was made by a team which included scientists from the Cochin University of Science and Technology (Cusat).

The clam species *Indosphenia kayalum* is named after the backwaters (*kayal*) it is found in.

"Enigmatic" clam

In 2016, one of Cusat's researchers and co-authors of the new study, Philomina Joseph, collected some thin-shelled, fragile clams or *kakka* from the brackish waters of the Kochi backwaters. But back in the lab, the research team could not identify the clam from existing literature or descriptions.

To identify the "enigmatic" clam, the team studied its morphology in detail and compared its features with that of similar-looking softshell clams (of three genera, *Sphenia*, *Corbula* also called *Potamocorbula*, and *Cuspidaria*) seen in the Indian subcontinent. They did this by also comparing museum specimens from the National Museum of Wales (Cardiff, the United Kingdom) and the Natural History Museum (London).

Morphological analyses under powerful microscopes revealed that their new find was distinct and therefore, a new species.

"We named it after *kayal* to make people aware about the ecological importance of our complex backwater ecosystems for conservation of our endemic fauna," said S. Bijoy Nandan, a professor at Cusat and one of the scientists who led the study, apart from P. Graham Oliver (National Museum of Wales), a world authority on molluscs and Jayachandran P.R. (Cusat).

New genus

However, it was when they studied the morphology of the other species too for comparison that the scientists realised that all the Indian brackish water species assigned to one genus - *Potamocorbula* - in fact belong to the family, the Myidae, and not Corbulidae as is currently thought.

To confirm this, they also used genetic data of some of these species as well as that of the new clam they found in the Kochi backwaters. With this, the team reassigned species under three existing genera - *Sphenia*, *Potamocorbula* and *Cuspidaria* - to a new Indian genus, *Indosphenia*. The new clam species from Kochi also falls into this new genus.

The classification of clam species - many of which look very similar to each other - is a confusing field.

According to the authors, this is because H.B. Preston, a collector and shell dealer who discovered and reported many new clam species from across India, did not describe the morphology of the clam's hinges, which is one of the distinguishing features for species identification.

Yet, taxonomy of these small estuarine and marine creatures is crucial because India supports extensive bivalve fisheries (mussels, oysters, and clams), with an estimated annual production of 84,483 tonnes, according to a report by the Central Marine Fisheries Research Institute.

Recently, the clam at a fishery in Kollam, which produces around 10,000 tonnes annually and earns over ₹10 crore for the country in foreign revenue, was reported as having been misidentified as short neck clam when it is actually Venus shell clam.