THE SYSTEMATICS, FLORISTICS AND ECOLOGY OF SELECTED MANGROVES OF KERALA

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Certificate

This is to certify that the thesis entitled "**The systematics, floristics and ecology of selected mangroves of Kerala"** is an authentic record of research work carried out by Mrs. Preethy C.M. (Reg.No: 4192), under my supervision and guidance in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfillment 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 other degree/ diploma of the same Institution where the work was carried out, or to any other Institution.

It is also certified that all the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommended by the doctoral committee have been incorporated in the thesis.

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Prof (Dr.) S. Bijoy Nandan
(Supervising Guide)

Declaration

I hereby declare that the thesis entitled "**The systematics, floristics and ecology of selected mangroves of Kerala**" is an authentic record of research work carried out by me under the supervision and guidance of Prof (Dr.) S. Bijoy Nandan, Professor, Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Marine Biology, Cochin University of Science and Technology under the faculty of Maine 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-682016 **Preethy C.M.**

January 2019

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Preethy C.M.

Dedication

To my beloved daughter…Chingy!!

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Abbreviations and symbols

km	-	Kilometer
ha	-	Hectares
m	-	Meters
Cm	-	Centimeters
mm	-	millimeters
Km2	-	Square kilometre
µ mol	-	Micro mol
ppt	-	Parts per trillion
g	-	gram
mg	-	Milligram
µm	-	Micrometer
nm	-	Nanometer
L	-	Litres
ml	-	Milliliter
wt	-	Weight
m^2	-	Square meter
m^3	-	Cubic meters
°C	-	degree Celsius
y^1	-	per year
day^1	-	per day
<	-	less than
>	-	Greater than
%	-	Percentage
et al	-	et alli, and others
FSI	-	Forest Survey of India
KSD	-	Kasaragod
KNR	-	Kannur
KZH	-	Kozhikode
MLP	-	Malappuram

TSR	-	Thrissur
EKM	-	Ernakulam
KTM	-	Kottayam
ALP	-	Alappuzha
KLM	-	Kollam
TVM	-	Thiruvananthapuram
TDS	-	Total Dissolved Solids
DO	-	Dissolved Oxygen
BOD	-	Biological Oxygen Demand
GPP	-	Gross Primary Productivity
NPP	-	Net Primary Productivity
Spp.	-	Species
No.	-	Number
PCA	-	Principle component analysis
CCA	-	Canonical Correspondence Analysis
MN	-	Monsoon
POMN	-	Post monsoon
PRMN	-	Pre monsoon
MDS	-	Non-metric Multidimensional Scaling
ANOVA	-	Analysis of variance

Chapter 1

General Introduction and Scope of the Study

Contents

Mangroves being one of the unique ecosystems of the world, comprises of diverse groups of trees, shrubs, palms, vines and ferns that are salt tolerant and are well adapted to the intertidal regions. They form an interphase ecosystem between land and sea along the tropical and subtropical coastline of 128 countries and territories (Spalding et al., 2010). According to Tomlinson (1986), mangroves constitute taxonomically diverse angiosperm plants exhibiting a set of physiological adaptations. They conquer a major position amidst the world's most productive ecosystems and provide immense goods and services to the coastal communities.

From way back around 325 BC onwards these ecosystems were being studied. Nearchus in 325 BC and Theophrastus in 305 BC had given the description of the *Rhizophora* trees of the Red Sea and the Persian Gulf (Snedakar and Snedakar, 1984). Most of the ancient studies depicted *Rhizophora* genera as the mangrove (Macnae, 1968; Chapman, 1976). Later on as research continued, more published information were added to the existing scientific knowledge. Even though mangroves and mangrove ecosystems have been studied extensively, they are still poorly understood and are always a topic of debate. From the very beginning on wards, their definition was a topic of controversy and various definitions were put forward by many researchers.

1.1 Definition

The exact origin of the term ‘Mangrove’ is not known till now. However it is reported to be a combination of two words; the Portuguese word ‘Mangue’ meaning tree and the English word ‘grove’ meaning group of trees. The mangroves were first defined in the oxford dictionary in 1613 as tropical trees or shrubs found in the coastal swamps with tangled roots that grow above the ground. Macnae (1968) referred the individual plant or tidal forest or both as mangroves. The inter-tidal plant communities were termed as “**Mangrove swamp**” by Percival and Womersley (1975) and Chapman (1976). These ecosystems were also termed as **"Mangrove forest"** by Watson (1928); Chai (1975); Smitinand (1976) and as **"Tidal forest"** by few others (Schimper, 1903; Chengapa, 1944). In 1983, Thawatchai Santisuk defined mangroves as a complex of plant communities fringing the sheltered tropical shores whereas the term **‘Mangle’** and **‘Mangue’** were used by the Americans, the Spanish and the Portuguese to describe only the Rhizophora genus (Mepham and Mepham, 1984). However many others opined that mangroves are plants growing in between the highest and lowest tidal limits (Davis, 1940; Aubreville, 1964; Macnae, 1968; Blasco, 1975, 1977; Grzimek et al., 1976; Clough, 1982; Naskar and Guha Bakshi, 1987; Tomlinson, 1987). All the above definitions describe mangroves as salt tolerant plants of tropics and subtropics preferring a set of environmental conditions such as high salinity, alternate inundation with fresh and salt water and fine textured alluvial soil with loose mud or silt, rich in humus and sulphide. Thus most recent definition by Spalding et al., 2010, describes mangroves as trees or large shrubs, including ferns and a palm which normally grow in or adjacent to intertidal zone and which have developed special adaptations in order to survive in this environment.

1.2 Classification

As all the definitions of mangroves include trees, shrubs, ferns and even a palm, which always led to misperception among the researchers regarding their classification. There were remarkable disparities in the usage of the term mangroves and the number of plant species grouped under the mangrove category by different workers. Thus, a large number of classifications are available based on distribution, zonation and plant taxonomy. The most ancient classification was one which was used mainly for the Floridian mangroves, but was not considered to be a scientific classification and instead was of regional usage. According to this classification mangroves were divided into three types, the red mangroves, black mangroves and white mangroves. The species *Rhizophora mangle* (walking tree) with its large network of aerial prop roots were known as **red mangroves**. The dark brown to nearly black and scaly bark of *Avicennia germinans,* gave it the name **black mangrove**. *Laguncularia racemosa* is called the **white mangrove** with white and relatively smooth bark growing more to the landward region.

Mangroves include plant species from different families which are adapted to intertidal environment. Thus the usage of the term 'mangrove' and number of species grouped under this category show a wide discrepancy between different researchers. Many of the plant species growing in the intertidal regions also occupied other landward expanses, which led to controversy among taxonomist regarding their classification. In 1984, Mepham and Mepham used the term **"Potential mangroves"** or **"Frequent mangroves"** for the species growing in tidal zones. Duke (1992) opined that mangroves are taxonomically diverse plants that are well adapted to intertidal fluctuations. The mangroves were grouped into two types by Tomlinson (1986). The first group known as the **Major element** of mangals or true mangroves are those which have complete fidelity to the mangrove environment and the other known as **Minor elements** of mangals are not much conspicuous in mangrove habitats and might also prefer the peripheral regions of mangrove habitats. Later, Li and Lee (1997) used the term **'True mangrove'** and **'Semi-mangrove'** for the same. **'Mangrove associate'** was the advanced term used by many authors for the herbaceous, sub-woody and climber species occupying both mangrove habitat and its surrounding peripheral regions (Watson, 1928; Tomlinson, 1980; Chai, 1982; Mepham and Mepham, 1984 and Naskar, 1993).Most recently, Spalding et al. (2010) used the term '**Core mangroves'** for the species that dominates most of the mangrove communities.

1.3 Distribution

i. Global cover

Mangroves are distributed globally along 128 countries and union territories, largely restricted between 30^0S and 30^0N latitudes. Japan (31° 22'N) and Bermuda (32° 20' N) forms the northern extensions of their limit of occurrence while in south they extend to New Zealand (38° 03' S), Australia (38° 45' S) and on the East Coast of South Africa (32° 59' S) (Spalding, 1997; Kathiresan and Bingham, 2001).The estimation of global mangrove cover was first undertaken by FAO/UNEP Tropical Forest Resources Assessment in 1980. According to this report the total mangrove cover was estimated as 15.6 million hectares, distributed along 51 countries.

Table 1.1 Time scale changes in the global mangrove cover

Sl.No.	Author	Year	Area (million ha)	No. of countries
1	FAO/UNEP	1980	15.6	51
2	Saenger et al.	1983	16.5	65
	Groombridge	1992	19.8	87
3	Bunt	1992	10	-
4	Twilley et al.	1992	24	-
5	ITTO/ISME survey	1993	12.4	54
6	Fisher & Spalding	1993	19.8	91
7	Schwamborn & Saint-Paul	1996	14-15	-
8	Spalding et al.	1997	18.1	112
9	Aizpuru et al.	2000	17	112
10	FAO	2007	12-20	-
11	Giri et al.	2010	13.7	118
12	Spalding et al.	2010	15.2	123
13	Duke	2014	15.2	-
14	Hamilton & Casey	2016	8.3	118

Duke et al. in 1998 categorised the global mangrove distribution into two: the Atlantic East Pacific and the Indo-West Pacific zones. Based on the reports of Food and Agriculture Organisation (FAO, 2007) during 1980, approximately 18.9 million ha of mangroves existed globally. Later on the global coverage was variously estimated during the course of time (Table 1.1). Bunt (1992) estimated 10 million ha, Twilley et al., (1992) estimated 24 million ha, Schwamborn and Saint-Paul (1996) estimated 14 - 15 million ha and Saenger (2002) estimated 18 million ha of mangrove forest globally. The variations in the global coverage of mangroves existed due to the lack of information on countries with least mangrove cover. According to the survey by FAO, 3.2 million ha of mangrove cover has been lost during 1980-2005 period (FAO, 2007). Later on Spalding et al. (2010) ; Duke, (2013, 2014) reported a mangrove cover around 152000 sq.km globally along the equatorial region including Indonesia, Brazil, Western Port bay (Australia), Papua New Guinea and New Zealand. However, Hamilton and Casey (2016) reported only 8.3 million ha of global mangrove cover. The most recent remote sensing studies by Thomas et al. (2017) showed nearly 12% loss of mangrove cover between 1996-2010 with the greatest proportion of mangrove loss along Southeast Asia.

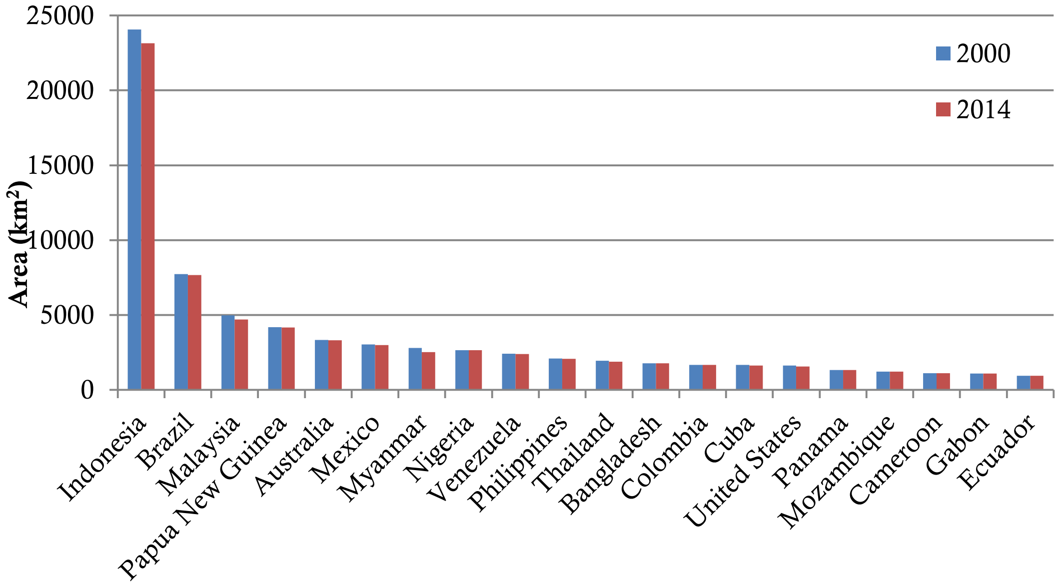

Figure 1.1 Global mangrove area changes from 2000 to 2014 (Hamilton & Casey, 2016)

Approximately 75% of the global mangroves are distributed in only 15 countries as per IUCN I-IV reports, of which 42% occur in Asia, 15% along North and Central America, 12% in Oceania and 11% in South America (Giri et al., 2011). The total area reported by Hamilton and Casey (2016) based on the landsat- based mangrove database portrayed a decrease of 54360 km^2 area from that reported by Giri et al., in 2011. The study also highlighted the changes in mangrove cover from 2000- 2014 (Figure 1.1). The most extensive mangroves were found mainly in four countries: Indonesia, Brazil, Australia and Mexico. Countries with small areas of mangroves were excluded during most of these studies, due to lack of information or because they did not significantly affect the world total mangrove cover.

ii. Indian Scenario

India having a coastline of about 7517km has both its coasts (West and East) fringed with mangroves. All the mangrove habitats are distributed between 69°E-89.5°E longitude and 7°N-23°N latitude in three distinct zones: East coast habitats, West Coast habitats and Island territories. The East coast has a coastline of about 2700km; facing Bay of Bengal contributes 70% of the total mangrove cover. The coastline of the west coast habitat is about 3000km, facing Arabian Sea and is characterized by the estuarine or backwater type of mangroves forming 12% of the total. The island territories have about 1816.6km coastline, supporting luxuriant mangrove growth along the small rivers, neritic islets and lagoons of the Andaman and Nicobar islands.

The mangrove cover in India was estimated to be 6,740km^2 by Krishnamurthy et al., 1987, which was only 7% of the total world mangroves. As per the latest study the total mangrove cover is 4,921km^2 (State of Forest Report, 2017). The mangrove area was estimated by several authors over the time (Table 1.2). Various studies had shown a decrease in mangrove forest cover during the course of time except certain citations by FAO(1980), Wacharakitty (1983), Spalding et al. (1995) and Aizpuru et al. (2000) and the discrepancy resulted may be due to changes in resolution of satellite imageries, differences in methodologies adopted and in scale of interpretation. But after the disaster of tsunami in December 2004, the importance of mangroves was realized by states and various conservation practices were also initiated by the government. Thus according to Forest Survey of India (2017) there is an increase in forest cover after 2009.

Table 1.2 Time scale changes in Indian mangrove cover

Year	Area (km^2)	Source
1957	6388	Waheed Khan
	5718	Mathauda, G.S.
1963	6819	Sidhu
1975	3565	Blasco, F.
1980	9100	FAO, UNEP.
1982	4046	Forest Survey of India
1983	9600	Wacharakitty, S.
1986	4255	Forest Survey of India
1987	6740	Government of India
	4200	Jagtap et al.
1988	4244	Forest Survey of India
1990	4256	Forest Survey of India
1992	4533	Forest Survey of India
1993	4474	Nayak, S.
1994	4827	Forest Survey of India
1995	5379	Spalding et al.
1997	4871	Forest Survey of India
2000	6700	Aizpuru et al.
	4482	Forest Survey of India
2003	4461	Forest Survey of India
2009	4639	Forest Survey of India
2011	4663	Forest Survey of India
2013	4628	Forest Survey of India
2015	4740	Forest Survey of India
2017	4921	Forest Survey of India

The Forest Survey of India (FSI) has been monitoring the mangrove cover using remote sensing and reported an overall area of 4,046 km^2 in 1987 (Table 1.3). During the course of time the extent of mangroves has undergone considerable changes in different states. In 1999, the estimated mangrove cover had increased to 4871 km^2, while the data dropped to 4448 km^2 in 2003. Even though the total extent of mangrove cover is losing in a considerable rate during the successive years the mangrove area had increased from 4662.56 km^2 in 2011 to 4921 km^2 in 2017. As per this current assessment, out of the 4921 km^2 of mangrove cover, 1481 km^2 are very dense mangroves (30.10%), 1480 km^2 are moderately dense mangroves

(30.07%) and 1960 km^2 are marked as open mangroves (39.83%). According to the FSI reports of 2017, the mangrove cover has increased (about 181 km^2) compared to 2015 assessment. Andhra Pradesh (37 km^2), Gujarat (33 km^2), Maharashtra (82 km^2), Odisha (12 km^2) and West Bengal (8 km^2) shows a positive change in mangrove area mainly due to plantation and regeneration activities.

Table 1.3 State-wise cover of mangrove forests of India (FSI, 2017)

State/UT	1987	1991	1995	1999	2001	2003	2005	2009	2011	2013	2015	2017
Andhra Pradesh	495	399	383	397	333	329	354	353	352	352	367	404
Goa	0	3	3	5	5	16	16	17	22	22	26	26
Gujarat	427	397	689	1031	911	916	991	1046	1058	1103	1107	1140
Karnataka	0	0	2	3	2	3	3	3	3	3	3	10
Kerala	0	0	0	0	0	8	5	5	6	6	9	9
Maharashtra	140	113	155	108	118	158	186	186	186	186	222	304
Odisha	199	197	195	215	219	203	217	221	222	213	231	243
Tamil Nadu	23	47	21	21	23	35	36	39	39	39	47	49
West Bengal	2073	2119	2119	2125	2081	2120	2136	2152	2155	2097	2106	2114
A & N Islands	686	971	966	966	789	658	635	615	617	604	617	617
Daman and Diu	0	0	0	0	0	1	1	1	2	1	3	3
Puducherry	0	0	0	0	1	1	1	1	1	1.63	2	2
Total	4046	4244	4533	4871	4482	4448	4581	4639	4663	4628	4740	4921

Based on the mangrove habitat, six different types of mangroves can be identified in India. The **Deltaic/ Estuarine** type existing along the east coast. Maximum area of mangroves falls under this category, distributed along the deltaic regions of the river Ganga, Mahanadi, Krishna, Godavari etc. The **Island mangroves** are the second dominant category, with best mangrove zones along the Andaman and Nicobar Islands. **Coastal mangroves** exist along the coastal areas. The mangroves of Karnataka, Goa, Maharashtra and Gujarat come under this category. **Mangroves of marshy backwaters** are found along the Kerala state. **Mangroves on the Gulf** are typically depicted by the mangroves distributed along the Gulf of Cambay and Kachchh. The mangroves of Lakshadweep and Minicoy islands portray the **mangroves of coral reef** category. India has a mangrove cover spread over 9 coastal states and 3 Union territories (Table 1.3). West Bengal, Gujarat, Odisha, Andhra Pradesh, Tamil Nadu, Andaman and Nicobar Islands, Kerala, Goa and Maharashtra are the major states occupying vast area of mangroves. Most of the immense mangrove patches are formed along the east coast due to the nutrient rich alluvial soil deposited by various rivers such as Ganga, Brahmaputra, Mahanadi, Godavari, Krishna and Cauvery.

Sunderbans is part of world's largest delta covering 80,000km^2 (40% in India and the rest in Bangladesh) forming the largest mangrove stand nourished by the sediment deposits of Ganga, Brahmaputra and Meghna rivers. The largest mangrove area found in this country is growing in the Sundarbans National Park, West Bengal (2106km^2) followed by Gujarat (1140km^2) and Andaman and Nicobar Islands (617km^2). Whereas Grace et al. (2010) reported 4,250 km^2 mangrove area under reserved forest and 1,781 km^2 under water in the Indian Sundarban forest. Sundarbans also exhibit rich species diversity with 24 species of true mangroves under 14 genera and 9 families (Jyotiskona and Soumyajit, 2014). *Avicennia* spp., *Excoecaria agallocha*, *Rhizophora* spp., *Bruguiera* spp., *Ceriops decandra*, *Phoenix paludosa* etc. are some of the dominant species of Sunderbans. Gujarat has the second largest mangrove distribution (1140km^2) of which 172 km^2 is moderately dense forest and 968km^2 area is open mangroves (FSI, 2017). The major dense mangroves are observed along the Gulf of Kachchh (798 km^2), Jamnagar (184 km^2), Bharuch (45 km^2), Ahmadabad (32 km^2) and Bhavnagar (22 km^2).

The mangrove vegetation of Andaman and Nicobar Islands is estimated to be 617km^2 (FSI, 2017) exhibiting rich species diversity. The fringes of creeks, backwaters and muddy shores of the islands are inhabited by mangroves and these were studied by many during the course of time. Ragavan (2014) reported 38 mangrove species belonging to 19 genera and 13 families. Species of *Rhizophora*, *Bruguiera*, *Aegiceras* and *Nypa* grow widely and are well preserved in these Islands. In Odisha, out of the 243km^2 of mangrove forest, 82 km^2 are very dense mangrove, 94 km^2 are moderately dense and 67km^2 are open mangrove vegetation (FSI, 2017). The Mahanadi delta, the Brahmani- Baitarani delta (Bhitarkanika mangroves) and the Balasore coast are lined by mangrove forests. Around 404 km^2 of mangrove cover occur in Andhra Pradesh, of which majority is open mangrove vegetation (213km^2) and the rest comes under moderately dense forest (191km^2). Most of the mangroves inhabit the network of creeks along the coast of Krishna, East and West Godavari, Nellore and Guntur. As per the reports of FSI (2017), the mangrove distribution in Maharashtra and Goa are 304km^2 and 26km^2 respectively. Most of the extensive patches of mangroves occur along the Mandovi estuary, Vasishta estuary, Savithri estuary, Kundalika estuary, the Dharamtar creek, Panvel creek, Vasai creek, Thane creek and Vaitarana creek. Out of the 49 km^2 of mangrove forest in Tamil Nadu, 23 km^2 are open vegetation and 25 km^2 are moderately dense mangroves (FSI, 2017). Pichavaram mangroves forest spread along Vellar and Coleroon estuarine areas exhibit luxuriant mangrove growth. Mangroves also occur near Vedaranyam, Kodiakarai (Point Calimere), Muthupett, Chatram and Tuticorin.

1.4 Mangrove adaptations

Mangrove ecosystems are subjected to continual mixing of water masses with different physico-chemical properties resulting in various changes in the hydrography and nutrient cycling. They are regularly water logged and often loaded with salt. Thus they have developed various structural and functional characters to endure these stressful environments. Developments of aerial roots for gas exchange, viviparous mode of reproduction, salt exclusion or excretion are some of the special adaptations of these flora. The true mangroves develop some or most of these features and have the ability to form pure stands compared to mangrove associates.

In order to withstand the loose saline sediments the plant develops various root modification. Each species has roots with different shape, size and structure to provide support, aeration during high tides and for removing excess salt. The species of *Rhizophora* develop numerous descending corky roots from the trunk base called as **prop roots** or **stilt roots**, which form a wide- spreading network around the trunk. The species of *Avicennia, Sonneratia* etc. develop negatively geotrophic peg-like roots called **pneumatophores.** These roots have numerous breathing pores (**pneumathodes**) and spongy cells which help to take up oxygen during low tide. In species of *Bruguiera, Ceriops* etc. the horizontal underground roots develop certain arched or knee shaped structures above the ground known as **knee roots.** Species of *Excoecaria* develop numerous irregular outgrowths at the trunk base known as

plank roots. Another type of root modification is the **buttress roots** (seen in *Xylocarpus*) which are certain plate like projections from the trunk base.

i. Stilt roots of *Rhizophora*

ii. Knee roots of *Bruguiera*

iii. Pneumatophores of *Avicennia*

iv. Pneumatophores of *Sonneratia*

v. Vivipary of *Bruguiera*

vii. Salt excretion in Avicennia

Plate1.1 (i-vi) Different types of adaptations in mangrove plants

A distinctive feature of mangroves is their ability to cope up with extreme variations in salt concentrations. **Salt exclusion** or **salt excretions** are the physiological adaptation which makes them survive in harsh saline environment apart from other terrestrial plants. Many of them exclude salt at the root level, preventing them from further entering the cell. The red mangroves are typical examples of salt excluding species at root level. On the other hand many are salt excreters like the black and white mangroves. These species develop thick and succulent leaves which store plenty of water thereby diluting the excess salt absorbed. The salt ions are also stored in large vacuoles of leaves which are later on shed down. The species of *Aegiceras, Avicennia, Acanthus* and *Aegialitis* also have specialised structures in leaves called salt glands for secreting out excess salt.

Viviparity and various dispersal mechanisms are the reproductive adaptations that give mangroves an increased chance for survival. Vivipary is the phenomenon of seed germination where the seed starts to germinate while they are still attached to their mother plant. This helps the young seedlings from facing extreme environmental condition like high salinity, muddy, oxygen deficient soil, tidal action etc. According to the favourability of environment conditions at the time of dispersal, they either take root in the sediment near the parent tree or they float with tides till a suitable substratum is attained for rooting. However species of *Avicennia*, *Aegiceras* and *Nypa* are crypto viviparous in nature, where the embryo starts growing and break through the seed coat while they are attached to mother plant but not the fruit wall. The shoots and roots are developed only after the falling of fruit on suitable ground with required temperature and salinity.

1.5 Importance and uses of Mangroves

Mangroves are dynamic ecosystem, providing surplus support and services to the adjacent ecosystems. The mangrove biodiversity alone provides approximately 1.6 billion US $ per year and support of coastal livelihoods worldwide (Polidoro et al., 2010).The mangrove ecosystems are utilised in two conducts: i) they are used as such or they are converted for other uses; ii) they are used for extracting various products. The benefits utilised from this ecosystem can be broadly divided into two categories: ecological benefits and economic benefits.

Ecologically speaking, mangroves are unique ecosystem, supporting diverse groups of marine and terrestrial flora and fauna. The tousled root system of *Rhizophora* spp. and the numerous pneumatophores of *Avicennia* spp. provide the best habitat for many marine fauna especially the juvenile forms. Many species of algae, sponges, fishes, crabs, prawns, insects etc. makes these roots their home. The mangroves are considered as ideal nursery grounds due to the following three reasons: (1) they are the most productive ecosystem and thus provide more food, (2) the structural complexity of mangrove roots and the soft sediment provide greater protection from predators, (3) these ecosystem also provide larval- retention mechanism by retaining the larval forms from being washed or disturbed by the local currents. They also support the avian fauna by providing suitable ground for roosting, feeding and breeding.

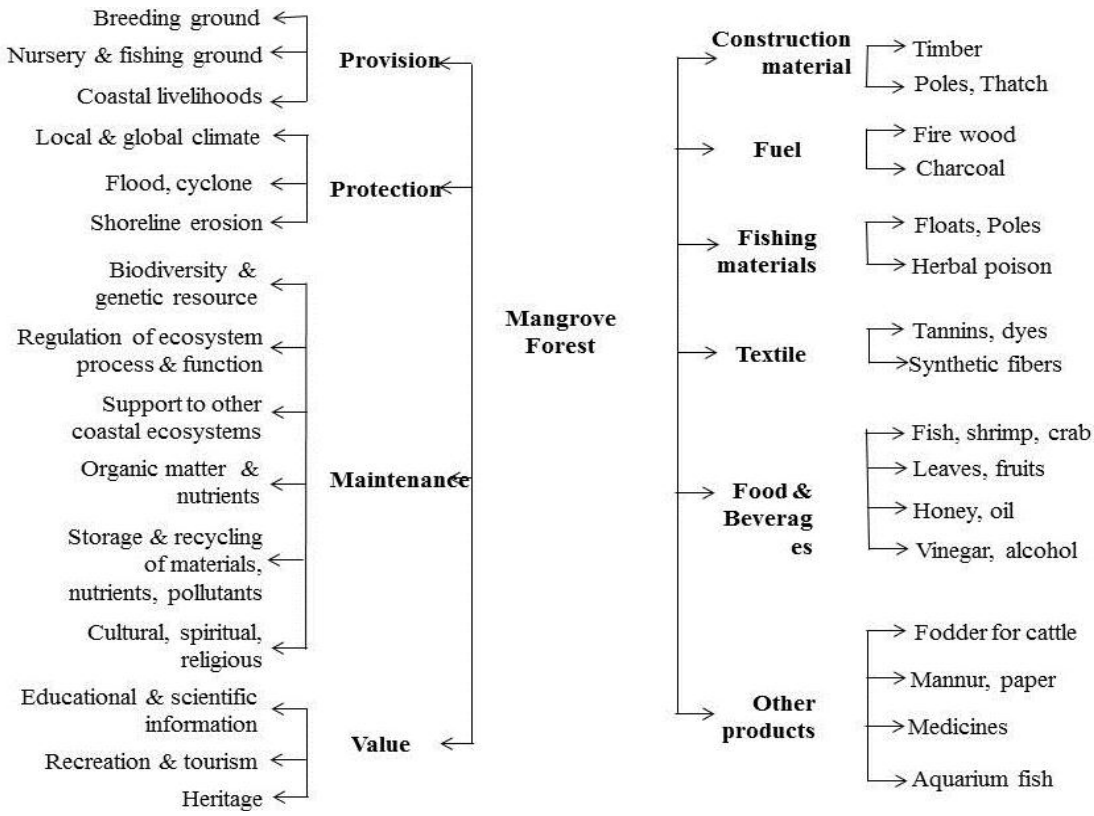

Figure 1.2 Importance and Uses of mangroves

Mangroves are the natural guards that protect the coastal areas in two ways: by preventing soil erosion and by reducing the effects of disasters such as tsunami and cyclones. Mangrove provide the mechanical protection for the shorelines by firmly holding the soil with its dense root system, thereby prevents from being washed away by the tidal actions. By filtering the sediments, they not only stabilize the coastline but also protect the adjacent coral reefs and seagrass meadows.

These green biosheild forms a natural barrier against the disasters. From years back, various studies have shown the role of mangroves in guarding the shorelines. The storm surges in 1970 and 1985 killed almost 3 lakh people in Bangladesh. In Odisha (1999), the cyclone that hit the coast, killed almost 10,000 people and destroyed many infrastructures. The dense belt of mangroves of Bhitarkanika played a major role in protecting human life and settlements in and around them, reducing the effects of cyclone. There are also reports on the tsunami (26 Dec. 2004) in Sumatra coast and Hudhud cyclone (12 Oct. 2014) in Andhra Pradesh and Odisha coast, which caused devastating damages to the coastal communities. All these reports clearly pointed out that the mangroves acted as the natural biosheild and the effects of these disasters were minimal at the coast guarded by them than the bear coastal plains. Mangroves also help in maintaining the coastal water quality and carbon sequestration. They remove, retain and cycle various nutrients, pollutants and other particulate matters thereby acting as a buffering unit, which filter out sediments and excess organic matter reaching the adjacent ecosystems.

From decades, there exist a strong relationship between mangroves and adjacent coastal communities. Globally major fish catches are directly or indirectly influenced by the relative abundance of mangroves. Mangroves yield both timber and non- timber products. Most of the mangroves have hardwood which is highly resistant to pests, fungi and salinity, thus they are used for various construction purposes. They are also exploited for extraction of pulp, wood chips and charcoal. Besides the good quality timber mangroves also provide enormous non- timber products such as tannins, food, fodder, oils, honey, wax, medicines etc. Many of the mangrove species also contain steroids, triterpenes, saponins, flavonoids, alkaloids and poisonous substances which impart them various medicinal properties. Besides these benefits, today mangroves are gaining importance as a source of income through tourism.

1.6 Are mangroves the next victims of human developments..?

For centuries, there exist an everlasting bond between mangroves and human. Being the most productive and biologically important ecosystem the goods and services they provide are innumerable. But during the recent years the increasing population pressure, industrial and urban development has significantly destroyed this pristine ecosystem. Worldwide, more than 60-80% of the mangrove forest cover has been removed over the last few decades due to increasing human interference such as land conversion for aquaculture and agriculture, coastal development and pollution. This alarming rate of destruction and degradation has devastating effects on biodiversity, food security and livelihoods of many coastal communities.

Indian mangroves were spread over 6740 km^2 (Krishnamurthy et al., 1987) which was about 7% of the Indian coastline. Later, due to wanton human destructions the mangrove cover has declined to 4921km^2 constituting about 3% of the global mangrove vegetation and 8% of Asian mangrove cover (India State of Forest report, 2017). Kerala also supported a dense and healthy mangrove patch along its coast. But the ecological importance of these ecosystems was never realized and was destroyed on large scale. The mangrove cover of Kerala declining from 700 km^2 to about 9 km^2 was clearly depicted in the reports of India State of Forest survey (2017).The mangroves of Cochin, Kerala are no exception in facing such a threat. Even though the Cochin mangroves are typically good breeding and feeding grounds for many estuarine and marine organisms, they were considered as a waste, sterile and unhealthy marsh for a long time.

Mangroves are declared as Costal Regulation Zone-I (CRZ-I), i.e. the most ecologically sensitive and important area, which requires protection of the highest order to strictly protect all the sensitive coastal and marine living ecosystems. In spite of this significant fact, the mangroves are facing wanton destruction due to human interferences. The present day urbanization rates and unsustainable economic development not only causes large scale clearing of these patches but also alters the ecological conditions. Even minor variations in the hydrology, sediment characteristics or tidal regimes cause noticeable changes or even mortality of species. In spite of knowing this significant facts mangroves are destroyed on large scale by man-made activities of different forms causing serious damage to these ecosystem and is silently becoming one of the reasons for global warming and climate change. It is clearly alarming that the mangroves that are shielding the coastline might become rare due to the population growth, fast rate of urbanization and unsustainable economic development. Reclamation of the green cover for various infrastructure projects has taken a toll on the ecological balance of this ecosystem.

To effectively counter the mangrove loss their restoration should be given the prime importance. Even though various steps have been initiated by few organizations to recover these already damaged and destroyed ecosystems, relatively few were only successful in long term rehabilitation. The long term restoration usually fails as the scientific aspects of these ecosystems are not being met. The scientific restoration method includes proper understanding on the ecology, reproduction and distribution patterns, of the mangrove species at the disturbed sites. Thus the present work is important and contextual as there are very limited empirical studies on the present status of mangroves of Kerala. The study would help in understanding the mangrove species, their zonation patterns and their ecology for further restoration measures.

1.7 Significance of the study

The world mangrove habitats have shown large scale decline in the species and resources, due to large scale reclamation and various developmental activities. Global studies have indicated that 38% (Thomas et al., 2017) of mangroves have declined and also in the Indian region due to human induced activities and natural calamities by about 54% (FSI, 2017). In the southern part of India, Kerala had a rich oasis and heritage of mangroves associated with all coastal life forms providing the food and various value added resources. However, analogy on the status of mangrove by Forest Survey of India and various other researchers in the country have documented a massive loss in the habitat as well as the floral and faunal resources.

Most of the documentation on the mangroves and ecology of habitat of Kerala emanated late 90’s and that too on the major mangrove habitats of Kannur and Kasaragod, but information on other mangrove patches especially Cochin region is still obscure to the scientific community. From the records and already available documents, the hypothesis is quiet true that there is a decline in the mangrove species number along with habitat changes sustaining to the ecological utilities of these priced habitats (Bijoy Nandan et al., 2015). But it is not understood whether the recent changes in environmental characteristics, the edaphic factors, is influencing the morphological characters of the mangroves in different region of the state; or whether it is governed by the changes in zonation pattern due to various developmental projects implemented in the region. Also there can be possibilities that changes in the environmental character along with climatic variability could also determine the phenotypic and genotypic characters of the plant. So in order to understand certain aspects of the mangrove habitats in Kerala, this PhD study was proposed as part of the Directorate of Environment and Climate Change, Govt. of Kerala funded project implemented in the Department of Marine Biology, Microbiology and Biochemistry by Prof. Dr. S. Bijoy Nandan, Principal Investigator.

1.8 Objectives

- To study the phenology, systematics of true mangroves and associated plants of Kerala with molecular characterisation of selected mangrove species.
- To provide detailed information on the diversity, distribution and zonation pattern of mangroves of Kerala.
- To study the anatomical features of selected true mangroves and associates.
- To assess the hydrography and productivity pattern of selected mangroves of Ernakulam.
- To provide a present status of mangrove cover of Kerala and to identify the threatened mangrove ecosystems, for future restoration programs.

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Chapter 2

Study Area and the Environment

Contents

Kerala, a state on Indian tropical Malabar Coast, lies between the Lakshadweep Sea and the Western Ghats. It has a landmass of 38,863 km^2 (1.18% of India), extending between northern latitudes 8°18' and 12°48' and eastern longitudes 71°52' and 77°22'. It has approximately 590km of Arabian Sea shoreline and is known for its palm-lined beaches, backwaters and network of canals. Kerala experiences humid equatorial tropical climate and has three distinct seasons: southwest monsoon (June- September), northeast monsoon/ post monsoon (October-January) and pre-monsoon (February- May). Geographically Kerala has three climatically distinct regions including the eastern highlands, the central midlands and the western lowlands. This tropical paradise is criss- crossed by a network of interconnected brackish water canals, lakes, estuaries and rivers. Vembanad backwater is the largest one in the state (200km^2) lying between Alappuzha and Kochi. Kerala bestowed with 1762 wetlands, have a total wetland area of 160590ha (National wetland atlas, 2011). Three of the world's Ramsar Convention listed wetlands, Sasthamkotta Lake, Ashtamudi Lake and Vembanad-Kol wetlands are in Kerala. Alappuzha (26079), Ernakulam (25065 ha), Kollam (13703 ha) and Thrissur (13285 ha) are the four wetland rich districts of the state.

Once these wetlands supported luxuriant mangroves patches; about 700km^2 (Ramachandran et al., 1986). But due to various developmental activities these ecosystems are under intense pressure. A large part of the mangrove habitats of the state has already been destroyed for construction of bridges, roads, harbours etc. The abundance and diversity of the mangroves and associated biota has declined due to reclamation of land for various purposes and unsustainable utilisation of these ecosystems. According to the recent reports, mangroves of Kerala had declined to about 9km^2 (Indian State of Forest Report, 2017).

The past and present distribution and diversity of mangroves in global (FAO, 2003; UNEP, 2007; Spalding et al., 2010) and Indian context (Basha, 1992; Naskar and Mandal, 1999; FSI, 2017) have been studied repeatedly. But an exact report on distribution and biodiversity of mangrove species on regional scale is still lacking. A scientific taxonomic evaluation on regional scenario is deficient from more than a decade. Existing literatures revealed that most of the mangrove ecosystems of Kerala were degrading due to constant threats from increasing population and other socio-economic pressures. As a result of extensive reclamation and intense anthropogenic activities, mangroves are restricted to small patches in most of the locations. The overall aim of the database is to generate the current diversity and distribution data of true mangroves and associated plants of Kerala in view of their ecological and productivity pattern. Thus the study was conducted on a regular basis from different mangrove habitats of the State as per the sampling plan given in Figure 2.1. All field sites were selected with the help of a Global Positioning System (Magellan ® Triton 200/300) after collecting information from local administration.

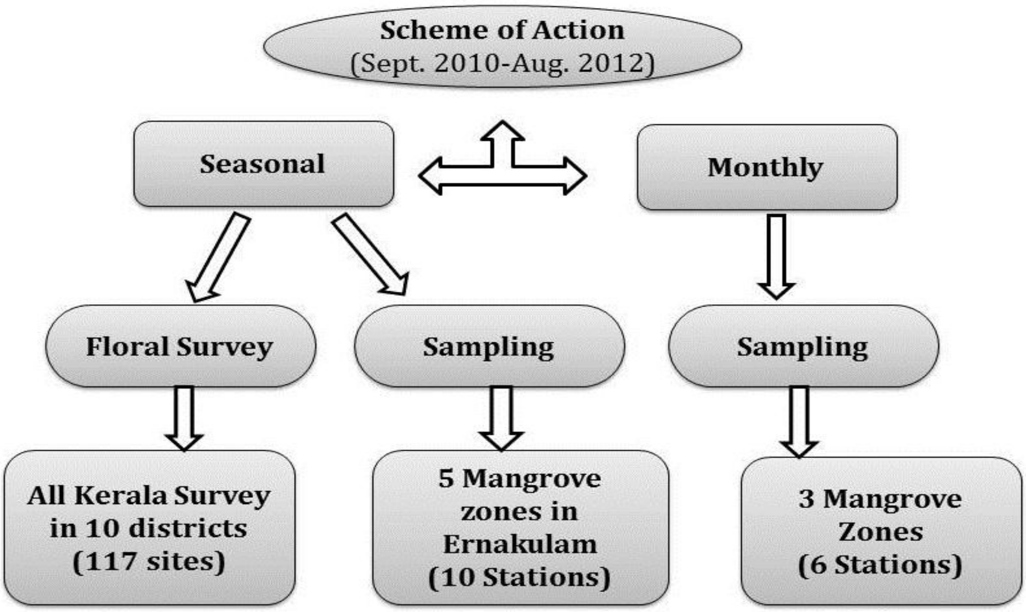


Figure 2.1 Field Sampling scheme

2.1 Kerala Survey

The all Kerala floristic survey was carried out throughout the Kerala coast to document the various mangrove patches scattered in the state and to identify the true mangrove flora and associates inhabiting these ecosystems. The floral survey was conducted covering almost ten districts of Kerala; Kasaragod (KSD), Kannur (KNR), Kozhikode (KZH), Malappuram (MLP), Thrissur (TSR), Ernakulam (EKM), Kottayam (KTM), Alappuzha (ALP), Kollam (KLM) and Thiruvananthapuram (TVM). Mangrove patches were identified from 117 sites along the ten districts, extending from Manjeswaram (12^0 42' 44″ N, 74^0 53' 14″ E) to Veli (8^0 30' 35″ N, 76^0 53' 25″ E).The entire study area was divided into three zones: the northern zone, the central zone and the southern zone.

2.1.1 Northern Zone

The northern zone included five districts: Kasaragod, Kannur, Kozhikode, Malappuram and Thrissur (Figure 2.2). In total, 51 sites were studied along the northern zone.

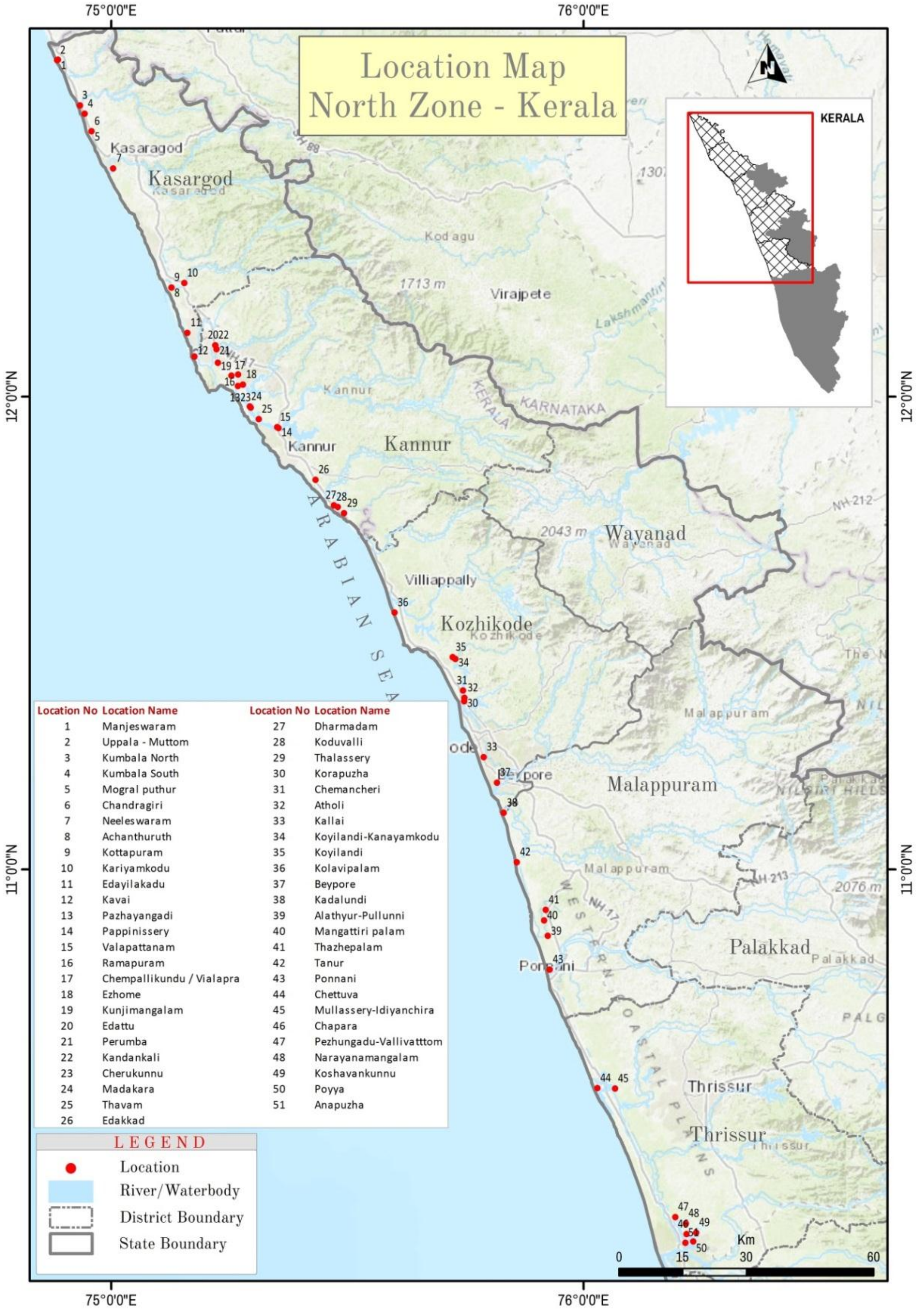


Figure 2.2 Mangrove sites along northern zone of Kerala

i. Kasaragod (KSD)

The Kasaragod district lies between 12^0 30’–12^0 39’N and 72^0 56’-74^0 59’ E. The estuaries and brackish water regions are shallow in nature (<5m deep) and are subjected to micro tidal actions. Of the 10 major kayals of the district, only Mogral, Kumbala and Pallam backwaters has representations of mangroves. All the three backwaters are connected to Arabian Sea and fishing practices are active in the regions. Sand extraction activities had greatly exploited the downstream of the backwaters.

The Kasaragod district mainly exhibited patchy and fringing type of vegetation along the upstream regions of Kayals of Kumbala, Mogral Puthur and backwaters at Pallam. Manjeswaram, Uppala – Muttom, Kumbala North, Kumbala South, Mogral puthur, Chandragiri, Neeleswaram, Achanthuruth, Kottapuram, Kariyamkodu, Edayilakadu and Kavai were the 12 transects selected for the study (Table 2.1).Ten true mangrove species were identified from the district. All the mangrove sites were estuarine type except Manjeswaram (coastal). Most of the sites were dominated by *Acanthus ilicifolius* as an under canopy stand followed by *Avicennia marina* and *Kandelia candel*. *Lumnitzera racemosa*, *Rhizophora mucronata* and *Avicennia officinalis* were the other prominent species observed along with occasional patches of *Aegiceras corniculatum* (Mogral puthur, Kariyamkodu and Edayilakadu). Even though small scale destruction was observed in Manjeswaram and Kumbala, the rate of destruction was less compared to other districts.

Table 2.1 Mangrove sites selected for floral survey along Kasaragod

No.	Station	Location
1	Manjeswaram	12° 42' 43.63" ; 74° 53' 13.63"
2	Uppala - Muttom	12° 42' 40.39" ; 74° 53' 7.979"
3	Kumbala North	12° 36' 55.69" ; 74° 56' 3.12"
4	Kumbala South	12° 35' 51.75"; 74° 56' 37.42"
5	Mogral puthur	12° 33' 39.56" ; 74° 57' 29.98"
6	Chandragiri	12° 33' 38.91" ; 74° 57' 29.08"
7	Neeleswaram	12° 28' 56.20" ; 75° 0' 14.75"
8	Achanthuruth	12° 13' 48.50" ; 75° 7' 38.46"
9	Kottapuram	12° 13' 49.22" ; 75° 7' 38.17"
10	Kariyamkodu	12° 14' 23.53" ; 75° 9' 16.52"
11	Edayilakadu	12° 8' 4.95" ; 75° 9' 40.03"
12	Kavai	12° 5' 4.70" ; 75° 10' 34.17"

i. Manjeswaram ii. Uppala iii. Mogral puthur

Plate 2.1 (i-iii). Mangrove zones of Kasaragod

ii. Kannur (KNR)

Kannur district exhibited luxuriant mangrove growth, with almost 500 hectares of undisturbed mangrove forests. Around 18 sites were studied along the Kannur coast from Pazhayangadi to Korapuzha (Table 2.2). Most of the mangrove habitats of Kannur were estuarine type (Pazhayangadi, Pappinissery, Valapattanam, Ramapuram, Chempallikundu / Vialapra, Ezhome, Perumba, Kandankali, Cherukunnu, Madakara, Koduvalli, Thalassery and Korapuzha) while landward type mangroves were observed in Kunjimangalam, Edattu and Edakkad. The mangroves of Dharmadam were of coastal type. Out of the 18 species of true mangroves identified in Kerala, 12 were observed in Kannur with characteristically giant sized trees of *Avicennia officinalis.* Matured and healthy patches of *Kandelia candel* were observed along Valapattanam estuary, which were rare in occurrence in other parts of the state. *Acanthus ilicifolius* was the most dominant species followed by *Avicennia marina* and *Excoecaria agallocha* while the species of *Bruguiera* (*B. gymnorrhiza* and *B. sexangula*) were completely absent. Innumerable rivers, estuaries and wetlands with comparatively low human settlements in the coastal areas, lesser developmental activities and human interference and extensive afforestation by forest departments and private entrepreneurs attributed to the rich species diversity and abundance in the district.

Table 2.2 Mangrove sites selected for floral study along Kannur

No	Station	Location
1	Pazhayangadi	12° 1' 19.59" ; 75° 16' 4.36"
2	Pappinissery	11° 55' 59.77" ; 75° 21' 14.00"
3	Valapattanam	11° 56' 6.28" ; 75° 21' 3.88"
4	Ramapuram	12° 2' 48.04" ; 75° 16' 6.45"
5	Chempallikundu	12° 2' 38.90" ; 75° 15' 16.52"
6	Ezhome	12° 1' 30.89" ; 75° 16' 44.00"
7	Kunjimangalam	12° 4' 16.61" ; 75° 13' 31.73"
8	Edattu	12° 6' 30.20" ; 75° 13' 12.79"
9	Perumba	12° 5' 59.31" ; 75° 13' 21.36"
10	Kandankali	12° 6' 30.20" ; 75° 13' 12.79"
11	Cherukunnu	11° 58' 34.93" ; 75° 17' 42.28"
12	Madakara	11° 58' 43.75" ; 75° 17' 36.67"
13	Thavam	11° 57' 7.16" ; 75° 18' 43.66"
14	Edakkad	11° 49' 25.75" ; 75° 25' 56.38"
15	Dharmadam	11° 46' 11.60" ; 75° 28' 17.18"
16	Koduvalli	11° 45' 58.64" ; 75° 28' 45.55"
17	Thalassery	11° 45' 32.76" ; 76° 29' 38.68"
18	Korapuzha	11° 21' 20.19" ; 75° 44' 49.81"

i. Valapattanam

ii. Thavam

iii. & iv. Thekkumbhagam Islands

Plate 2.2 (i-iv) Mangrove zones of Kannur

iii. Kozhikode (KZH)

The mangrove patches extending from Chemancheri (11° 22' 42.20", 75° 44' 40.56") to Beypore (11° 11' 0.67", 75° 48' 59.04") were studied along the district (Table 2.3). Of the 8 sites studied, except Kadalundi and Kolavipalam (coastal) all the mangrove habitats were of estuarine type (Chemancheri, Atholi, Kallai, Kariyamkodu, Koyilandi and Beypore). Beypore, Kallai, Koyilandi, Kolavipalam and Kadalundi had good patches of mangroves but were also facing threats due to unscientific land use pattern and real estate activities. The major species were *Avicennia officinalis* followed by *Acanthus ilicifolius* and *Acrostichum. Sonneratia caseolaris* also dominated many of the sites along with *Avicennia officinalis* and *Rhizophora mucronata.*

Table 2.3 Mangrove sites selected for floral study along Kozhikode

No.	Stations	Location
1	Chemancheri	11° 22' 42.20" ; 75° 44' 40.56"
2	Atholi	11° 21' 46.15" ; 75° 44' 51.39"
3	Kallai	11° 14' 15" ; 75° 47' 17.55"
4	Kadalundi	11° 7' 10.91" ; 75° 49' 50.48"
5	Koyilandi-Kanayamkodu	11° 26' 42.07" ; 75° 43' 42.13"
6	Koyilandi	11° 26' 55.28" ; 75° 43' 20.78"
7	Kolavipalam	11° 32' 35.01" ; 75° 35' 59.46"
8	Beypore	11° 11' 0.67" ; 75° 48' 59.04"

iv. Malappuram

Malappuram district exhibited less extent of mangroves compared to other districts of northern zone. The mangrove patches extended from Alathyur- Pullunni to Ponnani. All the five sites studied showed estuarine type of mangroves (Table 2.4). Of the seven true mangrove species identified, *Acanthus ilicifolius*, *Avicennia officinalis*, *Acrostichum aureum* and *Sonneratia caseolaris* were the dominant species. Certain sites showed the prevalence of *Excoecaria agallocha* (Ponnani) and *Kandelia candel* (Mangateripalam).

Table 2.4 Mangrove sites selected for floral study along Malappuram

No.	Station	Location
1	Alathyur-Pullunni	10° 51' 34.27" ; 75° 55' 26.65"
2	Mangateripalam	10° 53' 31.19" ; 75° 54' 57.70"
3	Thazhepalam	10° 54' 51.51"; 75° 55' 10.19"
4	Tanur	11° 0' 54.61" ; 75° 51' 30.13"
5	Ponnani	10° 47' 0.77" ; 75° 55' 5.66"

i. Kadalundi

ii. Mangathiripalam

Plate 2.3 (i, ii) Mangrove zones of Malappuram

v. Thrissur (TSR)

In Thrissur district mangroves are mainly confined to the backwaters of Chettuva, Kodungallur, Azhikode and few patches in Poyya, Anapuzha and Mullassery. The rivers of Kecheripuzha and Karanjirapuzha join with Arabian Sea through the Chettuva estuary and were marked with significant stretches of mangrove vegetation. Chettuva mangroves were completely demarcated by backwater systems exhibiting island ecosystem. The mangrove patches were studied from Chettuva to Anapuzha, covering around eight sites in the district (Table 2.5). Chettuva, Mullassery-Idiyanchira, Koshavankunnu, Poyya and Anapuzha exhibited estuarine type of mangroves while landward mangroves were evident in Chapara, Pezhungadu-Vallivatttom and Narayanamangalam.

Table 2.5 Mangrove sites selected for floral study along Thrissur

No.	Station	Location
1	Chettuva	10° 32' 10.28" ; 76° 0' 18.72"
2	Mullassery-Idiyanchira	10° 32' 11.32" ; 76° 3' 59.18"
3	Chapara	10° 13' 43.75" ; 76° 13' 3.54"
4	Pezhungadu-Vallivatttom	10° 15' 53.67" ; 76° 11' 37.89"
5	Narayanamangalam	10° 15' 5.18" ; 76° 12' 57.70"
6	Koshavankunnu	10° 13' 55.30" ; 76° 14' 17.12"
7	Poyya	10° 12' 47.84" ; 76° 13' 53.65"
8	Anapuzha	10° 12' 37.51" ; 76° 12' 54.89"


i. & ii. Chettuva


iii. Anapuzha iv. Mullassery

Plate 2.4 (i-iv) Mangrove zones of Thrissur

Acanthus ilicifolius followed by *Avicennia officinalis* and *Rhizophora mucronata* were the densest species among the nine true mangroves identified. Other species such as *Bruguiera*, *Excoecaria*, *and Avicennia* were also distributed towards the landward side. Ecotourism has also taken a toll of this fragile community resulting in a huge decline of mangrove cover. Real estate activities (mainly in the Pulloot region of Kodungallur) have also affected the natural regeneration.

2.1.2 Central zone

The central zone included two districts: Ernakulam and Kottayam. Altogether 24 sites were surveyed along both districts (Figure 2.3). Extended patches of mangroves were found along the Ernakulam district while the mangroves were much lesser in Kottayam district.

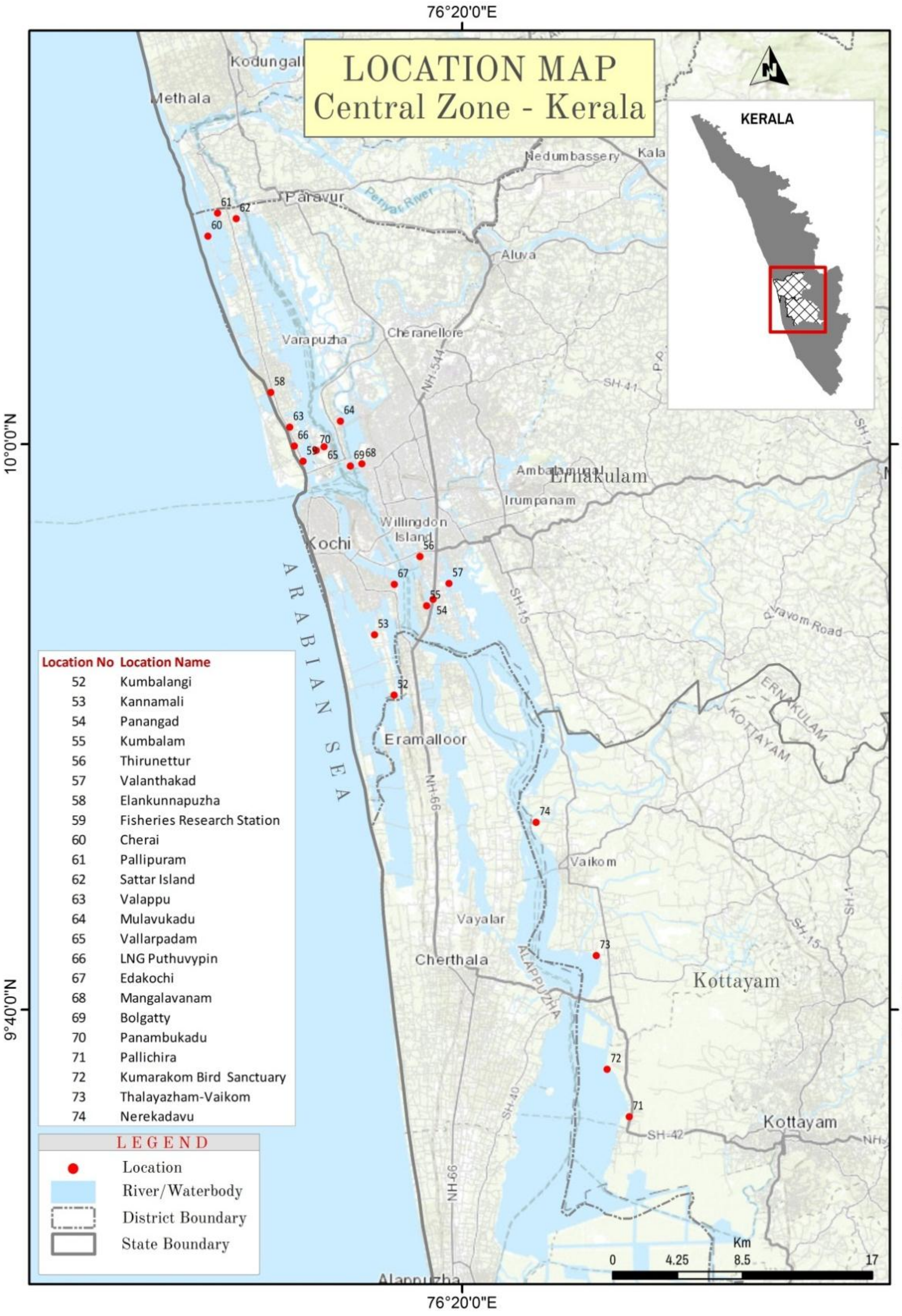


Figure 2.3 Mangrove sites along central zone of Kerala

i. Ernakulam (EKM)

Mangrove patches from twenty one sites extending from Kumbalangi to Sattar Island were studied along Ernakulam district (Table 2.6). Most of the sites such as Kumbalangi, Panangad, Aroor south, Kumbalam, Thirunettur, Valanthakad, Sattar Island, Mulavukad, Vallarpadam, Edakochi, Mangalavanam, Bolgatty and Panambukad portrayed estuarine mangrove type while Chellanam, Kannamali, Elankunnapuzha, Fisheries Research Station Puthuvypin, Valappu, LNG Puthuvypin mangroves were coastal type and only Pallipuram exhibited landward mangrove habitat. Of the fourteen species of true mangroves identified from Ernakulam district, *Avicennia officinalis, Excoecaria agallocha* and *Rhizophora mucronata* were the frequent species. Many of the rare species like *Rhizophora apiculata, Avicennia marina, Sonneratia alba* and *Bruguiera sexangula* were also noted in the district. Inspite of rich species diversity, maximum extent of destruction was also observed in this district mainly in regions of Panangad, Goshree, Vallarpadam, Vypin, Edakochi and Nettoor. Only conservation initiative is the declaration of Mangalavanam as bird sanctuary.

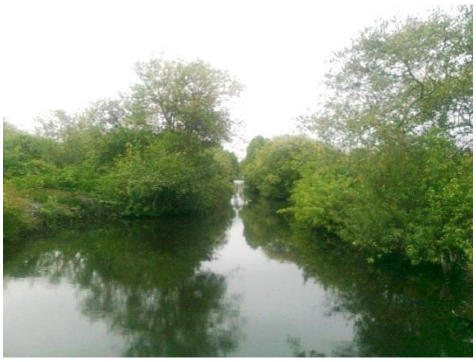
Table 2.6 Mangrove sites selected for floral study along Ernakulam

No	Station	Location
1	Kumbalangi	9° 51' 7.2" ; 76° 17' 35.59"
2	Chellanam	9° 47' 43.8" ; 76° 17' 57.11"
3	Kannamali	9° 53' 15.50" ; 76° 16' 54.26"
4	Panangad	9° 54' 30.81" ; 76° 18' 58.49"
5	Aroor south	9° 51' 45.50" ; 76° 18' 49.35"
6	Kumbalam	9° 54' 17.02" ; 76° 18' 44.81"
7	Thirunettur	9° 56' 1.49" ; 76° 18' 30.56"
8	Valanthakad	9° 55' 4.22" ; 76° 19' 31.87"
9	Elankunnapuzha	10° 1' 44.86" ; 76° 13' 2.53"
10	Fisheries Research Station Puthuvypin	9° 59' 12.91" ; 76° 13' 47.06"
11	Cherai	10° 5' 1.14" ; 76° 6' 30.49"
12	Pallipuram	10° 4' 42.77" ; 76° 6' 34.99"
13	Sattar Island	10° 6' 41.29" ; 76° 6' 35.20"
14	Valappu	10° 0' 22.89" ; 76° 7' 56.60"
15	Mulavukad	10° 0' 47.26" ; 76° 9' 7.2"
16	Vallarpadam	9° 35' 44.77" ; 76° 9' 10.36"
17	LNG Puthuvypin	9° 35' 18.09" ; 76° 8' 20.39"
18	Edakochi	9° 55' 02.41" ; 76° 17' 36.29"
19	Mangalavanam	9° 59' 18.09" ; 76° 16' 27.59"
20	Bolgatty	9° 59' 13.43" ; 76° 16' 03.14"
21	Panambukad	9° 59' 46.53" ; 76° 14' 50.63"

i. Puthuvypin

ii. Near LNG terminal site

iii. Mangalavanam



iv. Malippuram

v. Chellanam

vi. Valanthakad

Plate 2.5 (i-vi) Mangrove zones of Ernakulam

ii. Kottayam (KTM)

Kottayam district represented fragmented patches of mangroves along Kumarakom Bird sanctuary, Pallichira and Vaikom. Three sites at Pallichira (9° 36' 12.34", 76° 25' 53.97"), Kumarakom Bird Sanctuary (9° 37' 53.03", 76° 25' 6.92") and Thalayazham-Vaikom (9° 41' 54.41", 76° 24' 43.99") were studied. All the ten mangroves species identified mostly occupied landward positions. *Acrostichum aureum*, *Acanthus ilicifolius* and *Bruguiera sexangula* were the major species. Good patches of *Excoecaria indica* which was rare in other parts of the state were observed in this district. Kumarakom mangroves were facing threats due to tourism activities.

i. & ii. Kumarakom Bird Sanctuary

Plate 2.6 (i-ii) Mangrove zones of Kottayam

2.1.3 Southern zone:

The southern zone included three districts: Alappuzha, Kollam and Thiruvananthapuram (Figure 2.4). Of all the 43 sites studied along the southern zone, the sites of Thiruvananthapuram exhibited least mangrove extent and species diversity.

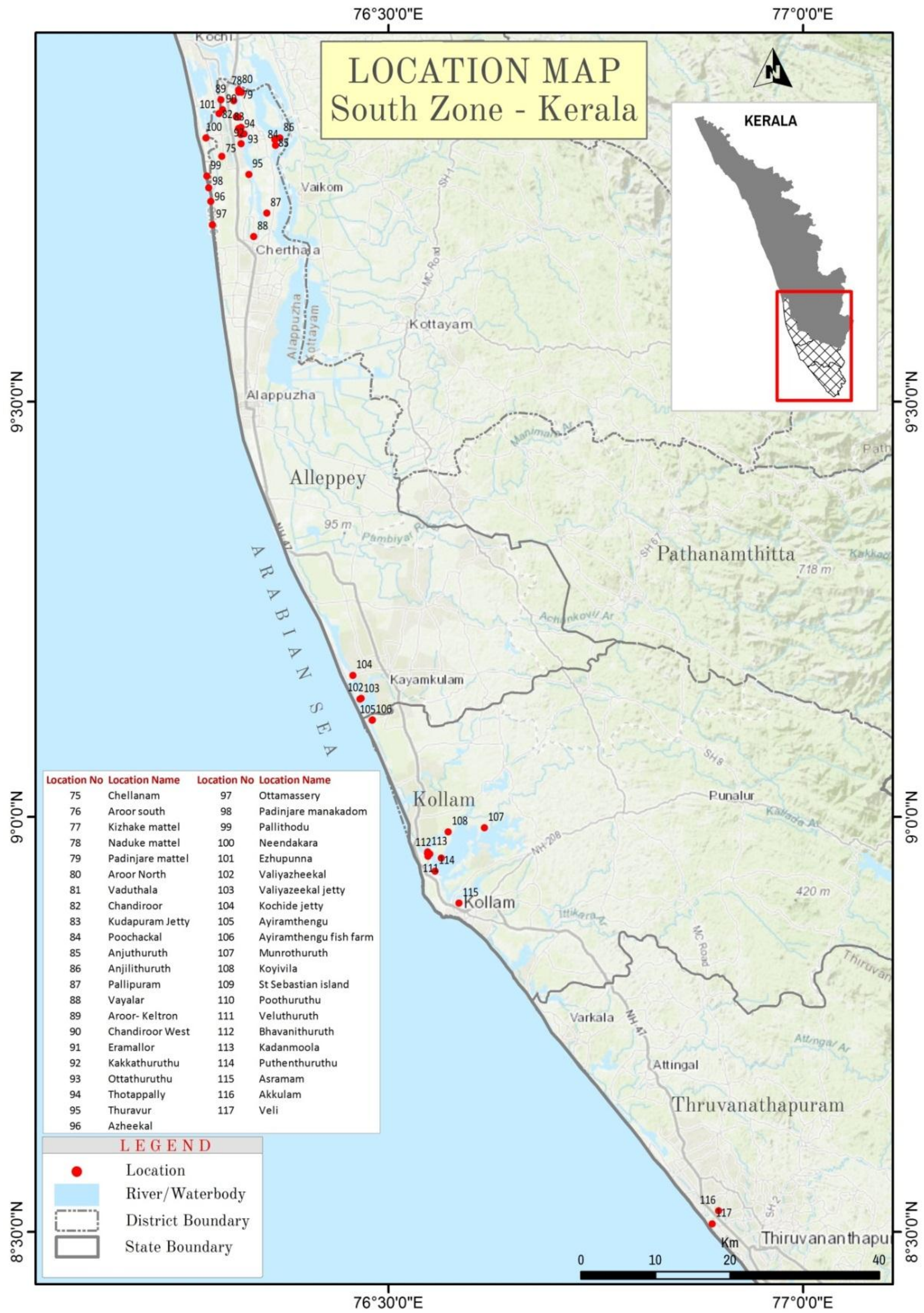


Figure 2.4 The mangrove sites along southern zone of Kerala

i. Alappuzha (ALP)

Mangroves of Alappuzha district fringed along the coast of Kayamkulam and Vembanad backwaters. Estuarine type of mangrove patches was common among the 28 sites studied along the coast extending from Nerekadavu to Kochide jetty (Table 2.8). The district exhibited rich species diversity (14sps.) with *Acanthus ilicifolius*, *Excoecaria indica* and *Rhizophora mucronata* as the major species. Many of the rare species such as *Lumnitzera racemosa*, *Excoecaria indica*, *Aegiceras corniculatum* etc. were noted in this district. Certain mangrove sites were invaded by mangrove associates like *Cerebra odollum, Clerodendron inermi*, *Derris trifoliata* and *Pandanus tectorius d*ue to obstruction in saline water availability.

Table 2.7 Mangrove sites selected for floral study along Alappuzha

No	Station	Location
1	Nerekadavu	9° 46' 37.30" ; 76° 22' 36.87"
2	Kizhake mattel	9° 52' 22.29" ; 76° 19' 22.58"
3	Naduke mattel	9° 52' 25.39" ; 76° 19' 13.44"
4	Padinjare mattel	9° 52' 21.68" ; 76° 19' 10.59"
5	Aroor North	9° 52' 31.54" ; 76° 19' 9.66"
6	Vaduthala	9° 50' 34.54" ; 76° 19' 8.50"
7	Chandiroor	9° 50' 35.33" ; 76° 18' 59.75"
8	Kudapuram Jetty	9° 49' 49.18" ; 76° 19' 20.71"
9	Poochakal	9° 48' 32.03" ; 76° 21' 50.54"
10	Anjuthuruth	9° 48' 56.91" ; 76° 21' 46.94"
11	Anjilithuruth	9° 49' 3.36" ; 76° 22' 9.62"
12	Pallipuram	9° 43' 37.77" ; 76° 21' 12.56"
13	Vayalar	9° 41' 56.32" ; 76° 20' 15.89"
14	Aroor- Keltron	9° 51' 49.46" ; 76° 17' 48.3"
15	Chandiroor West	9° 51' 6.69" ; 76° 17' 59.92"
16	Eramalloor	9° 49' 44.14" ; 76° 19' 9.66"
17	Kakkathuruthu	9° 48' 38.98" ; 76° 19' 21.21"
18	Ottathuruthu	9° 49' 21.79" ; 76° 19' 34.17"
19	Thotappally	9° 49' 18.69" ; 76° 19' 19.73"
20	Thuravoor	9° 46' 25.39" ; 76° 19' 54.33"
21	Azheekal	9° 44' 28.75" ; 76° 17' 9.34"
22	Ottamassery	9° 42' 47.19" ; 76° 17' 16.69"
23	Padinjare manakadom	9° 45' 27.10" ; 76° 17' 0.56"
24	Pallithodu	9° 46' 17.97" ; 76° 16' 52.75"
25	Neendakara	9° 49' 3.86" ; 76° 16' 48.14"
26	Ezhupunna	9° 50' 49.55" ; 76° 17' 44.91"
27	Valiyazheekal	9° 8' 33.71" ; 76° 28' 1.77"
28	Valiyazheekal jetty	9° 8' 30.58" ; 76° 27' 57.13"
29	Kochide jetty	9° 10' 13.58" ; 76° 27' 25.73"

ii. Kollam (KLM)

Kollam district represented small isolated strands and narrow belts of mangroves along the Ashtamudi and Kayamkulam backwaters. Even though the extend of mangroves is less in Kollam compared to many other districts, but is bestowed with rich species diversity (15sps.). Eleven sites were studied from Ayiramthengu to Asramam (Table 2.8). All the sites (Ayiramthengu, Ayiramthengu fish farm, Munrothuruthu, Koyivila, St Sebastian island, Poothuruthu, Veluthuruthu, Bhavanithuruthu, Kadanmoola and Puthenthuruthu) exhibited estuarine type of mangrove vegetation. Out of the 15 species identified, many rare species such as *Ceriops tagal* and *Avicennia alba* were found only in Ashtamudi and Kayamkulam wetlands throughout the Kerala State. *Avicennia officinalis*, *Rhizophora mucronata* and *Avicennia marina* were the common species in most of the sites along with *Lumnitzera racemosa* and *Aegiceras corniculatum* which were rare in other districts. Mangroves of Kayamkulam, Ashtamudi, Paravoor and Asramam were found to be degraded due to conversions and real estate activities.

Table 2.8 Mangrove sites selected for floral study along Kollam

No.	Station	Location
1	Ayiramthengu	9° 6' 58.60" ; 76° 28' 50.12"
2	Ayiramthengu fish farm	9° 7' 0.19" ; 76° 28' 50.33"
3	Munrothuruthu	8° 59' 12.33" ; 76° 36' 56.98"
4	Koyivila	8° 58' 55.23" ; 76° 34' 19.48"
5	St. Sebastian island	8° 57' 1.54" ; 76° 33' 49.28"
6	Poothuruthu	8° 57' 19.51" ; 76° 33' 0.21"
7	Veluthuruthu	8° 57' 8.78" ; 76° 32' 51.32"
8	Bhavanithuruthu	8° 57' 22.13" ; 76° 32' 49.77"
9	Kadanmoola	8° 57' 27.72" ; 76° 32' 51.25"
10	Puthenthuruthu	8° 56' 4.66" ; 76° 33' 22.93"
11	Asramam	8° 53' 45.74" ; 76° 35' 6.64"

i. & ii. Poothuruthu

iii. & iv. Puthenthuruthu

Plate 2.7 (i-iv) Mangrove zones of Kollam

iii. Thiruvananthapuram (TVM)

Thiruvananthapuram district, once had luxuriant mangrove vegetation, but at present due to severe anthropogenic activities most of the mangrove habitats are degraded. Only small patches of mangrove representations can be seen in the Akkulam- Veli estuarine region. At present the district represents the remnants of the past mangrove vegetation with least species diversity. Of the three sites studied, Asramam and Akkulam exhibited estuarine type and Veli represented coastal type of mangrove vegetation.

2.2 Monthly sampling

The monthly sampling for the analysis of various hydrographic parameters and productivity pattern along six mangroves ecosystems of Ernakulam district was carried out for a period of 2 years (September 2010 to August 2012). The stations studied were: Station -1, Aroor North; Station- 2, Aroor South; Station -3, Puthuvypin; Station -4, Malippuram; Station-5, Valanthakad- Magranazhi, Station-6,Valanthakad, Arkathadam (Figure 2.5).

Figure 2.5 Monthly sampling sites of Ernakulam district

The details of the sampling locations are given below:

Station 1: Aroor North

Aroor is located at the northern tip of Alappuzha district and southern tip of Cochin. It is usually considered as the suburb of Kochi and is famous for various seafood related industries located in this area. The study area is located at 9^0 86'N, and 76^0 31' E, dotted with small patches of mangroves with rich biodiversity. The area is dominated by *Rhizophora* species (*R. apiculata* and *R. mucronata)* with patchy distribution of *Avicennia officinalis*. Tall trees of *Sonneratia caseolaris* are also characteristic feature of this station. The entire mangrove habitat is surrounded by luxuriant growth of *Acanthus ilicifolius.* The depth of this station is very low nearly 0.75-0.8m and it usually dries up during the pre-monsoon season (Plate 2.8- i).

Station 2: Aroor South

This station has an impressive patch of mangroves and is about half a kilometer away from Station 1. *Sonneratia caseolaris* trees intermingled with *Avicennia officinalis* and *Rhizophora mucronata* are seen in the site. Rare mangrove species, like *Kandelia candel* was observed in this station. The average depth of the station is 1-1.5m. The station has a narrow channel of running water. Mangrove associates are extensively seen in this area (Plate 2.8-ii).

Station 3: Puthuvypin

The study area is near to the LNG Terminal and is a highly industrialized area located at 9^0 58' N and $76^0$13'E of Vypin. The island is about 27 km along Ernakulam district bordered by Vembanad Lake in the east and Arabian Sea to the west and south. The station is only few kilometers away from the sea and is highly saline as it receives direct tidal inflow from the sea. About 70% of the vegetation comprises of mangroves and its associates. The dominant species is *Avicennia officinalis* followed by *Sonneratia caseolaris* and *Rhizophora mucronata.* Various water quality parameters show great variation compared to other stations due to industrial activities taking place in the station. The average depth of this station ranged from 1.5-2 m (Plate 2.8- iii, iv).

Station 4: Malippuram

This station is 1.5 km away from Station 3 and is a moderately dense mangrove zone adjoining the Arabian Sea. The area is inhabited by human settlements and is also utilized for aquaculture and recreational activities. The island was affected by tsunami waves in December 2004. The station is dominated by *R. mucronata* and *Bruguiera* spp. A part of the mangrove stretch is also converted to a small mangrove park that has become one of the tourism spot of Vypin Island. The average depth ranged from 1.7- 2m (Plate 2.8- v, vi).

Station 5: Valanthakad (Magranazhi)

Valanthakad is situated on eastern side of Vembanad ecosystem (9^0 91' N, 76^0 32'E) having several mangroves and other fish and shell fish fauna. An array of mangroves, separate land from water providing a breeding ground for prawns, crabs, oysters and small fishes. The island is a hamlet inhabited by toddy tappers, fishermen and labourers. The station is rich with *R.mucronata* and is also inhabited by rare species like *R.apiculata* and *Kandelia candel.* The station is shallow ranging from 0.75- 1 m (Plate 2.8-vii).

Station 6: Valanthakad (Arkathadam)

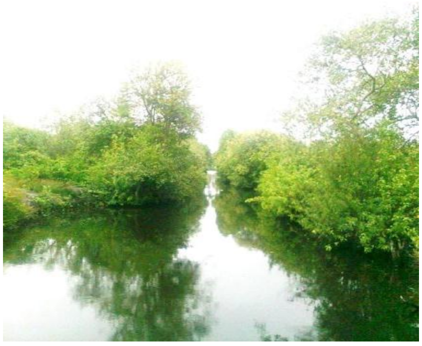
This station is nearly 1km away from station 5. The station receives tidal inflow from the Ameda kayal. Real estate groups had taken over a major area of this site and adjacent zones for construction activities. Clearing of the mangrove patches is also evident in this zone. Both the stations (St.5 & St.6) are important spots of various migratory birds. Similar to station 5 the station shows a depth ranging from 0.75- 1 m (Plate 9. viii).

i. Station 1 (Aroor North)

ii. Station 2 (Aroor South)

iii. Station 3 (Puthuvypin)

iv. Station 3 (Puthuvypin)



v. Station 4 (Malippuram)

vi. Station 4 (Malippuram)

vii. Station 5 (Valanthakad, Magranazhi)

viii. Station 5 (Valanthakad, Arkathadam)

Plate 2.8 (i-viii) Monthly sampling stations of Ernakulam district

Chapter 3

Phenology and Systematics of Mangroves and Associates of Kerala

Contents

3.1 Introduction

Mangroves include taxonomically diverse groups of plants sharing a common ecological condition. More precisely mangroves are an ecological grouping of plants rather than taxonomic grouping. Thus mangrove taxonomy are always a topic of debate as they included a group of genetically different species assigned together based on certain environmental adaptations. Various taxonomic studies evolved during the course of time, with each classification designating the species differentially as all the coastal estuarine vegetation that occurs in the inter-tidal zones i.e. between the highest and the lowest tidal limits were considered to be mangroves. Thus based on the occurrence of species in the tidal region various terms were put forward by taxonomist, such as potential/ frequent mangroves, major and minor elements of mangal, true and semi mangroves and mangrove associates. This ambiguity in classification is clearly depicted in the various studies reported in India, where 36 true mangrove species were reported by Dagar et al. (1993) while Selvam et al. (2004) reported 35 spp. from the along the Indian coast. The number of species reported by Mandal and Naskar, 2008 (30spp.) and Kathiresan, 2008 (39spp.) also showed great variations.

According to Wang et al., 2010, there are two categories of mangroves: true mangroves and mangrove associates. True mangroves are those species which occur only in that environment and have developed certain adaptations to thrive in such environments. The majority of true mangroves fit into four genera; *Bruguiera*, *Sonneratia*, *Avicennia* and *Rhizophora*. There are families exclusively containing mangroves such as Aegialitidaceae, Avicenniaceae, Nypaceae and Pellicieraceae and 25% of all mangrove families falls under the two major orders; Myrtales and Rhizophorales. Around 30-40 species of *Rhizophora, Kandelia, Ceriops, Bruguiera, Aegiceras and Sonneratia* forms the core group of true mangroves (Spalding, 2010). Both numerically and structurally, they form the main components and occur in almost all the mangrove ecosystems. According to the latest classification of Spalding et al. (2010), 38 species out of the 73 species of true mangroves, dominates most of the mangrove habitats and forms the 'core mangroves'. On the other hand there are many plant species that exist in both the mangrove habitats and in other coastal environments, such species are grouped as mangrove associates (Melana et al., 2000).Species of *Hibiscus, Morinda, Clerodendron*, *Barringtonia* etc. are some of the mangrove associates. These mesophytic plants usually form the plant communities of mangrove habitats. However, there are many fringe species that overlap the landward transitional zones, which are still under uncertainty among researchers in their classification (Wang et al., 2010).

Even though a large quantum of data on mangroves are available based on extensive studies on global scale, an exact species composition of Kerala mangroves is still imprecise. According to Duke (2006), each taxonomic study should provide a detailed phylogenetic understanding of individual taxa. This phylogenetic understanding can only be acquired through detailed systematic studies based on the morphological, chemical and genetic variations of individual species across their distributional range. The exact information on species composition is useful in understanding the structure, function and biogeographical affinities of mangroves and this would be further useful in planning strategies for their better conservation and management (Jayatissa et al., 2002, Wang et al., 2003). A comprehensive data on exact number of mangroves species in Kerala are still deficient due to lack of extensive field surveys and proper taxonomic identities of mangrove species. Thus the present study becomes important and contextual as it helps to generate scientific information on current diversity and morpho-taxonomy of true mangrove species and associated flora of Kerala.

3.2 Review of literature

3.2.1 Global species diversity

The global distribution of mangroves in the past and present have been studied repeatedly (Spalding et al., 1997; FAO, 2003; Taylor et al., 2003; Gienson et al., 2007; UNEP, 2007; Spalding et al., 2010; Polidoro et al., 2010). Even though information on mangrove distribution is available on the global as well as national level, detailed and precise information on biodiversity of mangrove species of Kerala is still lacking. One of the major reasons for this is the ambiguity in mangrove taxonomy i.e. the confusion in placing the flora under true mangroves or as associates. Tomlinson (1986) classified the mangroves into three groups: the major component, which is also known as true/ strict/ specialized mangroves; the minor components including the non-specialised mangroves and mangrove associates which include species that occupy mangrove habitats but never get immersed even in high tides. According to this classification he identified 34 species as major components and 20 species as minor components. This classification was widely accepted for some extent of time and further classifications by Kathiresan and Bingham (2001), Lacerda et al. (2002), Saenger (2002), Wang et al. (2003), Duke (2006) were based on this grouping. However approaches were also laid to classify mangroves species based on zonation patterns (Duke, 1992; Lin, 1999; Smith, 1992). All the flora of the intertidal regions including trees, shrubs, palms and even ferns that grows beyond 0.5m height were included as true mangroves by Duke (1992) and globally he identified 69 true mangroves.

Table 3.1 List of true mangroves by World Atlas of mangroves, 2010

	Family	Species		Family	Species
1	Acanthaceae	*Acanthus ebracteatus*	39		*Heritiera littoralis*
2		*A. ilicifolius*	40	Rhizophorceae	*Kandelia candel*
3	Pteridaceae	*Acrostichum aureum*	41		*K. obovata*
4		*A. danaeiifolium*	42	Combretaceae	*Laguncularia racemosa*
5		*A. speciosum*	43		*Lumnitzera littorea*
6	Plumbaginaceae	*Aegialitis annulata*	44		*L.racemosa*
7		*A. rotundifolia*	45		*L. x rosea*
8	Myrsinaceae	*Aegiceras corniculatum*	46	Caesalpiniaceae	*Mora oleifera*
9		*A. floridum*	47	Araceae	*Nypa fruticans*
10	Meliaceae	*Aglaia cucullata*	48	Myrtaceae	*Osbornia octodonta*
11	Avicenniaceae	*Avicennia bicolor*	49	Pellicieraceae	*Pelliciera rhizophorae*
12		*A. germinans*	50	Lythraceae	*Pemphis acidula*
13		*A. integra*	51	Rhizophorceae	*Rhizophora x neocaledonica*
14		*A. marina*	52		*R. apiculata*
15		*A. alba*	53		*R.x lamarckii*
16		*A. officinalis*	54		*R. mangle*
17		*A. rumphiana*	55		*R.mucronata*
18		*A. schaueriana*	56		*R. racemosa*
19	Rhizophorceae	*Bruguiera cylindrica*	57		*R. samoensis*
20		*B. exaristata*	58		*R. x selela*
21		*B.gymnorrhiza*	59		*R.stylosa*
22		*B.hainesii*	60		*R. x harrisonii*
23		*B. parviflora*	61	Sonneratiaceae	*Scyphiphora hydropyllacea*
24		*B. sexangula*	62		*Sonneratia alba*
25		*B. x rhynchopetala*	63		*S. apetala*
26	Bombacaceae	*Camptostemon philippiensis*	64		*S. caseolaris*
27		*C.schultziii*	65		*S. x gulngai*
28	Rhizophoraceae	*Ceriops australis*	66		*S. griffithii*
29		*C.decandra*	67		*S. lanceolata*
30		*C. tagal*	68		*S. ovate*
31	Combretaceae	*Conocarpus erectus*	69		*S. x urama*
32	Caesalpiniaceae	*Cynometra iripa*	70		*S. x hainanensis*
33	Ebanaceae	*Diopyros littorea*	71	Bignoniaceae	*Tabebuia palustris*
34	Bignoniaceae	*Dolichandrone spathacea*	72	Meliaceae	*Xylocarpus granatum*
35	Euphorbiaceae	*Excoecaria agallocha*	73		*X. moluccensis*
36		*E. indica*			
37	Sterculiaceae	*Heritiera fomes*			
38		*H. globosa*			

The global mangrove species identified varied among various taxonomists even from the time of Chapman in 1976. He identified 90 species while in 1983, Saenger et al., reported 83 species only. Tomlinson (1986) reported 54spp. (34 major and 20 minor mangroves) however the reports of UNDP/UNESCO showed much higher number (65spp.). There after integrating the classifications of Tomlinson and Duke, Kathiresan and Bingham (2001) put forth another classification and identified 65 mangroves (22 genera, 16 families). As per the World atlas of Mangroves there are globally 73 species of true mangroves (Table 3.1). However Polidoro et al., 2010 reported only 70 spp. of true mangroves under 17 families and the list excluded all the plant hybrids as the IUCN Red list guidelines did not assess hybrids. Sheue et al., 2010 reported a new mangrove species *Ceriops pseudodecandra.* Polidoro et al. (2010) considered *Bruguiera hainesii* as a distinct species while the species was considered as a hybrid between *B. cylindrica* and *B. gymnorrhiza* by Ono et al. (2016).

Even though many studies on mangrove species diversity were reported during the course of time, most of them were restricted to selected mangroves habitats of few countries and an insight of global species diversity was highlighted only in very few studies. The state of art of mangroves of Indonesia was provided by Muhammad et al. (2011) and Cecep Kusaman (2014). Richard and Daniel, 2016 provided the current state, rate of deforestation and major threats on the mangroves of Southeast Asia. The extent of mangroves in Malaysia was monitored by Kamaruzaman (2013); Hong (2016) and Muhd-Ekhzarizal et al. (2018) while Coutinho (2012) studied the Brazilian mangroves. Other studies included: Shearman, 2010 (Papua New Guinea), Laurence et al., 2011 (Australia), Perera et al., 2013 (Sri Lanka), Suk-ueng et al., 2013 (Thailand), Bosire et al., 2014 (Kenya), Perera and Amarasinghe, 2014 (Sri Lanka), Long et al., 2014 (Philippine) and many more which were constrained to only selected mangrove chunks.

3.2.2 Species diversity of Indian mangroves

Reviewing the Indian scenario, the number of species reported varied to a great extend among researchers due to the disparities in classification of true mangroves and associates. Many of the species such as *Acrostichum, Acanthus,* *Pemphis, Dolichandrone* etc. are globally considered as true mangroves (Polidoro et al., 2010) while these species are variably classified in India. Besides these many other littoral beach vegetation are also included in the list by many authors. Goutham Bharathi et al., 2014 also opines that inclusion of such species and inclusion of earlier reported species in the current checklist without proper investigation contribute to flawed results.

Blasco et al., (1975) studied both West and East coast of India and identified 33 and 47 species respectively. During 1987, Untawale reported 55 mangrove species while the works of Naskar and Guha Bakshi (1987) also gained importance. They reported 35 true mangrove species, 28 mangrove associates and 7 back mangals. More than 60 mangrove species, including 25 major mangroves were reported from East coast zones by Naskar (1993). Other works include those of Banerjee et al., 1989 (59 sp.); Deshmukh, 1991 (59 sp.); Jagtap et al., 1993 (50 sp.); Rao et al., 1998 (35 sp.) and Botanical Survey of India, 2002 (59 sp.). In 2008, Naskar and Mandal reported 82 species of mangroves (52 genera, 36 families) from 12 major mangrove habitats of India. Latter 125 species (39 true mangroves and 86 associates) were reported by Kathiresan (2008). He reviewed the mangrove species diversity of Indian states and reported the highest in Orissa (101sp.) followed by Sundarbans of West Bengal (92 spp.); Andaman and Nicobar Islands (91 spp.); Andra Pradesh (70 spp.); Tamil Nadu (70 spp.); Kerala (64 spp.); Maharashtra (63 spp.); Karnataka (58 spp.) and Goa (53 spp.) Gujarat with 40 species exhibited least species diversity. Ragavan et al., 2016 listed out 80 species as true mangroves by including all the newly identified species and other natural hybrids reported by Duke (1992), Kathiresan (1995) and Ono et al. (2016). The checklist included 70 species reported by Polidoro et al. (2010) and 10 natural hybrids. Many of the hybrids such as *Sonneratia alba* x *Sonneratia griffithii* (Qiu et al., 2008); *Rhizophora* x *tomlinsonii* (Duke, 2010); *Avicennia marina* x *Avicennia rumphiana* (Huang et al., 2014); *Rhizophora mucronata* x *Rhizophora stylosa* (Ng et al., 2013; Ragavan et al., 2015); *Acrostichum aureum* x *Acrostichum speciosum* (Zhang et al., 2013; Ragavan et al., 2014) were not included in this list as molecular evidences were lacking for these species. Out of the 80 spp. listed, he reported 46 true mangrove species belonging to 14 families and 22 genera from Indian mangroves. This includes 42 species and 4 natural hybrids.

Ragavan et al., 2016 also reported 40 mangroves (14 families, 22 genera) and 27 mangroves (11families, 16 genera) from East and West coast of India. Sundarbans (West Bengal) is one of the World Heritage Site in terms of its rich biodiversity and ecology. An elaborate description on the mangroves and associates of Sundarbans were given by Naskar and Guha Bakshi (1987). Around 84spp. (26 true mangroves, 58 associates) were reported by Banerjee (1998). The species *Acanthus volubilis*, earlier recorded as extinct from the mangrove habitats of India were revived from here. Later on the species diversity was reported by: Susanta, 2011 (34 true mangroves, 40 associates); Jyotiskona and Soumyajit, 2014, (24 true mangroves in 9 families); Hema and Ghose, 2014 (13 true mangroves, 8 associates) and Ragavan et al., 2016 (33 true mangroves; 21 genera, 14 families). Even though the mangrove species diversity was reported by many, the number of species varied among authors.

Among the mangrove rich habitats in India, Andaman and Nicobar Islands represents highest species diversity with 38 spp. of true mangroves belonging to 13 families and 19 genera (Ragavan et al., 2016). In Odisha the mangroves are found along deltas of Mahanadi, Brahmani and Baitarani (later two forming the Bhitarkanika mangrove zone) and Balasore coast. Among the Odisha mangroves, Bhitarkanika accounts rich biodiversity (35spp. of true mangroves) and has been well documented over the period of time. While Panda et al., 2013 opines that various other mangrove habitats such as Devi, Budhabalanga, Subarnarekha etc. are comparatively less monitored. The mangroves of Gulf of Kachchh, Gulf of Khambhat, Kori creek altogether represents 15 spp. of true mangroves (Ragavan et al., 2016). A total of 16 spp. of true mangroves were reported from Karnataka along the estuaries of Netravathi-Gurupur, Mulki-Pavanje, Udayavara-Pangala, Chakra-Haladi-Kollur, Baindur hole, Shiroor hole, Honovar, Venkatapur, Sharavathi, Aghanashini (Ragavan et al., 2016).

In Andhra Pradesh, the estuaries of Godavari and Krishna support mangrove vegetation. Small patches of mangroves are also reported along the coast of

Visakhapatnam, Guntur district and Prakasam district. Arisdason et al. (2008) reported 20 eumangroves and 48 associates while 22 true mangroves (15 genera, 11 families) were reported by Ragavan et al., 2016. He also reported 22 spp. (15 genera, 11 families) and 16 spp. (11 genera, 7 families) from Maharashtra and Goa respectively. In Tamil Nadu, the major mangrove chunks are found along Pichavaram, Muthupet and Gulf of Mannar. The mangrove species of Tamil Nadu were well documented by Kathiresan and Bingham (2001); Eganathan (2002); Selvam et al. (2005). Kathiresan (1995) reported 35 species (26 genera, 20 families) of true mangroves from the Pichavaram mangrove estuary while Ragavan et al., 2016 recognized only 17 true mangrove species from the entire coast. *Rhizophora annamalayana* Kathir., the hybrid of *R. apiculata* x *R. mucronata* is an endemic species recorded from the region.

Among the various mangrove species as listed by various authors, some are endemic to Indian mangroves. *Heritiera fomes* is endemic to West Bengal while *Heritiera kanikensis* is restricted to Bhitarkanika. *Sonneratia griffithii* and *Xylocarpus mekongensis* is confined to West Bengal, Odisha and Andaman Islands only. *Lumnitzera littorea* and *Xylocarpus moluccensis* are restricted to West Bengal and Andamans. The mangroves of Sundarban and Andamans also credits for the existence of mangrove palms; *Nypa fruticans* and *Phoenix paludosa*. *Acanthus ebracteatus* is restricted to Andaman and Kerala coast. Andaman and Nicobar Islands also accounts for the restricted occurrence of *Rhizophora* × *lamarckii*, *Lumnitzera littorea, Sonneratia ovata, S. lanceolata, S.* × *urama* and *S.* × *gulngai*. On the other hand, the natural hybrid, *Rhizophora* x *annamalayana* is spotted only from Pichavaram mangroves.

3.2.3 Species diversity of mangroves of Kerala

Kerala was once rich in mangroves and the mangrove patches that are witnessed today are the relics of the past. The extensive mangrove habitats along the Kerala coast were described by Van Rheede (1678-1703) in his monumental work of *Hortus Indicus Malabaricus*. In the third volume he describes the mangroves of the Malabar Coast and recorded 8 true mangrove species. Lieut. Colonel Drury (1864) studied the mangroves along the coast of Quilon and added few more species such as

Ceriops tagal, Bruguiera malabarica, B. parviflora and *B. eriopetala* to the contributions of Van Rheede while the recent studies could not trace these species in Kerala. Later on Hooker (1879-1885), Gamble (1919), Rama Rao (1914), Chand Basha (1992) also studied mangrove ecosystems of Kerala. Velu Pillai (1940) reported the occurrence of many mangroves and back mangroves along the Travancore coast. *Bruguiera gymnorrhiza* and two species of *Rhizophora* were reported by Bourdillon (1908) from Kollam mangroves. The mangroves of Kerala coast were also studied by Gamble (1967). Various other studies reported on Kerala mangroves were by Troup (1921), Erlanson (1936), Mudaliar and Kamath (1954), Thomas (1962), Ernakulam District Gazetteer (1965), District Gazetteer of Cannanore (1972), Rao and Sastri (1974), Blasco (1975), Kottayam District Gazetteer (1975), Kurien (1980), Ramachandran et al. (1986) and Ramachandran and Mohanan (1987). Many of these studies clearly depicted the fast disappearance of mangroves from Cochin region towards north. The large scale destruction of mangrove habitats for the construction of Cochin Port are clearly mentioned in these studies.

Studies by Kurian (1980) revealed the occurrence of small patches of *Acanthus ilicifolius, Avicennia alba*, *Rhizophora* spp. and *Bruguiera* spp. in the Cochin region of the Vembanad estuary. Rajagopalan et al. (1986) suggested that, the mangroves of Cochin are dominated by species of *Acanthus, Excoecaria, Clerodendron, Aegiceras, Avicennia* and *Rhizophora* indicating a formative ecosystem developing mainly on small reclaimed or natural islands. During 1985-86 period, Ramachandran et al., conducted a detailed survey along the Kerala coast and identified 39 mangrove species and associates. Banerjee et al. (1989) and Basha (1991) described 32 species (24 genera, 19 families) and 27 species (21 genera, 17 families) respectively. Later on 39 species of mangroves and associates were identified by Nair and Bijoy Nandan (1994). Six major mangrove families (Rhizophoraceae, Avicenniaceae, Myrsinaceae, Sonneratiaceae, Papilonaceae and Acanthaceae) were identified. Besides the scientific floristic survey conducted by Anupama and Sivadasan (2004), many regional studies were carried out by Suma (1995), Mohanan (1997), and Sivadasan (1997). According to the study of Sunil Kumar and Antony (1994) the most dominant species of Cochin mangroves is *Rhizophora mucronata* followed by *Avicennia officinalis* and *Acanthus* *ilicifolius*. The mangroves of Vypeen, Cochin was studied by Suma (1995) and reported the dominance of *Acanthus ilicifolius* along with *Rhizophora mucronata* and *Avicennia officinalis* whereas Mohanan (1997) opined that the early colonizer is *Avicennia* followed by *Rhizophora, Derris* and *Acanthus* at Puthuvypin area. The mangrove flora of Puthuvypin and Mangalavanam were also studied by Krishnan Nair (1997) and Sivadasan (1997) respectively.

An investigation by Anupama and Sivadasan (2004) could identify 15 true mangroves belonging to 9 genera and 7 families and 49 mangrove associates from Kerala. The family Rhizophoraceae is the most represented one with 6 species belonging to 3 genera. Vidyasagaran and Madhusoodanan (2014) reported 15 true mangrove and 33 mangrove associates from Kerala coast. The species diversity, structural dynamics and regeneration status of mangroves of Kerala was also reported by Vijayan et al. (2015) and Grinson et al. (2018). Even though mangroves of Kerala were studied during the time span, many of them were restricted to mangrove patches of specific area only. Various studies were reported from the dense mangrove patches of Kannur and Ernakulam districts. Sreeja and Khaleel (2010) studied the mangroves of Thekkumbad, Kannur covering an area of approximately 2788m^2 with 11 true mangroves and 6 associates. Arun and Shaji (2013) studied the diversity and distribution of mangroves of Kumbalam Island, Ernakulam and identified 7 true mangroves, 2 semi mangroves and 8 mangrove associates. The extent of mangrove vegetation in Ernakulam district was also investigated by Sharanya et al., 2014. Vaiga and Sincy (2016) reported 7 true mangroves from Vellikkeel and 10 true mangrove species from Ezhome regions of Kannur. Praveen et al., 2016 reported 13 eumangroves and 9 associates from the Kunhimangalam region of Kannur. The study considered *Acrostichum aureum* as an associate and also highlighted the need for immediate conservation of this large and least disturbed mangrove patch of Kerala. The forest structure and species composition of Cochin mangroves were also highlighted by Rani et al., 2016. Sahadevan et al. (2017) reported 11 true mangroves and 32 associates from Puthuvypin. Besides these reports from Kannur and Ernakulam districts, few studies were also reported from other districts. The quantitative estimation of mangrove vegetation in Poyya backwaters of Thrissur district was reported by Saritha and Tessy (2011). The study identified only 4 true mangroves and 6 associated flora from the region. Vishal et al., 2015 reported 9 mangrove species from Ayiramthengu, Kollam. The species diversity, structural characteristics and zonation pattern of mangrove patches along Ashtamudi and Kayamkulam backwaters were highlighted by Sreelekshmi et al., 2017.

Even though various taxonomists attempted to classify mangroves and associates based on various other features besides zonation patterns, the results did not remove uncertainty. Thus, modern taxonomic studies based on molecular techniques (using DNA sequencing data) were evolved for resolving the disputes in identification of species.

3.2.4 Is molecular taxonomy important in present day research?

Mangrove ecosystems are studied on taxonomic, floristic, physiological and ecological aspects on global, national and even regional scales. However many of the specimens reported in various studies as well as represented in many herbaria are misidentified and are questioned by various other workers. Remadevi and Binoj Kumar in 2000 argued that the specimen in Indian herbaria mentioned as *Acanthus ilicifolius* were actually the species of *Acanthus ebracteatus*. They reported the presence of this species from the marshy areas of Aroor in Alappuzha district. However, this identification was again questioned by Anupama and Sivadasan in 2004. The ecological varieties of many species such as *Avicennia marina* and *Ceriops tagal* are still unrecognised and many of the species faces difficulty in relating their local names with botanical names (Singh, 2003). Also several natural hybrids and their parent species are not clearly identified in many of the studies. Due to this increasing conflicts among taxonomists, led to the new aspect of molecular taxonomy. Duke (2006) opined that rigorous systematic studies based on morphological, chemical and genetic variations are required to develop phylogenetic understanding of individual taxa across their distributional ranges. Initialy only few reports on chromosome number and isoenzymes were available (Mc Millan, 1986). Calvin McMillan (1986) studied the allozyme patterns of *Avicennia germinans* population in the Gulf of Mexico. Detailed techniques for the electrophoresis of allozymes from the leaf tissues of mangrove were given by Goodall and Stoddart (1989). During the same year various allozyme analyses studies were conducted by Baba et al. Species of *Rhizophora*, *Kandelia candel*, *Lumnitzera racemosa* and *Avicennia marina* from Iriomote and Okinawa Islands were examined for genetic diversity. Allozymes and intersimple sequence repeats were also used to study the reproductive biology and genetic diversity of *Aegiceras comiculatum* by Ge and Sun (2001).

Later on the use of molecular markers for studing genetic variability and relationships within the mangrove ecosystem became an essential pre-requisite in conservation programmes. Many researchers studied both inter- and intra-population genetic diversity and species relationship among Rhizophoracean species using molecular markers (Gottlieb, 1977; Hardrys et al., 1992; Williams et al., 1990). Chalmers et al. (1992) and Waugh and Powell (1992) opined that the extent of genetic diversity within and between populations can be accurately quantified using molecular markers. Unlike the morphological markers, these molecular markers are not prone to environmental influence, thus portray better genetic relationship between taxa (Brown, 1979; Gottlieb, 1977; Beckmann and Sollar, 1986; Tan- ksley et al., 1989; McCouch and Tanksley, 1991). The vital information from these markers helps in developing genetic sampling, conservation and improvement strategies (Waugh and Powell, 1992; Newbury and Ford-Lloyd, 1993; Chalmers et al., 1994). Taxonomic studies using PCR-RFLP of chloroplast gene region and Nuclear ribosomal RNA genes (rDNA) were also studied by many (Zimmer et al.,1988; Wagner et al., 1987; Palmer and Zamir, 1982; Tsumura et. al., 1995, 1996). Studies on gene diversity components such as total gene diversity, gene diversity between inter- and intra- populations were carried out in *Ceriops decandra* and *C. tagal* by Huang et al., (2007); in *Lumnitzera racemosa* by Su et al., (2007); in *Heritiera littoralis* by Jian et al., (2004) and in *Ceriops australis* by Ge and Sun (2002).

Studies were carried out in DNA sequence divergence to index the revalutionary relationships and direct and indirect methods to measure genetic diatance. Chalmers et al. (1994); Lin et al. (1996); Russell et al. (1997); Parani et al., (1997, 1998); Lakshmi et al., (1997, 2000, 2002); Mukherjee et al., (2004); Sahoo et al., (2007); Smita et al., (2009) quantified the inter- and intra –specific variability using the molecular markers: Random Amplified Polymorphic DNA (RAPD) and Amplified Fragment Length Polymorphism (AFLP). Population structure and phylogenetic relationships are best studied using molecular techniques using different types of macromolecules, such as proteins (allozymes) and DNA (RFLR RAPD, sequence data) (Avise, 1994). Isolation and characterisation of microsatellite markers were yet another aspect of molecular studies. Islamet al., (2006) and Geng et al., (2009) isolated and characterized chloroplast microsatellite markers from various mangrove species.

Behnkeet al. (2006) studied the genetic diversity using RAPD and RFLP markers of 31 spp. of mangroves from various sites of Bhittarkanika. Pragnya et al., 2007 used the chromosome and RAPD markers in indentifying the phylogenetic relationship between four species of *Bruguiera*. Sameera et al. (2011) carried out DNA barcoading of various arid plants in order to evaluate the success rate of universal primers maturase K (*mat K*) and ribulose- 1, 5-bisphosphate carboxylase oxygenase large subunit (*rbcL*) in amplification. Arun et al. (2011) carried out molecular analysis of *Acanthus ilicifolius* to identify the intra-site and inter- specific polymorphism of the species along Pichavaram, Cuddalore and Cochin. Zhang et al., 2013 provided the molecular evidences of natural hybridisation in mangrove fern species of *Acrostichum aureum* and *A. speciosum* of China. Surya et al.(2013) carried out the molecular study of *Acanthus volubilis* of Sundarban region. Surya and Hari (2017) evaluated the mangroves of Kumbalam, Ernakulam district using DNA bar coding. The molecular analysis of *Acanthus* and *Bruguiera* species revealed that the *rbcL* and *mak K* genome were not ideal tool for discrimating these at species level.

Earlier the information available on the genetic structure of mangrove species, are scanty while during the last decade the use of molecular data in plant studies has increased dramatically. Reviewing the molecular studies clearly depict that most of the studies are based on global mangroves and studies on Indian contex as well as on regional scales are still scanty. The new molecular methods in mangrove research has provided new directions to address unresolved issues in mangrove studies. Thus the current trents in sequencing strategies and bioinformatics hold great potential to light up the hidden corners of ancient plant taxonomy and these molecular markers are intricate tools for new insights in mangrove genetics.

3.3 Methodology

3.3.1 Collection of Plant specimens

An all Kerala survey along the mangrove ecosystems was carried out as detailed in previous chapter for the collection and identification of mangrove species. Typical plant specimens, representative of the population were collected from different mangrove ecosystems. The healthy plant twigs devoid of insect-damage or diseases were collected. The twigs with foliage, flowers and fruits were cut, wrapped in wet papers and placed in polythene bags to keep them fresh until the time of identification. The specimens with flowers and fruits are preferred rather than vegetative parts for identification as they are not much affected by environmental changes. Comprehensive notes of each specimen were noted in the field dairy and collected samples were tagged with specific notes to avoid confusion during identification. The note included the following information's:

i. Collection number: The serial number specific to the plant specimen were recorded starting from 1.

ii. Name of the plant: The name of the plant is important to identify the specimen even if the labels are accidently lost or mixed up. If the collector has no idea of the name of the plant, any of its identifying features (eg. Big leaf/ scarlet flower) or as unknown (eg. Unknow#12) can be recorded instead.

iii. Locality: The latitudinal and longitudinal positions of the specimen were recorded with the help of handheld GPS. Besides these the additional details of the location such as town/district/ country/roads, lakes, estuaries in the vicinity etc. were also recorded.

iv. Description: Salient features of the plant regarding habitat, habit, type of bark, colour and size of fruits and flowers etc. were recorded.

v. Date: the date of collection was recorded in each specimen tag.

vi. Name of Collecter (s): the date of specimen collector was also recorded in the tag.

3.3.2 Identification

The collected specimens were identified using standard references and identifying keys of: Gamble, 1967 (Flora of Presidency of Madras); Tomlinson, 1986 (The botany of Mangrove); Naskar and Mandal, 1999 (Ecology and biodiversity of Indian mangroves); Spalding et al., 2010 (World atlas of mangroves). Most of the keys and classifications are based on the flowers and fruits (floral/sexual parts) rather than leaves or stem characteristics (vegetative parts) as the floral characters are much stable to environmental changes and exhibit better relationships of plants. The flowers are detached from the twigs and various morphometric attributes such as its colour, shape, size, texture, number of petals and sepals etc. were noted before dissection. The detailed floral parts were observed using magnifying hand lens and dissection microscope. The morphometric measurements of various taxonomic characters as mentioned in Table 3.2 were recorded.

Table 3.2 Taxonomic characters selected for morphometric measurements

	Characters		Characters
1	Leaf :Shape, Length & width	10	Calyx: No. of sepals
	Shape of apex & base		Colour, Shape & Aestivation
2	Mucron: Presence/ absences		Sepal length & width
	Length	11	Corolla: No. of petals
3	Petiole: Length		Colour, Shape & Aestivation
4	Inflorescence: Type & Position		Petal length & width
	Length	12	Androecium: No. of stamens, Colour
	No. of flowers		Length of Filaments
5	Bracts: Presence/ absences, Length		Type of anther lobes
6	Bracteoles : Presence/ absences, Length	13	Gynoecium: Length of style
7	Peduncle: Length & Width		Type of stigma
8	Pedicel: Length & Width		Position of ovary
9	Bud: Shape, Length	14	Fruit: type, Length/width

3.3.3 Molecular Analysis

Most of the mangroves produce a wide range of polysaccharides, polyphenols and other secondary metabolites causing interferences in extracting pure genomic DNA. Even though numerous plant DNA isolation protocols are reported, the DNA extraction from mangrove species is highly challenging. Cetyl trimethylammonium bromide method (Saghai-Maroof et al., 1984) was used for extraction of DNA from three mangrove species; *Acanthus ilicifolius*, *Acanthus ebracteatus* and *Aegiceras corniculatum* using universal primer mat*K* and *rbcL* regions.

DNA extraction and PCR analysis

The leaf tissues of the mangroves were taken for the isolation of DNA. About 100mg of leaves were ground into fine powder in liquid nitrogen using a mortar and pestle and transferred to microcentrifuge tube. The samples were kept in ice until the addition of lysis solution. The DNA isolation was done using GenElute Plant Genomic DNA Miniprep Kit (Sigma). After extraction the quality of the DNA was checked using agarose gel electrophoresis on 0.8% agarose gel containing 0.5 µg/ml ethidium bromide. Electrophoresis was performed with 0.5X TBE as electrophoresis buffer at 75 V. The gels were visualized in a UV transilluminator (Genei) and the image was captured under UV light using Gel documentation system (Bio-Rad). PCR amplification reactions were carried out in a 20 µl reaction volume which contained 1X PCR buffer, 0.2mM each dNTPs, 2.5mM $MgCl_2$, 20ng DNA, 1 unit of AmpliTaq Gold DNA polymerase enzyme (Applied Biosystems), 0.1 mg/ml BSA and 4% DMSO, 5pM of forward and reverse primers (Table 3.3).

Table 3.3 Forward and Reverse Primers used for Analysis

Target	Primer Name	Direction	Sequence (5' → 3')	Reference/Remarks
matK	matK_xf	Forward	TAATTTACGATCAATTCATTC	CCDB Protocols
	matK_MALPR1	Reverse	ACAAGAAAGTCGAAGTAT	
rbcl	rbcLa_f	Forward	ATGTCACCACAAACAGAGACTAAAGC	CBOL Plant Working Group (http://www.barcoding.si.edu /plant_working_group.html)
	rbcL724_rev	Reverse	GTAAAATCAAGTCCACCRCG	

The PCR amplification was carried out in a PCR thermal cycler (GeneAmp PCR System 9700, Applied Biosystems). The PCR amplification profile for matK genes was initiated by denaturation at 95 ^{o}C (5 min) followed by 10 cycles of 95 ^{o}C (0.30min), annealing at 45 ^{o}C (0.40 min) followed by final extension at 72 ^{o}C (1 min).

The process was repeated with 30 cycles of 95 ^{o}C (0.30min), 51 ^{o}C (0.40min) and 72 ^{o}C (7min) respectively and held at 4 ^{o}C. The amplification of *rbcL* gene included 40 cycles of denaturation (94 ^{o}C, 5 min), annealing (55 ^{o}C, 0.30 min), extension at (72 ^{o}C, 0.30 min) and final extension (72 ^{o}C, 5 min) and finally held at 4 ^{o}C.

The amplified PCR products were checked in 1.2% agarose gels with 0.5 µg/ml ethidium bromide and the image was captured under UV light using Gel documentation system. Unwanted primers and dNTPs were removed by treating 5µl of PCR product with 2 µl of ExoSAP-IT and incubated at 37^{o}C for 15 minutes followed by enzyme inactivation at 80^{o}C for 15 minutes. Sequencing reaction was done in a PCR thermal cycler using the BigDye Terminator v3.1 Cycle sequencing Kit. The PCR mix consisted of the following components: PCR Product (10-20 ng), primer (3.2 pM), sequencing mix (0.28 µl), reaction buffer (1.86 µl) and sterile distilled water. The sequencing PCR temperature profile consisted of a 1st cycle at 96^{o}C (2 min) followed by 30 cycles at 96^{o}C (30 sec), 50^{o}C (40 sec) and 60^{o}C (4 min) for all the primers. The sequence quality was checked using Sequence Scanner Software v1 (Applied Biosystems). Sequence alignment and required editing of the obtained sequences were carried out using Geneious Pro v5.6 (Drummond et al., 2012).

3.4 Results

3.4.1 True mangrove species of Kerala

The true mangrove species identified from 117 mangrove sites along the Kerala coast comprised of 18 species, belonging to 11 genera under 8 different families (Table 3.4). The Rhizophoraceae family was represented by 7 species coming under four genera: *Rhizophora*, *Bruguiera*, *Ceriops* and *Kandelia.* Family Avicenniaceae represented three species of *Avicennia*; *A. officinalis*, *A. marina* and *A. alba.* Family Sonneratiaceae (*Sonneratia alba* and *S. caseolaris*) and Euphorbiaceae (*Excoecaria agallocha* and *E. indica*) were represented by two species each. *Aegiceras corniculatum* and *Lumnitzera racemosa* were the single representatives of the family Mrysinaceae and Combretaceae respectively. The ferm family Pteridaceae was exemplified by a single species; *Acrostichum aureum.* The taxonomic description of the species under the respective families are described. The district wise variations in the morphometric measurements of ecah species are also discussed herewith.

Table 3.4 Mangrove species identified from Kerala with their taxonomic details

Division	Class	Order	Family	Genus	Species		
				Rhizophora	*Rhizophora apiculata* Bl.	Peekandel	Rare
					Rhizophora mucronata Poir.	Bhranthankandel, Panachikandel	Very common
					Bruguiera gymnorrhiza (L.) Lamk.	Penakandel, Karakandel	Common
			Rhizophoraceae	Bruguiera	*Bruguiera sexangula* (L.) Bl.	Swarna kandel	Rare
		Malphigiales			*Bruguiera cylindrica* (L.) Bl.	Cherukandel	Common
				Kandelia	*Kandelia candel* (L.)Druce	Ezhuthanikandel	Common
				Ceriops	*Ceriops tagal* (Perr.) C.B.Rob.	Manjakandel, Anakandel	Very rare
			Euphorbiaceae	Excoecaria	*Excoecaria agallocha L.*	Kammatti	Very common
Magnoliophyta	Magnoliopsida				*Excoecaria indica* (Willd.) Muell. Arg.	Chillakammatti	Rare
			Acanthaceae	Acanthus	*Acanthus ilicifolius* L.	Chullikandel	Common
					Avicennia officinalis L.	Uppatti, Orai	Common
		Lamiales	Avicenniaceae	Avicennia	*Avicennia marina* (Forssk.) Vierh	Cheru uppatti	Rare
					Avicennia alba Blume	-	Very rare
			Combretaceae	Lumnitzera	*Lumnitzera racemosa* Willd.	Kadakandel	Rare
		Mrytales	Lytheraceae	Sonneratia	*Sonneratia alba* Griff.	Nakshatrakandel	Very rare
					Sonneratia caseolaris (L). Engler	Blathi, Chakkarakandel	Common
		Mrysinales	Myrsinaceae	Aegiceras	*Aegiceras corniculatum* L. Blanco	Pookandel, Puzhakandel	Rare
	Filicopsida	Polypodiales	Pteridaceae	Acrostichum	*Acrostichum aureum* L.	Machitholu	Very common

I. Family Rhizophoraceae:

Key to the identification of mangrove genera

1. a. Flowers ebracteolate; calyx:8-13, lobed; petals: 2 lobed….***Bruguiera***

   b. Flowers bracteolate; calyx:4-6; petals entire………………………..**(2)**

2. a. Calyx: 4, petals without apendages; sturd prop roots….***Rhizophora***

   b. Calyx more than 4; petals with appendages……………….**(3)**

3. a. Calyx: 5, petals: 5, short with clavate appendages……………***Ceriops***

   b. Calyx:5, petals:5, long with apical papilae…………………….***Kandelia***

a. Genus: *Rhizophora*

Key to *Rhizophora* species

a. Leaf: ovate- elliptic; flowers: 4, pedicellate;

calyx: light green; stamens: 8……………………***R.mucronata***

b. Leaf: ovate- lanceolate flowers: 2, sessile;

calyx: creamy white; stamens: 10-12………… ***R. apiculata***

i. *Rhizophora mucronata* Poir. (1804)

Common name: Stilt mangrove

Local name: Bhranthankandel, Panachikandel

Distribution in Kerala: Kasaragod, Kannur, Kozhikode, Thrissur, Ernakulam, Alappuzha and Kollam.

Abundance: Very common.

Habit: medium to tall, 15-18m. Bark: brownish to whitish grey, longitudinally fissured. **Root:** profuse stilt root, hard, corky. **Stem:** branched with nodes and internodes, leaf- scars prominent. **Leaves:** 12.5-16.2cm x 7.5-8.9cm, simple, entire, ovate- elliptic, mucronata (0.3-0.9cm), exstipulate, petiolate (3.8-4.8cm), dorsiventral, opposite-decussate, inconspicuous reticulate venation. **Inflorescence:** cyme, 4 flowers, long peduncle (1.5-5.8cm); bud 1.2-1.8cm long. **Flowers:** regular, complete, hermaphrodite, bracteolate, pedicel 1.3-2.1cm. **Calyx:** 4 sepals, 1.2-1.9cm x 1.2-1.6cm, polysepalous, green, entire, acute, fleshy, valvate aestivation, persistent. **Corolla:** 4 petals, 1.4-1.9cm x 0.9-1.2cm, white, polysepalous, lanceolate, entire, odourless, deciduous, valvate aestivation, alternate to sepals. **Androecium:** 8 stamens, white, basifixed anther lobes, short filaments (1-1.2cm). Anthers bilobed, introrse, sagittate. **Gynoecium:** 2 carpels, syncarpous, inferior globose ovary, 2 chambered, 2 ovules, axile placentation, short style (0.1cm), bifurcated stigma. **Fruit:** capsule with persistent sepals, hypocotyl 39-49cm long.

Remarks: District wise variations in morphometric characters were negligible for most of the characters. Length of style and stamen showed uniformity throughout the study area.

Table 3.5 District wise variation in morphometric measurements of *R. mucronata*

Characters	Districts						
	KSD	KNR	KZH	TRS	EKM	ALP	KLM
Leaf length	14.44± 1.2	14.61± 0.8	14.59± 0.67	16.10± 0.2	15.83± 0.26	14.7± 0.38	14.56± 0.31
Leaf width	7.90±0.23	7.87±0.23	8.07±0.35	8.27±0.61	8.40±0.34	7.65±0.16	7.88±0.23
Petiole length	4±0.14	4.08±0.27	4.42±0.16	4.4±0.35	4.26±0.27	4.14±0.27	4.32±0.17
Mucron length	0.63±0.1	0.80±0.06	0.50±0.07	0.53±0.08	0.77±0.1	0.38±0.09	0.60±0.14
Bud length	1.48±0.23	1.56±0.08	1.24±0.05	1.58±0.04	1.44±0.05	1.34±0.15	1.46±0.11
Peduncle length	1.62±0.21	1.98±0.08	1.38±0.14	1.74±0.18	1.82±0.19	1.58±0.25	1.54±0.16
Pedicel length	0.24±0.55	0.09±0.64	0.05±0.56	0.04±0.24	0.05±0.36	0.15±0.14	0.11±0.48
Sepal length	1.72±0.08	1.7±0.1	1.42±0.14	1.64±0.08	1.74±0.19	1.52±0.08	1.75±0.2
Sepal width	1.43±0.1	1.45±0.05	1.28±0.04	1.50	1.42±0.04	1.28±0.07	1.48±0.09
Petal length	1.65±0.23	1.725±0.17	1.475±0.09	1.72±0.17	1.6±0.18	1.45±0.05	1.52±0.09
Petal width	1.08±0.1	1.2	1.04±0.08	1±0.1	1.12±0.10	1.1±0.14	1.1±0.14
Stamen length	1.07±0.1	1.1±0.1	1	1	1	1	1
Style length	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fruit length	43.67±3.9	46.85±1.2	46.27±2.3	45.85±2.4	46.93±1.2	48.30±0.7	47.72±0.8

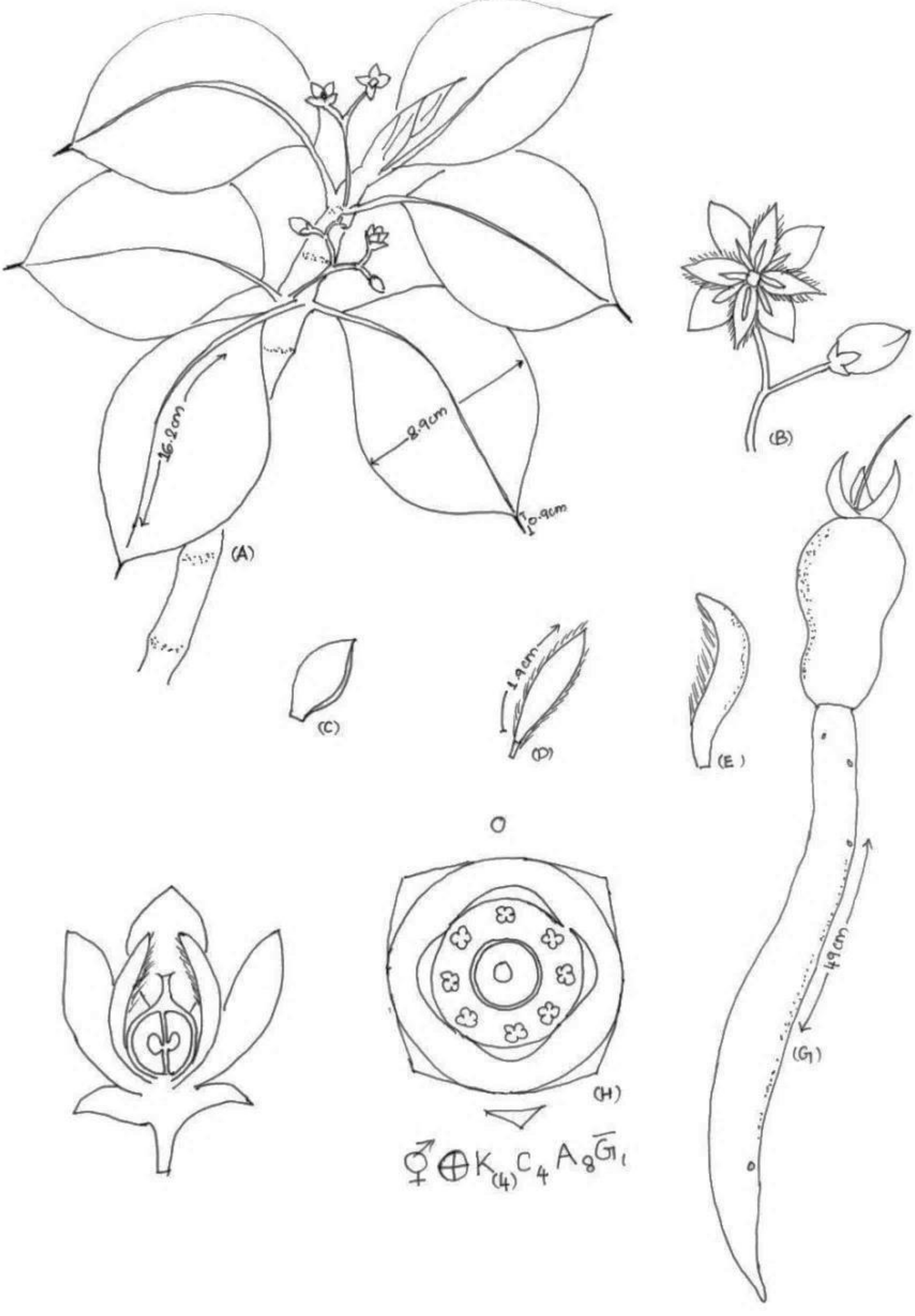
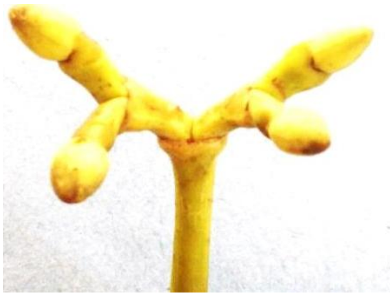


Figure 3.1 ***Rhizophora mucronata*** (A) Habit (B) Flower (C) Sepal (D) Petal (E) Stamen (F) L.S of flower (G) Fruit (H) Floral diagram

(a) **(b)**



(c) **(d)**

(e) **(f)** **(g)**

Plate 3.1 ***Rhizophora mucronata*** (a) Habit (b) Stilt roots (c) Flowering twig (d) Inflorescnce (e)Leaf (f) Leaf mucron (g) vivipary.

ii. *Rhizophora apiculata* Blume (1827)

Common name	:	Tall fruited stilted mangrove
Local name	:	Peekandal
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Ernakulam, Kottayam, Alappuzha and Kollam
Abundance	:	Rare

Habit: medium sized trees, deliquescent and spreading branches. **Root:** slightly corky, woody, cylindrical stilt roots. **Stem:** brownish to grey, fissured bark, distinct nodes and internodes, leaves clustered at the shoot apex, prominent leaf-scars. **Leaves:** 12.3-16cm x 4.6-6.5cm, simple, exstipulate, petiolate (3.2-4.2cm), pulvinous, lamina entire, acute, tapering, mucronata (0.2-0.7cm), ovate- elliptic, green, dorsiventral, coriaceous, unicostate inconspicuous reticulate venation. **Inflorescence:** cymose, opposite-decussate, peduncles short (0.3-0.8cm), unbranched, 2 flowered, bud 0.6-1.3cm long. **Flowers:** erect, sessile, complete, regular, hermaphrodite, ebracteate, odourless, globose, fleshy. **Calyx:** 4 sepals, polysepalous, 0.6-1.3cm x 0.8-1.2 cm, ovate, entire, acute, fleshy, thick, green, glabrous, superior, valvate aestivation, persistent. **Corolla:** 4 petals, polypetalous, 0.6-1cm x 0.3-0.5cm, white, entire, acute, odourless, fleshy, glabrous, deciduous, alternate to sepals. **Androecium:** 11-12 stamens, 0.8-1.1cm long, free, sessile; anthers bilobed, introrse, sagittate. **Gynoecium:** bicarpellary, syncarpous, globose ovary, inferior, 2 chambered, 2 ovules, axile placentation, style short (0.1cm), bifurcate stigma. **Fruit:** capsules, hypocotyl 45-52cm long.

Table 3.6 District wise variation in morphometric measurements of *R. apiculata*

Characters	Districts						
	KSD	KNR	KZH	EKM	KTM	ALP	KLM
Leaf length	12.66±0.41	14.29±0.5	13.77±0.3	14.39±0.5	13.44±0.1	15.01±0.8	14.61±0.3
Leaf width	5.5±0.4	6.03±0.3	5.95±0.4	6.11±0.2	5.63±0.3	5.61±0.2	5.05±0.2
Petiole length	3.6±0.2	4±0.1	3.8±0.3	3.92±0.2	3.7±0.2	4.12±0.1	3.48±0.2
Mucron length	0.45±0.1	0.51±0.1	0.28±0.07	0.33±0.08	0.33±0.1	0.41±0.08	0.43±0.08
Bud length	1.1±0.1	1.52±0.08	1.18±0.1	1.52±0.08	1.28±0.13	1.4±0.15	1.44±0.11
Peduncle length	0.14±0.1	0.08±0.1	0.10±0.07	0.08±0.05	0.13±0.08	0.15±0.1	0.11±0.1
Sepal length	0.68±0.19	1.04±0.2	0.52±0.08	1	0.44±0.11	0.74±0.36	0.84±0.05
Sepal width	0.93±0.15	1.26±0.05	1±0.15	1.1±0.1	0.81±0.04	1.01±0.13	1.13±0.12
Petal length	0.7±0.08	0.85±0.05	0.57±0.09	0.85±0.05	0.45±0.05	0.425±0.09	0.725±0.17
Petal width	0.37±0.09	0.44±0.08	0.3	0.36±0.13	0.36±0.15	0.32±0.08	0.38±0.04
Stamen length	0.66±0.19	1.06±0.1	0.73±0.16	1.06±0.05	0.73±0.12	0.95±0.16	1.01±0.13
Style length	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fruit length	50.25±1.3	50.63±1.2	49.25±1.5	49.81±1.4	47.75±1.7	49.45±0.9	49.91±1.3

Remarks: Leaves were smaller than *R.mucronata* and mucron was not much prominent as compared to other species. Flowers were sessile and much significant variation was not observed in various morphometric characters. Only the style length exhibited uniformity throughtout the Kerala coast.

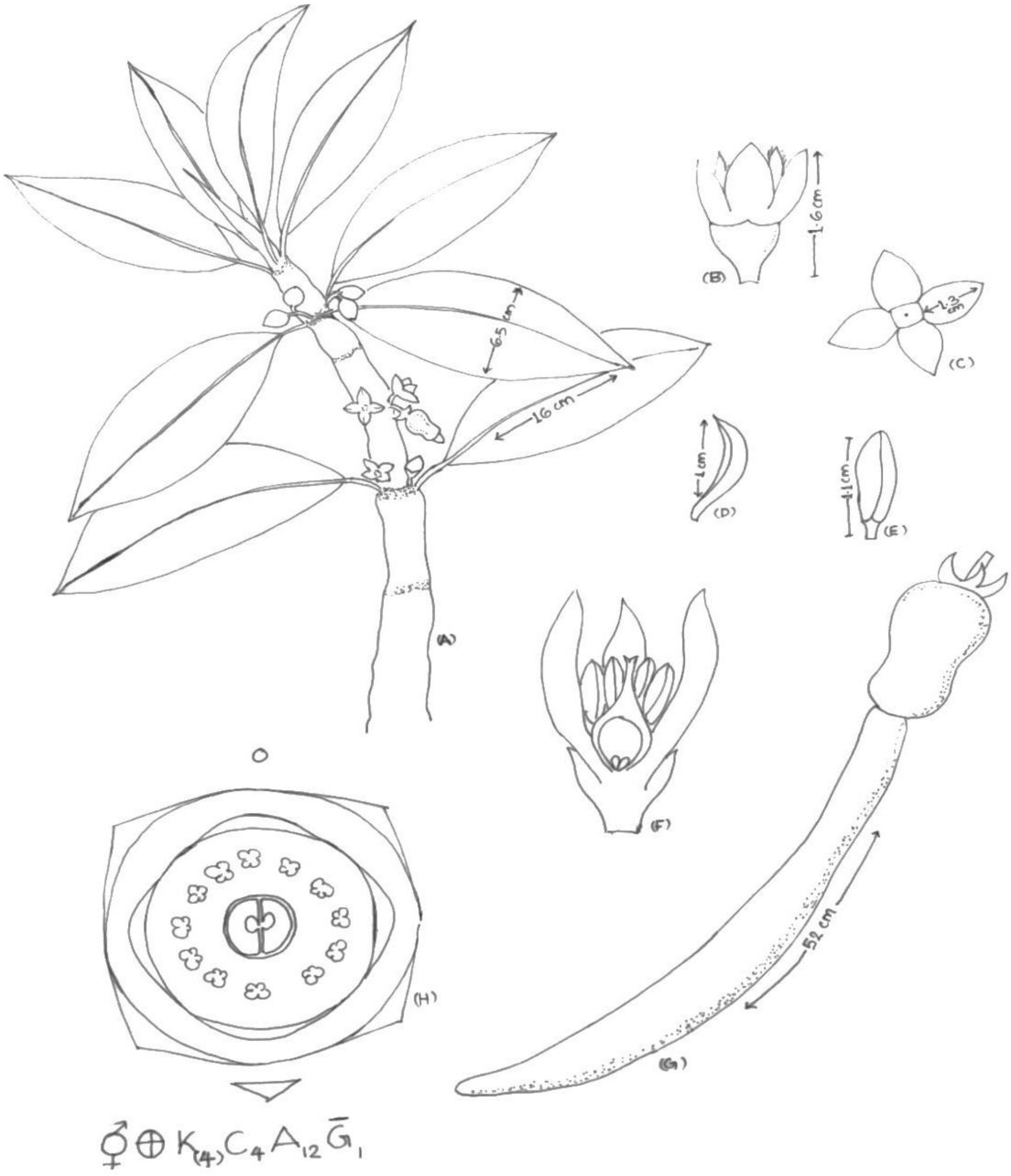


Figure 3.2 ***Rhizophora apiculata*** (A)Habit (B)Flower (C)Calyx (D)Petal (E)Stamen (F)L.S.of flower (G)Fruit (H)Floral diagram.

(a)

(b)

(c)

(d)

(e)

(f)

Plate 3.2 ***Rhizophora apiculata*** (a) Habit (b) Stilt roots (c) Flowering twig (d) Inflorescnce (e) Flower (f) Calyx

b. Genus: *Bruguiera*

Key to *Bruguiera* species

1. a. Flowers multiple (3nos.); white, small (less than 2cm)……***B. cylindrica***

b. Flowers solitary; large (2.5-4cm long)………………………. **(2)**

2. a. Calyx: 13-16; reddish…………………………***B. gymnorrhiza***

b. Calyx: 10-12; small, yellowish……………………..***B. sexangula***

i. *Bruguiera cylindrica* (L.) Bl. (1827)

Common name: Small leaved orange mangrove

Local name: Cherukandal

Distribution in Kerala: Kannur, Kozhikode, Thrissur, Ernakulam, Alappuzha and Kollam

Abundance: Common

Habit: medium to large sized perennial, evergreen trees, woody, erect with dark green leaves, grey, smooth bark. **Root:** Knee roots and buttresses. **Stem:** apical shoot green, glabrous, nodes and internodes with inconspicuous leaf-scars. **Leaves:** 7.5-9.8cm long, 2.4-3.2 cm broad, simple, opposite – decussate, dorsiventral, reticulate venation, cauline, exstipulate, petiolate (1.4-2.2cm). Lamina entire, ovate-lanceolate, acuminate leaf tip, cuneate base. **Inflorescence:** cymose, flowers 3, peduncle 1.4-2cm long, green. **Flowers:** small, complete, regular, ebracteate, bisexual, erect and greenish. **Calyx:** yellowish green when young, turn brown at maturity, sepals 8, 1.5-2cm x 0.2cm, fused, thick, entire, persistent, valvate aestivation. **Corolla:** 8 petals, 0.5-0.8cm x 0.5cm, polypetalous, white, thin, small, ciliated, basal margins hairy, alternate to sepals. **Androecium:** 16 free stamens, two in each petal, filaments unequal in length (0.3cm), white, basifixed, introrse anthers. **Gynoecium:** 2/3 carpels, syncarpous, single ovule, axile placentation, single terminal style (0.3-0.4cm), white, hairy, bifid stigma. **Fruit:** berry with persistent calyx tube, hypocotyl 13-15cm long. Germination is viviparous.

Remarks: The species exhibited the smallest leaf size among other identified Rhizophoracean members. Various characters such as sepal width, petal width and bristle length displayed uniformity in size in all districts. Flower size was much smaller compared to other species of Bruguiera.

Table 3.7 District wise variation in morphometric measurements of *B. cylindrica*

Characters	Districts						
	KSD	KNR	KZH	TRS	EKM	ALP	KLM
Leaf length	9.15± 0.3	8.8±0.8	8.66±1	11.65±0.9	9.38±0.1	7.7±0.5	8.15±0.26
Leaf width	3.1± 0.17	2.91± 0.4	2.87± 0.6	3.17± 0.1	3.27± 0.3	2.91± 0.3	2.6± 0.2
Petiole length	2.02± 0.4	2.06± 0.1	1.6± 0.1	1.62± 0.2	1.46± 0.08	1.86± 0.2	1.28± 0.1
Bud length	1.82± 0.1	1.84± 0.05	1.76± 0.3	1.84± 0.08	1.64± 0.1	1.92± 0.08	1.66± 0.1
Peduncle length	1.58± 0.2	1.9± 0.1	1.56± 0.05	1.5± 0.08	1.73± 0.2	1.55± 0.13	1.48± 0.07
Pedicel length	0.47± 0.09	0.52± 0.05	0.67± 0.1	0.6± 0.1	0.65± 0.1	0.45± 0.1	0.52±0.1
Sepal length	1.82± 0.1	1.84± 0.05	1.76± 0.3	1.84± 0.08	1.64± 0.1	1.92± 0.08	1.66± 0.1
Sepal width	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Petal length	0.65± 0.1	0.8	0.7± 0.1	0.77± 0.05	0.77± 0.05	0.75± 0.05	0.75± 0.05
Petal width	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bristle length	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Stamen length	0.38± 0.08	0.4± 0.1	0.34± 0.05	0.36± 0.05	0.46± 0.05	0.36± 0.08	0.46± 0.1
Style length	0.35± 0.05	0.4± 0.1	0.32± 0.05	0.35± 0.05	0.47± 0.05	0.32± 0.05	0.45± 0.1
Fruit length	14.65± 0.1	15± 0.1	13.8 0.8	14.65± 0.2	13.95± 0.8	14.35± 0.5	14.4± 0.5

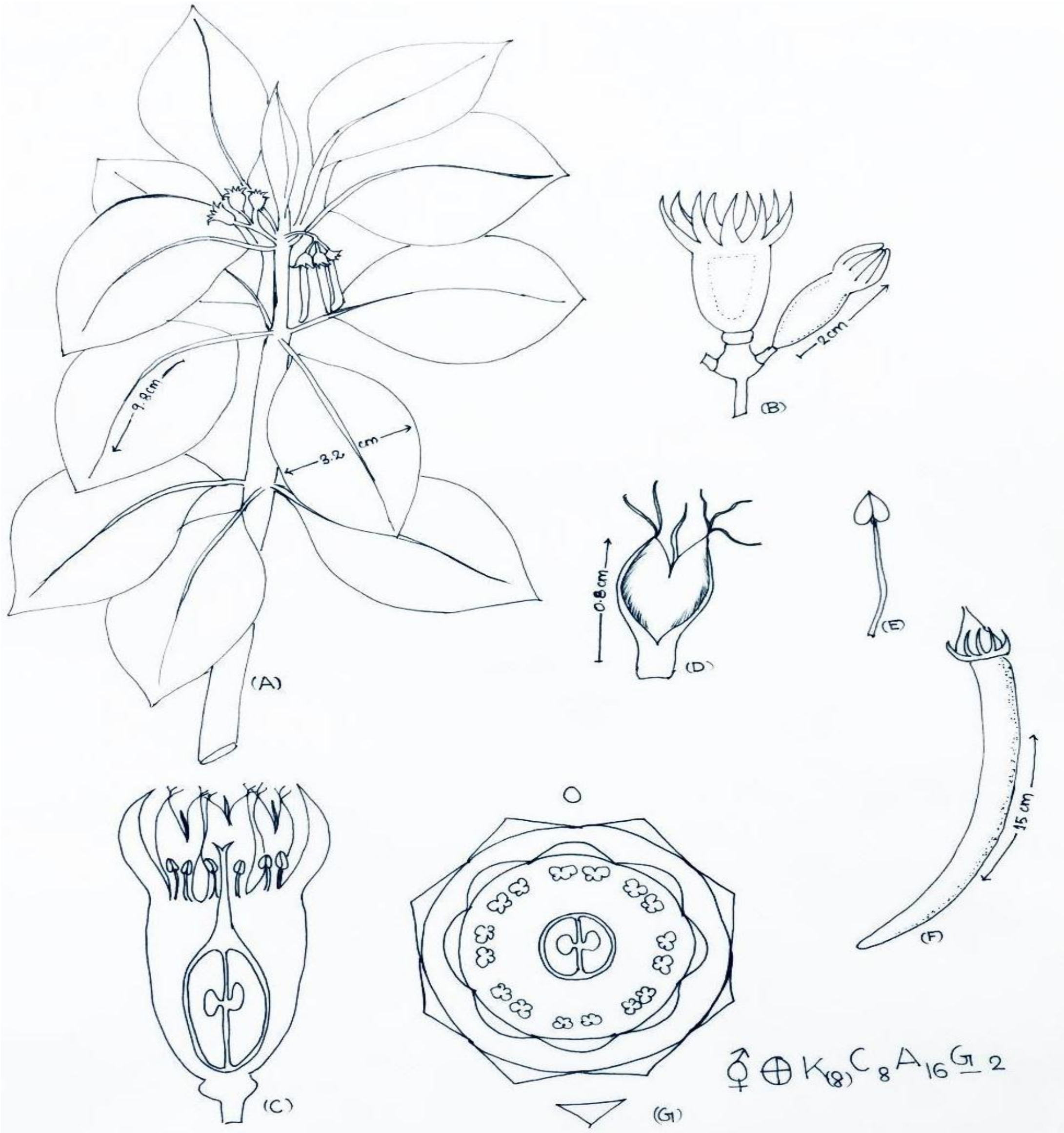


Figure 3.3 ***Bruguiera cylindrica*** (A) Habit (B) Flower (C) L.S of flower (D) Petal (E) Stamen (F) Fruit (G) Floral diagram.

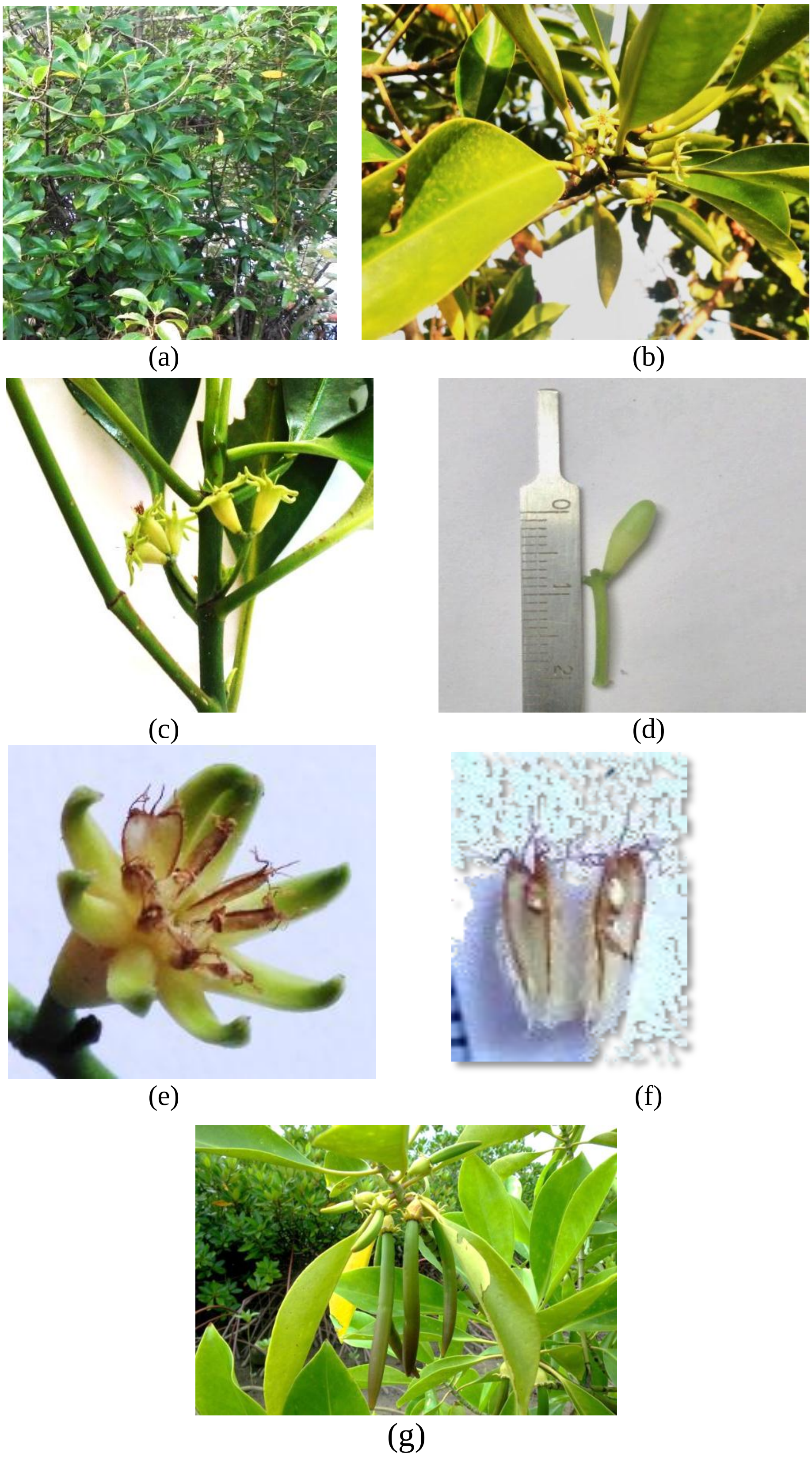


Plate 3.3 ***Bruiguiera cylindrica*** (a)Habit (b) Flowering twig (c)Inflorescnce (d)Bud (e) Flower (f) Petals (g) Vivipary

ii. *Bruguiera gymnorrhiza* (L.) Lamk. (1798)

Common name: Large-leaved orange mangrove

Local name: Penakandel, Karakandel

Distribution in Kerala: Malappuram, Ernakulam, Kottayam, Alappuzha and Kollam

Abundance: Common

Habit: medium sized (12m), evergreen trees. **Root:** knee root, buttress roots. **Stem:** blackish green to grey, differentiated into nodes and internodes, leaf- scars inconspicuous. **Leaves:** 8.2- 12.2cm x 3.2-4.5cm,simple, cauline, exstipulate, petiolate, opposite- decussate, petioles 2-2.6cm, pulvinous, glabrous, reddish, lamina entire, acute, dorsiventral, coriaceous, broadly ovate- lanceolate. **Inflorescence:** solitary flowers, pedicel 1.8-2.1cm long. **Flowers:** 2-3.2cm, complete, regular, pendulous, ebracteate, bisexual. **Calyx:** 13-16 sepals, 2-3.2cm x 0.2- 0.3cm, fused at base, reddish, glabrous, persistent. **Corolla:** 13-16 petals, 1.5-2.5cm x 0.5cm, polypetalous, stiff, folded into two, 3-4 apical cilia (0.3cm), silky hair at base and margin. **Androecium:** 26-32 free stamens, 0.5cm, 2 inserted in each petal, anthers bilobed, introrse, basifixed. **Gynoecium:** 3 carpels, syncarpous, cup- shaped, inferior, ovary 2-4 locular, 2 ovules in each chamber, terminal style, 1.4-2cm long, trifid stigma. **Fruit:** pendulous capsules with persistent reddish calyx, hypocotyl 15-17.6cm, viviparous mode of germination.

Remarks: The species displayed rare occurrence along the northern zone. Most characters (sepal width, petal width, bristle length and stamen length) showed uniformity in size in all districts. The floral characters exhibited similarity with that of *B. sexangula* except slightly larger size and difference in calyx colour (reddish). The fruit size was also larger than *B. sexangula*.

Table 3.8 District wise variation in morphometric measurements of *B.gymnorrhiza*

Characters	Districts				
	MLP	EKM	KTM	ALP	KLM
Leaf length	9.2± 0.6	10.7± 1.1	9.4± 0.6	10.9± 1.1	9.71 0.7
Leaf width	3.7±0.2	3.83±0.3	3.61±0.3	4±0.2	4.08±0.3
Petiole length	2.43±0.1	2.25±0.1	2.46±0.08	2.2±0.1	1.95±0.1
Bud length	2.71±0.2	3.05±0.08	2.18±0.1	2.566±0.1	2.76±0.2
Pedicel length	1.94±0.08	2	1.88±0.08	2.04±0.05	1.94±0.05
Sepal length	2.71±0.2	3.05±0.08	2.18±0.1	2.56±0.1	2.76±0.2
Sepal width	0.3	0.3	0.3	0.3	0.3
Petal length	1.78±0.1	1.95±0.08	1.58±0.1	1.5±0.1	1.6±0.2
Petal width	0.5	0.5	0.5	0.5	0.5
Bristle length	0.3	0.3	0.3	0.3	0.3
Stamen length	0.5	0.5	0.5	0.5	0.5
Style length	1.58±0.1	1.64±0.2	1.56±0.2	1.84±0.1	1.66±0.2
Fruit length	15.66±0.7	17.06±0.7	15.9±0.5	16.55±0.2	16.5±0.3

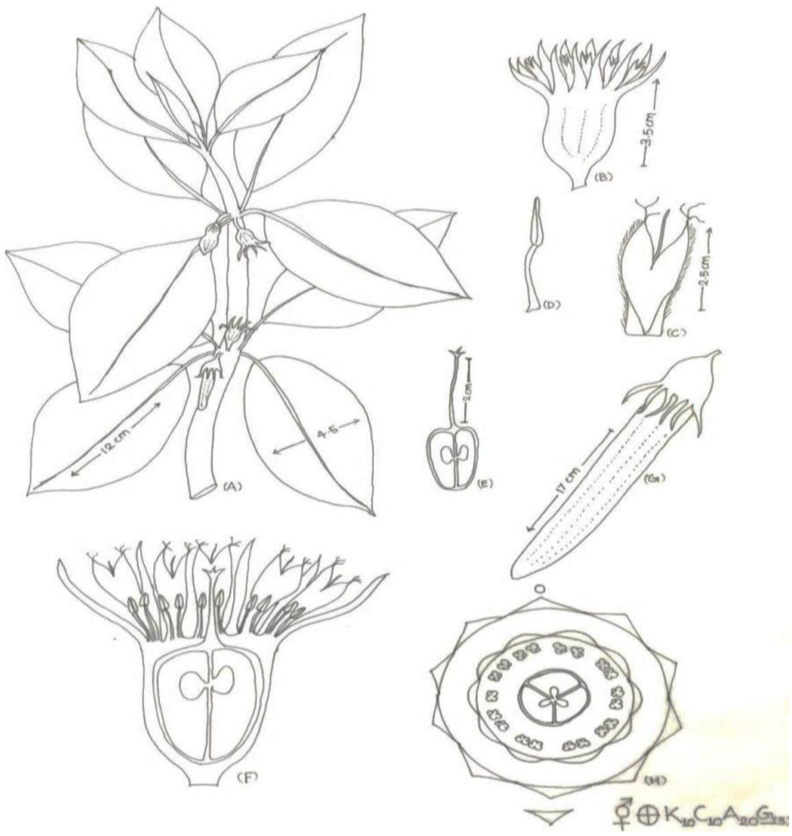


Figure 3.4 ***Bruguiera gymnorrhiza*** (A) Habit (B) Flower (C) Petal (D) Stamen (E) Ovary (F) L.S of flower (G) Fruit (H) Floral diagram

(a)

(b)

(c)

(d)

(e)

Plate 3.4 ***Bruiguiera gymnorrhiza*** (a)Habit (b) Buttress roots (c) Flowering twig (d) Calyx (e) Vivipary

iii. *Bruguiera sexangula* (Lour.) Poir. (1816)

Common name: Orange mangrove

Local name: Swarna kandel

Distribution in Kerala: Kasaragod, Ernakulam, Kottayam and Alappuzha

Abundance: Rare

Habit: evergreen, erect, small trees. **Root:** profusely branched root buttress, broom like appearance. **Stem:** yellowish shoot, with nodes, internodes and leaf scars. **Leaves:** 7.5-12.2cm x 2.8-3.5cm, simple, opposite – decussate, entire, acute, exstipulate, petiolate (1.5-2.5cm), glabrous, pulvinous, yellowish. Lamina ovate-lanceolate, inconspicuous reticulate venation, dark green. **Inflorescence:** solitary flowers. **Flowers:** large, 1.9-2.6cm, complete, bisexual, ebracteate, pedicellate (1.5-1.9cm), yellowish, glabrous, smooth, pendulous. **Calyx:** 10-12 sepals, 1.9-2.5 cm long x 0.2cm broad, free above, funnel like tube at base, yellowish, fleshy, hard, persistent, valvate aestivation. **Corolla:** Petals 10-12 nos., 1.5-2cm x 0.5cm, polypetalous, alternate to sepals, bilobed, coriaceous, pubescent basally, yellowish, light brownish after maturation. **Androecium:** 20-24 stamens, 0.4 cm long, folded in petals, anthers introrse, basifixed, soft, round, bilobed, yellowish. **Gynoecium:** 3 carpels, syncarpous, cup-shaped, ovary superior, 2 ovules, axile placentation, style white, 1-1.5 cm long, glabrous, fleshy, trifid stigma. **Fruit:** capsule or berry, dark green, slightly ridged pendulous, yellowish persistent calyx tube, seed germination-viviparous, hypocotyl 14.6-15.6cm long.

Table 3.9 District wise variation in morphometric measurements of *B. sexangula*

Characters	Districts			
	KSD	EKM	KTM	ALP
Leaf length	8.56±0.9	10.03±1.2	9.46±0.6	10.95±1.1
Leaf width	3.13±0.08	3.2±0.2	3±0.1	3.25±0.2
Petiole length	2.03±0.1	2.23±0.4	2.1±0.4	2.38±0.09
Flower length	2.15±0.1	2.43±0.1	2.31±0.04	2.38±0.1
Pedicel length	1.7±0.1	1.7±0.1	1.54±0.05	1.6±0.1
Sepal length	2.15±0.1	2.43±0.1	2.31±0.04	2.38±0.1
Sepal width	0.3	0.3	0.3	0.3
Petal length	1.73±0.18	1.85±0.05	1.65±0.16	1.85±0.18
Petal width	0.5	0.5	0.5	0.5
Bristle length	0.3	0.3	0.3	0.3
Stamen length	0.4	0.4	0.4	0.4
Style length	1.32±0.08	1.4±0.1	1.4±0.1	1.14±0.1
Fruit length	15.15±0.17	15.03±0.13	15±0.27	15.38±0.11

Remarks: Similar to *B. gymnorrhiza*, the species was also absent in most districts of northern zone and was rare in distribution in other study sites. Most characters showed negligable variation between districts and were smaller compared to *B. gymnorrhiza*. Petal length, width, bristle length and stamen length exhibited uniformity.

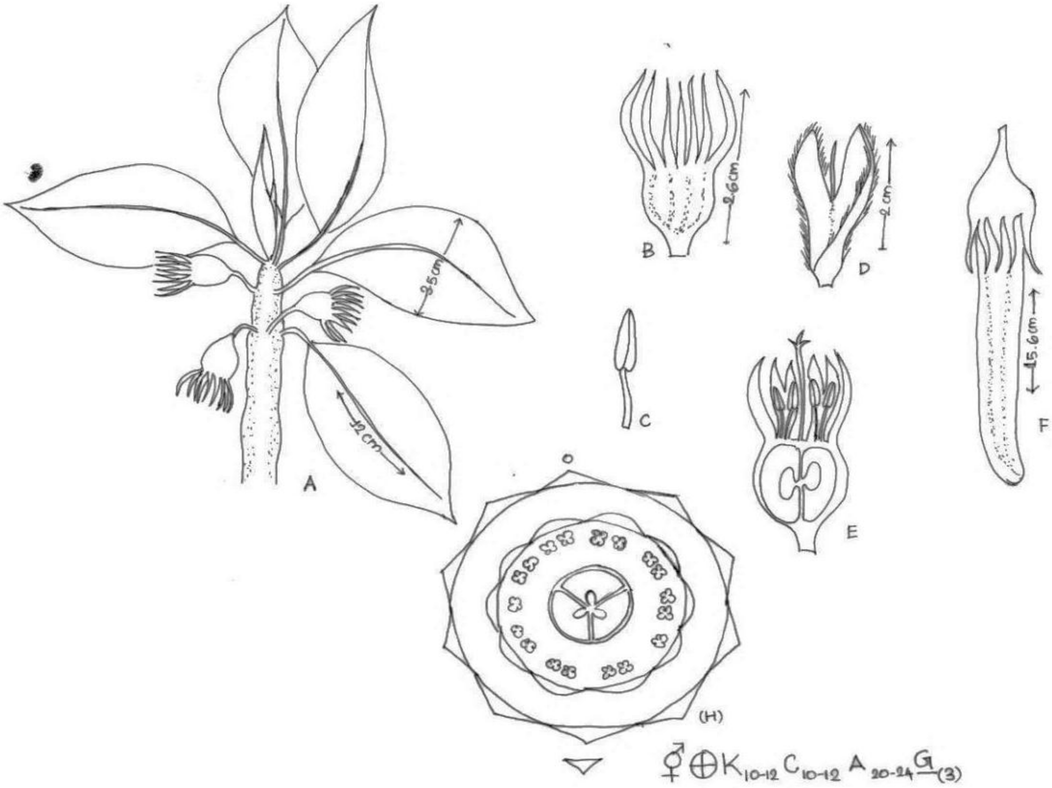


Figure 3.5 ***Bruguiera sexangula*** (A)Habit (B)Flower (C)Stamen (D)Petal (E) L.S of flower (F)Fruit (G)Floral diagram.

(a) (b)

Plate 3.5 ***Bruguiera sexangula*** (a)Habit (b) Vivipary

c. Genus: *Ceriops*

i. *Ceriops tagal* (Perr.) C.B. Robinson (1908)

Common name: Yellow mangrove

Local name: Manjakandel, Anakandel

Distribution in Kerala: Kollam

Abundance: Very rare

Habit: Small sized tree, upto 8m. **Root:** broom-like buttress roots. **Stem:** pyramidal, swollen nodes, short internodes, grey bark. **Leaves:**3.8-5cm x 2.5-3cm, simple, opposite- decussate, dorsiventral , exstipulate, pulvinous petiole ((1.5-2cm), lamina elliptic, rounded leaf tip, cuneate base. **Inflorescence:** cymose axillary, peduncles short. **Flowers:** 10-12 white, complete, regular, bisexual, pentamerous, resinous. **Calyx:** 5 sepals, polysepalous, superior, entire, thick, green, acute, elliptic- lanceolate, persistent, woody-spine like after maturation. **Corolla:** 5 petals, polypetalous, valvate aestivation, thin, white, 3 clavate appendages, alternate to sepals. **Androecium:** 10 stamens, free, long, unequal filaments, anthers bilobed, sagittate, reddish, dorsifixed, introrse. **Gynoecium:** 3 carpels, syncarpous, ovary inferior, elliptic globose, 2-chambered, 2 ovules, axile placentation, terminal style, short, greenish white, trifid stigma. **Fruit:** capsule with persistent spiny calyx, hypocotyl- 25-32cm, germination viviparous.

Remarks: Species was very rare in occurrence and was observed only in Kollam district. Morphometric measurements revealed bigger leaf size than *B. cylindrica* but smaller compared to other Rhizophoracean members. The species produced numerous flowers in each inflorescence dissimilar to other members of the family. Vivipary displayed similarity (thin and slender) with *Kandelia candel* but was longer in length.

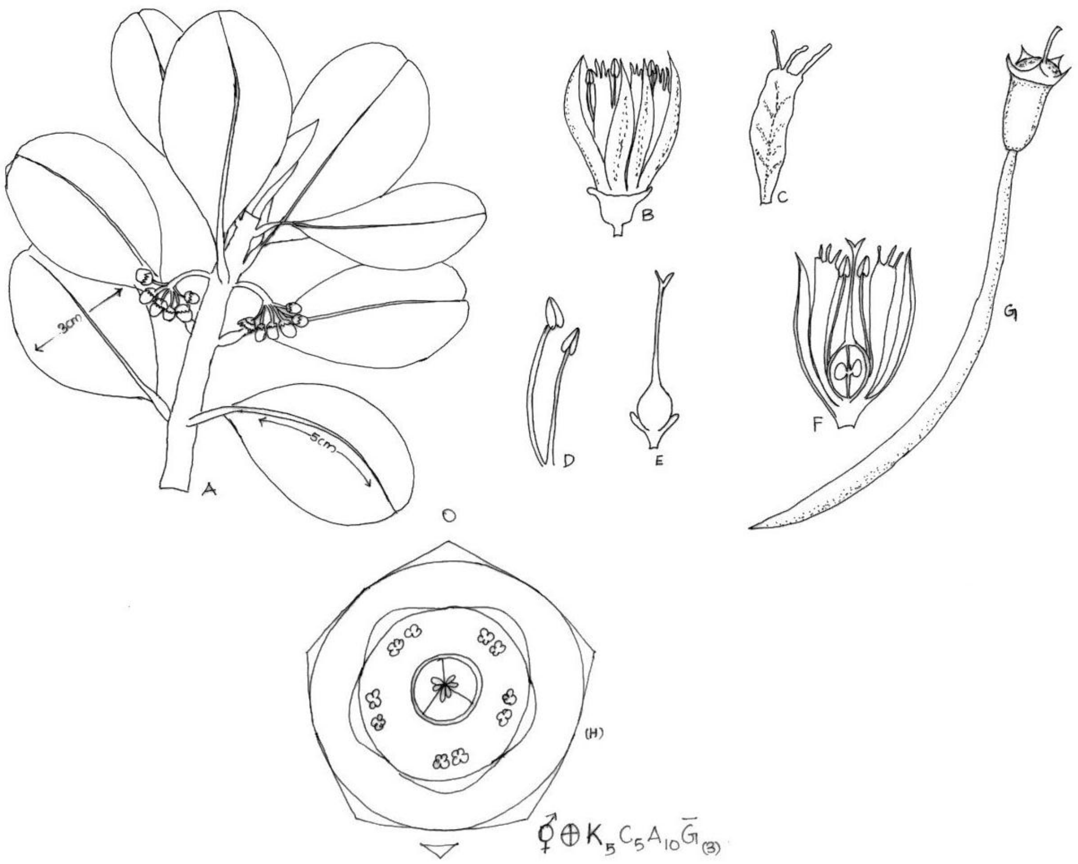


Figure 3.6 ***Ceriops tagal*** (A) Habit (B) Flower (C) Petal (D) Stamen (E) Ovary (F) L.S of flower (G) Fruit (H) Floral diagram

Plate 3.6 *Ceriops tagal* habit

d. Genus: *Kandelia*

i. *Kandelia candel* (L.) Druce (1914)

Common name: Narrow leaved kandelia

Local name: Ezhuthanikandel

Distribution in Kerala: Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha and Kollam

Abundance: Common

Habit: small-medium, evergreen trees. **Root:** fused broom like roots at trunk base. **Stem:** nodes with leaf scars and peduncle scars. **Leaves:** simple, 3.5-6cm x 1.3-3cm, opposite- decussately, petiolate, green, glabrous, lamina entire, coriaceous, oblong – lanceolate, slightly fleshy, dorsiventral. **Inflorescence:** cymose, axillary, opposite-decussate, peduncle 1-2cm x 0.2-0.3cm, green, glabrous, slightly flattened, dichotomously branched. **Flowers:** complete, regular, bisexual, erect, pedicellate. **Calyx:** 5 sepals, 0.5cm x 0.3cm, polysepalous, thick, fleshy, green, slender, entire, lanceolate, glabrous, imbricate aestivation, superior, persistent, spin like at maturity. **Corolla:** 5 petals, 0.2cm x 0.2cm, thin, white, polypetalous, superior, deciduous, apical papillae, valvate aestivation. **Androecium:** stamens 34- indefinite, 0.2-0.4cm long, free, slender, filaments white, glabrous, soft, unequal in length, anthers orange, round, globose, basifixed, introrse. **Gynoecium:** tricarpellary, syncarpous ovary, globose, inferior, unilocular, 6 ovules, axile placentation, style single, trifid stigma. **Fruit:** capsules, hypocotyl long (28-35cm), slender, green, persistent calyx lobes. Germination is viviparous.

Remarks: The species was recorded from all districts except Thiruvananthapuram. The species observed along the northern zone (mainly Kannur) were matured trees, while those noted in central and southern zones were young and emerging vegetation. All the characters exhibited minute variations between districts. None of the morphometric characters exhibited uniformity.

Table 3.10 District wise variation in morphometric measurements of *K. candel*

Characters	Districts								
	KSD	KNR	KZH	MLP	TRS	EKM	KTM	ALP	KLM
Leaf length	13.66± 1.8	12.72± 1.7	13.53± 1.12	13.8± 0.82	13.9± 0.76	11.32± 0.83	9.52± 0.59	13.07± 0.5	14.62± 1.1
Leaf width	4.17± 0.46	3.40± 0.24	3.66± 0.45	3.49± 0.19	3.64± 0.22	3.03± 0.14	2.83± 0.20	2.96± 0.39	3.8± 0.31
Petiole length	1.60± 0.23	1.29± 0.09	1.36± 0.11	1.34± 0.16	1.44± 0.10	1.19± 0.09	0.93± 0.16	1.37± 0.15	1.31± 0.11
Peduncle length	3.66± 5.09	3.25± 4.79	3.37± 5.13	3.31± 5.32	3.35± 5.33	2.76± 4.32	2.37± 3.64	3.07± 5.01	3.55± 5.59
Pedicel length	0.73± 0.13	0.70± 0.13	0.63± 0.17	0.54± 0.11	0.55± 0.08	0.54± 0.11	0.34± 0.05	0.53± 0.09	0.49± 0.08
Bud length	1.50± 0.13	1.66± 0.23	1.55± 0.21	1.71± 0.19	1.64± 0.21	1.48± 0.07	1.33± 0.10	1.50± 0.09	1.70± 0.19
Sepal length	2.70± 0.24	2.87± 0.08	2.40± 0.09	2.38± 0.04	2.65± 0.25	2.62± 0.25	2.33±0.08	2.80± 0.21	2.82± 0.19
Sepal width	0.36± 0.09	0.42± 0.08	0.38± 0.08	0.42± 0.08	0.40± 0.07	0.44± 0.05	0.34± 0.05	0.42± 0.08	0.42± 0.08
Petal length	2.18± 0.22	2.42± 0.08	2.18± 0.18	2.16± 0.13	2.20± 0.10	2.36± 0.11	2.10± 0.14	2.40± 0.07	2.42± 0.08
Petal width	0.64± 0.18	0.60± 0.16	0.46± 0.05	0.36± 0.05	0.46± 0.05	0.72± 0.08	0.48± 0.08	0.52± 0.08	0.76± 0.05
Stamen length	0.92± 0.19	0.68± 0.19	0.95± 0.15	0.92± 0.15	0.80± 0.26	0.98± 0.13	0.72± 0.04	0.98± 0.13	1.02± 0.17
Style length	1.06± 0.09	1.16± 0.09	1.06± 0.09	1.00± 0.00	1.16± 0.09	1.20± 0.00	1.00± 0.0	1.14± 0.05	1.14± 0.09
Fruit length	40.08± 2.6	44.3± 1.29	40.60± 1.51	40.6± 1.9	43.9± 1.42	40.65± 1.63	38.67± 1.04	41.6± 1.27	42.63± 1.3

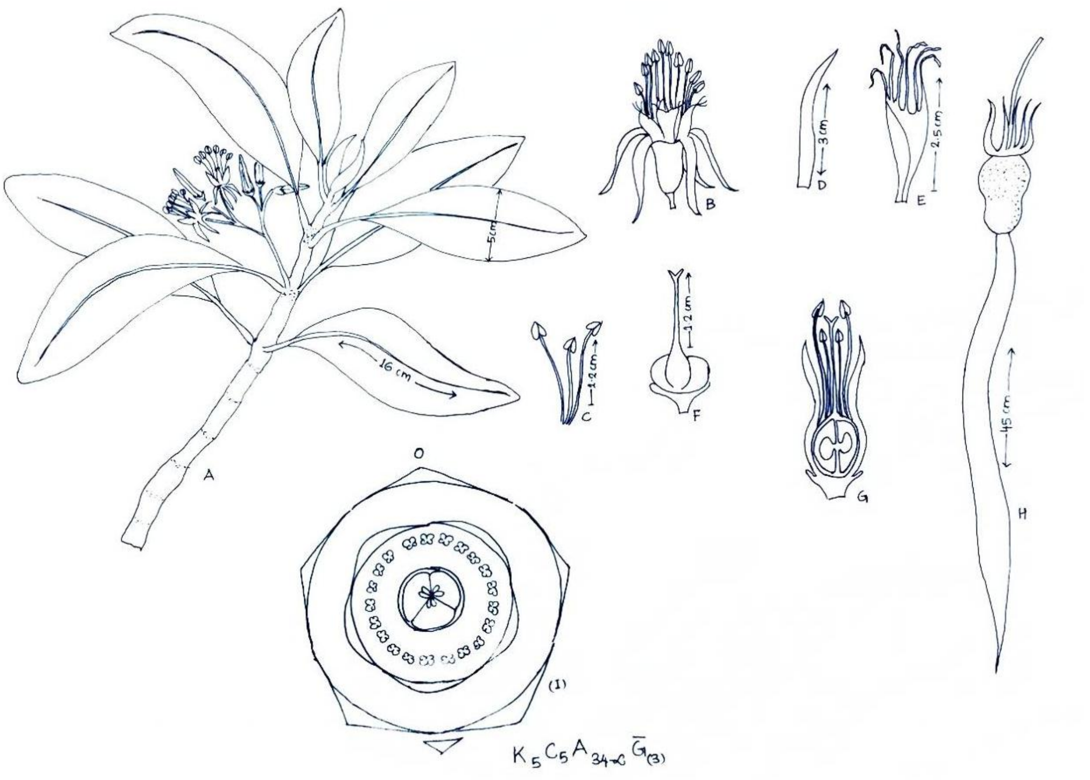


Figure 3.7 ***Kandelia candel*** (A) Habit (B) Flower (C) Stamen (D) Sepal (E) Petal (F) Ovary (G) L.S of flower (H) Fruit (I) Floral diagram

(a)

(b)

(c)

(d)

(e)

(f)

Plate 3.7 *Kandelia candel* (a) Habit (b) Flowering twig (c) Flower (d) Bud (e) Calyx (f) Vivipary

II. Family Euphorbiaceae

a. Genus *Excoecaria*

Key to *Excoecaria* species

1. Leaf ovate- elliptical; wavy/ serrate margin;

female flower: cyme; fruit-schizocarp………………***E. agallocha***

2. Leaf elliptic lanceolate; serrate margin;

Female flower: solitary; fruit- globose berry………….***E. indica***

i. *Excoecaria agallocha* L. (1759)

Common name: Blind- your-eye mangrove or blinding tree

Local name: Kammatti, Kannampotti

Distribution in Kerala: Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha and Kollam

Abundance: Very common

Habit: small tree, up to 8-10m high, dioecious, woody, perennial, prefer landward margins. **Root:** aerial roots absent, horizontal roots forms knots, have numerous lenticels. **Stem:** grey, smooth bark, green, round, solid, prominent lenticels, persistent stipules on petiole base, produce poisonous milky latex. **Leaves:** simple, 5-12cm long, 2-5cm broad, exstipulate, petiolate (1-3.2cm), ovate elliptic, thick, glabrous, colour changes from greenish- yellow- reddish, clustered at the tip, spirally arranged when internodes expand. **Inflorescence:** separate male and female inflorescence. Male inflorescence: catkin, 5-10cm long; female inflorescence: mixed cyme, erect/pendulous, 2-5cm long, axillary. **Male Flowers:** narrow cones, upright, elongate into longer spikes usually drooping, flowers small, sessile, yellow, 3 stamens (0.3-0.5cm), free, fertile, filaments glaborous, bilobed, basifixed anthers. **Female Flowers:** sessile, glabrous, achlamydous, zygomorphic, superior, ovoid, 3 lobed, bracteates; green, glaborous ;ovary tricarpellary, syncarpous, superior, ovoid, 3 chambered, 1 ovule, basal placentation, trifid stigma. **Fruit:** tri-lobed schizocarp, small sized, green turn black.

Remarks: The species was common in most of the study sites. The floral characters were smaller in size compared to all other identified mangrove species. All the floral characters exhibited minute variations in most of the districts

Table 3.11 District wise variation in morphometric measurements of *E. agallocha*

Characters	Districts								
	KSD	KNR	KZH	MLP	TRS	EKM	KTM	ALP	KLM
Leaf length	8.23± 2.63	10.08± 1.94	9.52± 0.83	10.02± 0.55	10.93± 0.76	11.02± 0.56	9.13± 0.64	11.02± 0.59	11.63± 0.31
Leaf width	3.26± 0.93	4.58± 0.45	4.02± 0.18	4.76± 0.21	4.58± 0.38	4.90± 0.10	3.72± 0.82	4.44± 0.47	4.56± 0.35
Petiole length	2.07± 0.49	2.23± 0.63	2.38± 0.77	2.23± 0.52	2.77± 0.30	2.85± 0.31	2.60± 0.21	2.62± 0.20	3.10± 0.36
Male infl. length	7.16± 2.49	8.32± 1.96	8.60± 0.19	8.54± 0.99	8.52± 0.95	9.12± 0.80	9.50± 0.63	8.82± 0.59	8.20± 1.40
Female infl. Length	3.00± 0.79	3.82± 1.09	4.12± 0.36	4.40± 0.70	3.70± 0.22	4.58± 0.33	4.08± 0.48	3.75± 0.34	4.10± 0.10
Stamen length	0.40± 0.10	0.42± 0.08	0.34± 0.05	0.36± 0.09	0.42± 0.08	0.40± 0.07	0.38± 0.08	0.34± 0.05	0.38± 0.08

Figure 3.8 ***Excoecaria agallocha*** (A) Habit (B) Female inflorescence (C) Male flower (D) Fruit

(a)

(b)

(c)

(d)

(e)

Plate 3.8 *Excoecaria agallocha* (a) Habit (b) Roots (c) Flowering twigs (d) Inflorescence (e) Fruits

ii. *Excoecaria indica* (Willd.) Muell. Arg. (1863)

Local name	:	Chillakammatti
Distribution in Kerala	:	Ernakulam, Kottayam and Alappuzha
Abundance	:	Rare

Habit: evergreen, dioecious /monoecious, 18-20m tall. **Root:** aerial roots absent. **Stem:** short, brown greyish- olive bark. **Leaves:** simple, 8-17cm x 3-4cm, elliptic/ lanceolate, alternately arranged, acuminate apex, subacute base, short petioled (0.8-2cm). **Inflorescence:** raceme-like, terminal/sub-terminal; peduncle short/almost sessile. **Flowers:** unisexual, dioecious/monoecious. **Male flowers:** yellowish-green, puberulous, yellowish green; stamens 3, short, free. **Female flowers:** solitary, pedicellate; tepals 2/3, triangular, ciliolate, green, connate base; ovary bilobed. **Fruit:** woody, globose capsules, green.

(a)

(b)

Plate 3.9 *Excoecaria indica* (a) Habit (b) Fruits

III. Family: Avicenniaceae

a. Genus *Avicennia*

Key to *Avicennia* Species

1. a. Leaf apex: acute…………………..**(2)**

   b. Leaf apex: obtuse……………….. **(3)**

2. a. Terminal inflorescence; 15-18 medium sized flowers……… ***A. marina***

   b. Terminal/ axillary inflorescence; 8-32 small flowers…………***A. alba***

3. a. Terminal/ axillary inflorescence; 10-12 large flowers…………***A. officinalis***

i. *Avicennia marina* (Forssk.) Vierh. (1907)

Common name	:	Grey mangrove
Local name	:	Cheru uppatti
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Ernakulam, and Kollam
Abundance	:	Common

Habit: evergreen, perennial, 3-8m, up to 20cm in diameter, irregularly spreading branches. **Root:** numerous pneumatophores, narrow pointed apex, spongy. **Stem:** yellowish brown, smooth bark, peels off, bears lenticels. **Leaves:** simple, 3-10.5cm x 3-5.5cm, opposite decussate, exstipulate, petiolate (0.5-1.5cm), elliptic - oblong, acute, tapering base, coriaceous, dorsiventral, shining dorsal side, whitish pubescent ventral side. **Inflorescence:** compound spike, long peduncle, bud length 0.5-0.8cm. **Flowers:** complete, bisexual, hypogynous, pale yellow to orange- yellowish, sweet scented. **Calyx:** 5 sepals, 0.4cm x 0.4cm, polysepalous, imbricate aestivation, elliptic, persistent, inferior. **Corolla:** 4 petals, 0.3-0.5cm x 0.3-0.4cm, gamopetalous, inferior, orange-yellow, acute, ovate, rosaceous, valvate aestivation. **Androecium:** 4 stamens, 0.3cm long, epipetalous, filaments white, basifixed, extrorse, bilobed anthers. **Gynoecium:** tricarpellary ovary, superior, short style (0.4cm), bifid hairy stigma. **Fruit:** spherical ovoid capsule, 1.5-3cm long, 2-2.5cm broad, shortly beaked, silvery grey to green, single seeded, crypto-viviparous germination.

Table 3.12 District wise variation in morphometric measurements of *A. marina*

Characters	Districts				
	KSD	KNR	KZH	EKM	KLM
Leaf length	5.38± 0.34	5.12± 2.86	8.42± 0.13	6.25± 3.33	8.55± 0.19
Leaf width	4.19±0.33	4.34±1.15	4.63±0.43	3.99±0.99	5.10±0.23
Petiole length	0.93±0.15	1.03±0.43	0.93±0.15	0.98±0.47	1.28±0.12
bud length	0.60±0.09	0.75±0.08	0.62±0.12	0.65±0.12	0.68±0.10
Sepal length	0.4	0.4	0.4	0.4	0.4
Sepal width	0.4	0.4	0.4	0.4	0.4
Petal length	0.46±0.05	0.48±0.04	0.38±0.08	0.46±0.05	0.38±0.08
Petal width	0.36±0.05	0.38±0.04	0.34±0.05	0.38±0.04	0.32±0.04
Stamen length	0.3	0.3	0.3	0.3	0.3
Style length	0.4	0.4	0.4	0.4	0.4
Fruit length	2.05±0.51	2.78±0.23	2.57±0.18	2.87±0.20	2.87±0.08
Fruit width	2.24±0.23	2.46±0.05	2.46±0.05	2.48±0.04	2.48±0.04

Remarks: The species was rare in distribution. The leaf morphology exhibited a bimodal variation in Kannur and Ernakulam district. Many of the trees exhibited small sized leaves (3-5 cmx 3-3.5cm) and were yellowish in colour. On the other hand many trees displayed large sized leaves (3-10.5cmx 3-5.5cm) with dark green coloration. Sepal length, sepal width, stamen length and style length were uniform sized in all districts.

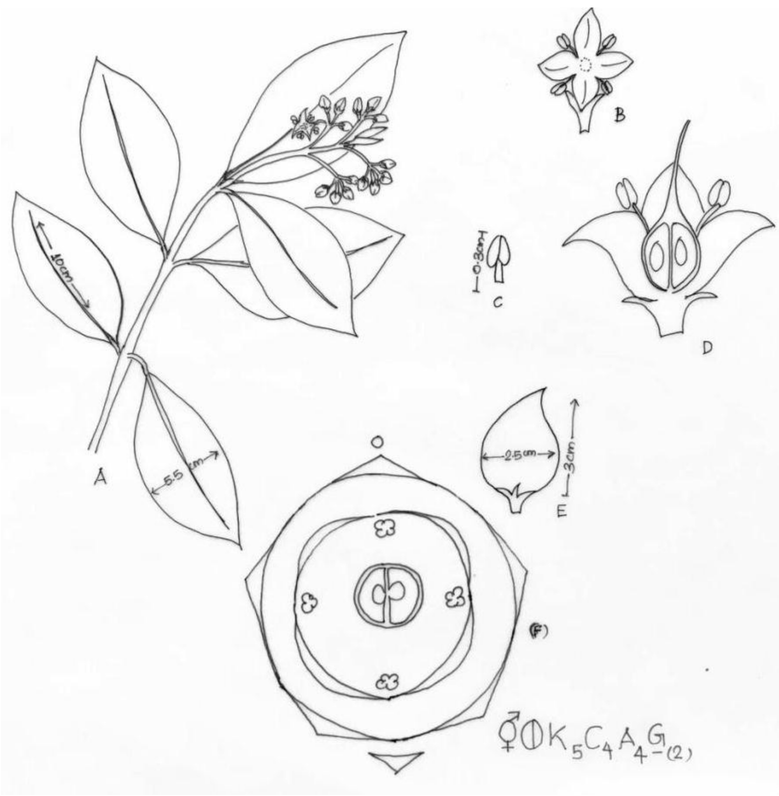


Figure 3.9 ***Avicennia marina*** (A)(Habit (B)Flower (C) Stamen (D) L.S of flower (E) Fruit (F)Floral diagram

(a)

(b)

(c)

(d)

Plate 3.10 ***Avicennia marina*** (a) Habit (b) Twig (c) Leaf (d) Capsule

ii. *Avicennia alba* Blume (1826)

Common name	:	White mangrove
Local name	:	Charakandel
Distribution in Kerala	:	Kollam
Abundance	:	Very rare

Habit: evergreen, perennial, small sized, irregularly spreading branches, woody trunk. **Root:** pencil like pneumatophores, spongy, usually unbranched. **Stem:** dark, greyish- black bark, lenticellate. **Leaves:** simple, 9.2-12cm long x 1.5-2cm broad, cauline, exstipulate, petiolate (1-1.8cm), opposite- decussate, entire, acute, lanceolate to elliptical, whitish green or pale green dorsal side, ventral side- bright silvery white. **Inflorescence:** long spikes, 8-32 flowers, terminal/axillary, bud 0.4-0.8cm long. **Flowers:** sessile, dull yellow, acropetally arranged, bisexual, regular, cyclic, hypogynous. **Calyx:** 5 sepal,0.3-0.4cm long,0.4cm broad, polysepalous, entire, ovate, mucronata, inferior, imbricate, persistent. **Corolla:** 4 petals, 0.3-0.4cm long x 0.2-0.3cm broad, gamopetalous, orange- yellow, entire, ovate, inferior, valvate. **Androecium:** 4 epipetalous stamens, 0.3cm long, opposite to sepals; filaments short; anthers bilobed, dorsifixed, introrse. **Gynoecium:** bicarpellary, superior, style small (0.4cm), bifid stigma. **Fruit:** conical capsule, 2.5-3.5cm long, 1.5-2cm broad, narrow terminal beak, germination is cryptoviviparous.

Figure 3.10 ***Avicennia alba*** (A) Habit (B) Flower (C) Petal (D) Stamen (E) Ovary (F) L.S of flower (G) Floral diagram.

(a) (b)

Plate 3.11 ***Avicennia alba*** (a) Habit (b) Fruit

iii. *Avicennia officinalis* L. (1753)

Common name	:	White mangrove
Local name	:	Uppatti, Uppootti, Uppootha, Orai
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram.
Abundance	:	Common

Habit: evergreen, perennial, up to 15-20m; smooth, whitish bark. **Root:** pneumatophores spongy, pencil- like, blunt apex. **Stem:** bark - grey to light coloured, papery. **Leaves:** simple, 5.3-11cm long, 3-7.2cm broad, cauline, exstipulate, opposite- decussate, petiolate (1-2cm); lamina- green, leathery, elliptic obovate, rounded apex, coriaceous, dorsiventral, reticulate venation. **Inflorescence:** compound spike, zygomorphic, sessile, dull yellow flowers, bud 0.8-1.2cm long. **Flowers:** complete, regular, cyclic, bisexual, hypogynous, sessile, rosaceous, erect. **Calyx:** sepals 5, size 0.4-0.5cm x 0.5cm, polysepalous, elliptical, inferior, imbricate, persistent. **Corolla:** petals 4, 0.3-0.5cm x 0.5-0.7cm, gamopetalous, orange yellow, curved tips, inferior, imbricate. **Androecium:** stamens 4, 0.3cm long, epipetalous, white filaments; anthers- round, yellow, bilobed, basifixed, extrorse. **Gynoecium:** single loculed ovary, elliptical, superior; single terminal style (0.4cm), short trifid stigma. **Fruit:** capsules, 1.5-2.5cm long, 2-3cm broad, fleshy, green, broad, short apical beak, cryptoviviparous germination.

Table 3.13 District wise variation in morphometric measurements of *A. officinalis*

Characters	Districts									
	KSD	KNR	KZH	MLP	TRS	EKM	KTM	ALP	KLM	TVM
Leaf length	7.22±1.98	10.42±0.54	7.98±0.72	7.65±0.16	7.78±0.33	8.50±0.24	7.22±0.17	8.20±0.19	8.87±0.60	7.47±0.28
Leaf width	4.83±1.65	6.87±0.23	6.19±0.20	6.36±0.36	7.41±1.05	7.03±0.10	5.91±0.39	6.49±0.38	6.63±0.35	5.69±0.28
Petiole length	1.75±0.38	1.77±0.29	1.65±0.18	1.40±0.17	1.63±0.15	1.83±0.19	1.15±0.20	1.63±0.12	1.60±0.21	1.68±0.12
bud length	0.77±0.10	0.98±0.18	0.95±0.15	0.87±0.08	1.03±0.08	0.92±0.15	0.82±0.04	1.00±0.11	1.07±0.12	0.83±0.05
Sepal length	0.49±0.04	0.50±0.00	0.49±0.04	0.49±0.04	0.49±0.04	0.49±0.04	0.44±0.05	0.47±0.05	0.46±0.05	0.41±0.04
Sepal width	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Petal length	0.38±0.08	0.46±0.05	0.40±0.07	0.42±0.08	0.42±0.04	0.46±0.05	0.34±0.05	0.42±0.04	0.48±0.04	0.33±0.05
Petal width	0.58±0.08	0.62±0.08	0.54±0.05	0.52±0.04	0.58±0.08	0.66±0.05	0.52±0.04	0.50±0.00	0.66±0.05	0.52±0.04
Stamen length	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Style length	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Fruit length	2.18±0.39	2.13±0.40	1.78±0.17	1.50±0.28	2.50±0.26	2.23±0.41	1.75±0.21	1.77±0.19	1.63±0.23	1.63±0.23
Fruit width	2.94±0.09	2.90±0.10	2.62±0.31	2.52±0.23	2.92±0.08	2.92±0.08	2.52±0.23	2.72±0.20	2.92±0.08	2.60±0.20

Remarks: The species is most commonly distributed along Kerala coast. The stamen length and style length exhibited uniform size in all districts while the other characters showed minute variation among districts.

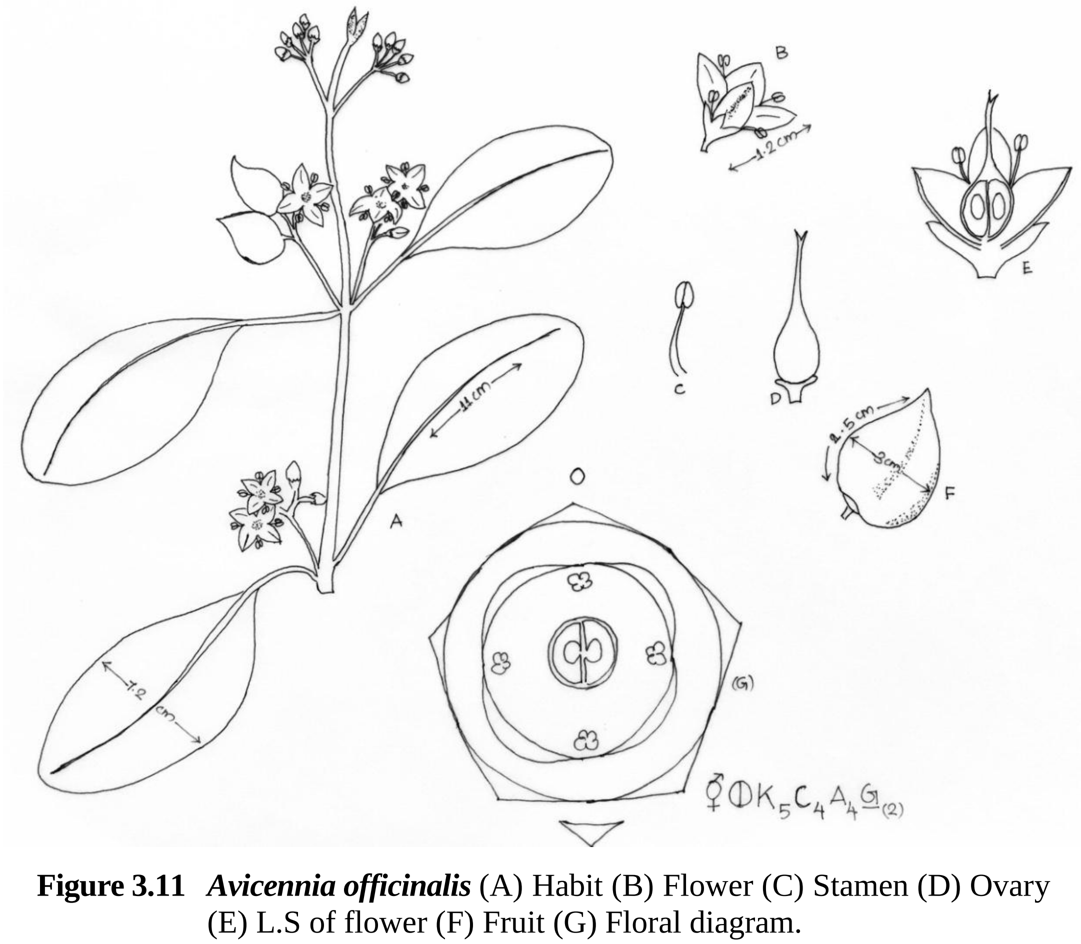


Figure 3.11 ***Avicennia officinalis*** (A) Habit (B) Flower (C) Stamen (D) Ovary (E) L.S of flower (F) Fruit (G) Floral diagram.

(a)

(b)

(c)

(d)

(e)

Plate 3.12 ***Avicennia officinalis*** (a) Habit (b) Pnuematophore (c)Flowering twig (d) Flowers (e)Fruit

IV. Family: Acanthaceae

a. Genus *Acanthus*

i. *Acanthus ilicifolius* L. (1753)

Common name	:	Sea Holy
Local name	:	Chulli kandel, Uppu chulli
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha and Kollam
Abundance	:	Common

Habit: thorny shrubs, up to 2m. **Root:** stilt roots. **Leaves:** simple, dark green, thick, leathery, opposite decussate, lanceolate, narrow base, serrate margins, armed with spines. **Inflorescence:** spike, terminal. **Flowers:** bisexual, zygomorphic, sessile, light blue - violet. **Calyx:** 5 sepals, polysepalous, twisted aestivation. **Corolla:** single large petal, fleshy, coriaceous, showy. **Androecium:** stamens 4, free; anthers basifixed, bilobed, introrse. **Gynoecium:** 2 carpels, syncarpous, axile placentation, terminal style, bifid stigma. **Fruit:** capsule, ovoid – oblong, compressed, apiculate, green-brown, shining.

Table 3.14 District wise variation in morphometric measurements of *A.ilicifolius*

Characters	Districts								
	KSD	KNR	KZH	MLP	TRS	EKM	KTM	ALP	KLM
Leaf length	6.9±0.59	11.25±1.5	11.33±1.0	12.11±1.9	13.13±1.8	13.02±1.6	10.57±0.6	13.01±1.0	12.42±2.0
Leaf width	4.42±1.4	5.8±1.2	6.06±0.5	5.32±0.1	6.16±0.2	6.17±0.4	6.32±0.1	6.88±0.3	6.54±0.6
Spine at leaf tip	0.26±0.08	0.23±0.05	0.25±0.05	0.25±0.08	0.28±0.07	0.31±0.13	0.35±0.1	0.28±0.07	0.36±0.12
Petiole length	0.85±0.17	0.87±0.12	0.59±0.26	0.41±0.13	0.38±0.12	0.51±0.16	0.33±0.08	0.54±0.18	0.41±0.14
Bracteole length	0.43±0.13	0.51±0.09	0.36±0.1	0.56±0.16	0.51±0.11	0.913±0.02	0.6±0.12	0.74±0.08	0.61±0.07
Axial spin	0.76±0.1	0.51±0.17	0.41±0.07	0.6±0.2	0.41±0.11	0.5±0.08	0.45±0.18	0.55±0.11	0.59±0.13
Infl. length	14.18±0.90	14.8±0.53	13.75±1.2	14.28±0.61	14.45±0.64	14.85±0.31	13.71±0.53	14.62±0.53	14.54±0.46
Flower length	3.93±0.9	4.14±1.1	3.88±0.1	3.47±1.2	3.53±1	4.23±1.8	3.58±1.2	3.41±1	3.5±1
Sepal length	1.32±0.11	1±0.1	1.15±0.15	2.73±3.88	1.17±0.08	1.21±0.19	1.375±0.13	1.33±0.08	1.3±0.1
Sepal width	0.87±0.25	0.95±0.1	0.98±0.15	0.93±0.1	0.81±0.13	0.89±0.1	1.2±0.14	1.05±0.09	0.71±0.13
Petal length	3.87±0.3	4.22±0.35	4.08±0.47	3.51±0.24	3.55±0.2	4.22±0.3	3.48±0.38	3.48±0.1	3.38±0.13
Petal width	2.32±0.2	2.15±0.16	2.11±0.22	2.24±0.17	2.17±0.14	2.24±0.16	2.35±0.09	2.35±0.17	2.14±0.14
Stamen length	2.3±0.24	2.25±0.28	1.78±0.11	1.23±0.13	1.71±0.53	2.26±0.21	1.76±0.18	1.48±0.11	1.56±0.26
Style length	2.54±0.38	3.01±0.14	2.6±0.18	2.24±0.19	2.18±0.22	2.24±0.19	2.38±0.21	2.68±0.41	2.6±0.28
Fruit length	2.8±0.3	2.38±0.14	2.616±0.45	2.4±0.06	2.36±0.2	3.25±0.24	2.35±0.37	2.6±0.21	2.33±0.22

Remarks: The species was common in all districts except Thiruvananthapuram. The morphometric characters were more or less uniform in all the districts. None of the characters were identical in size in any of the study area.

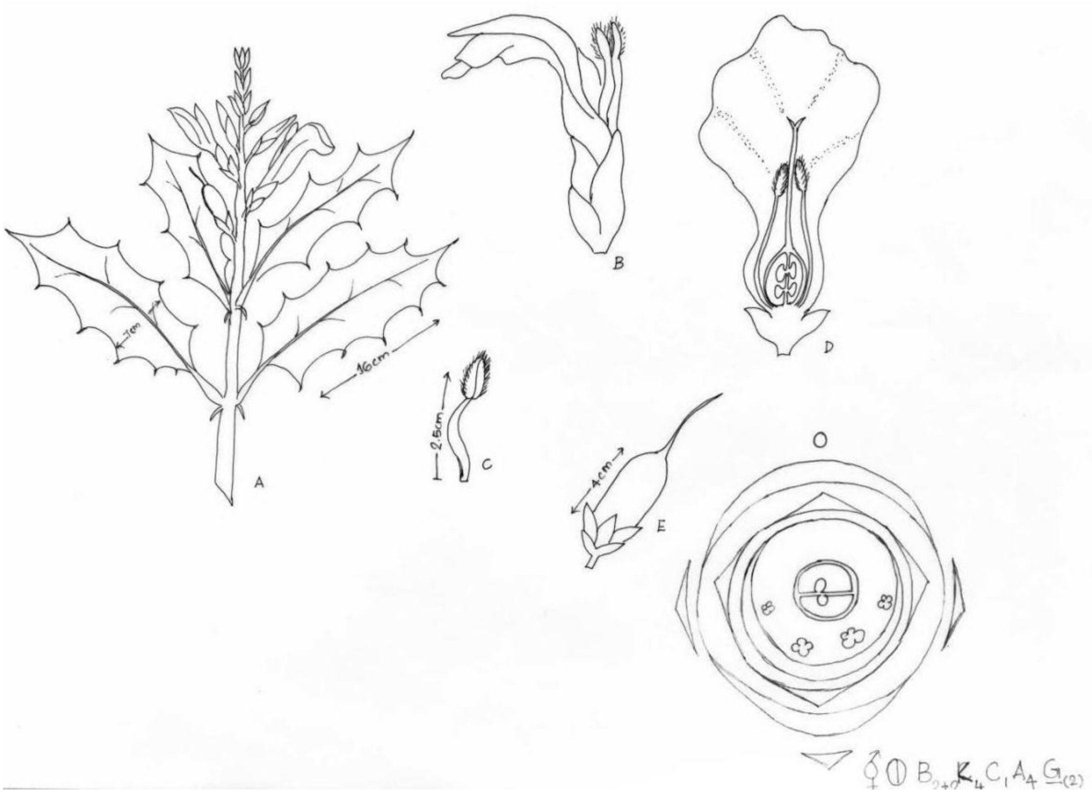


Figure 3.12 *Acanthus ilicifolius* (A)Habit (B)Flower (C)Stamen (D) L.S of flower (E)Fruit (F)Floral diagram.

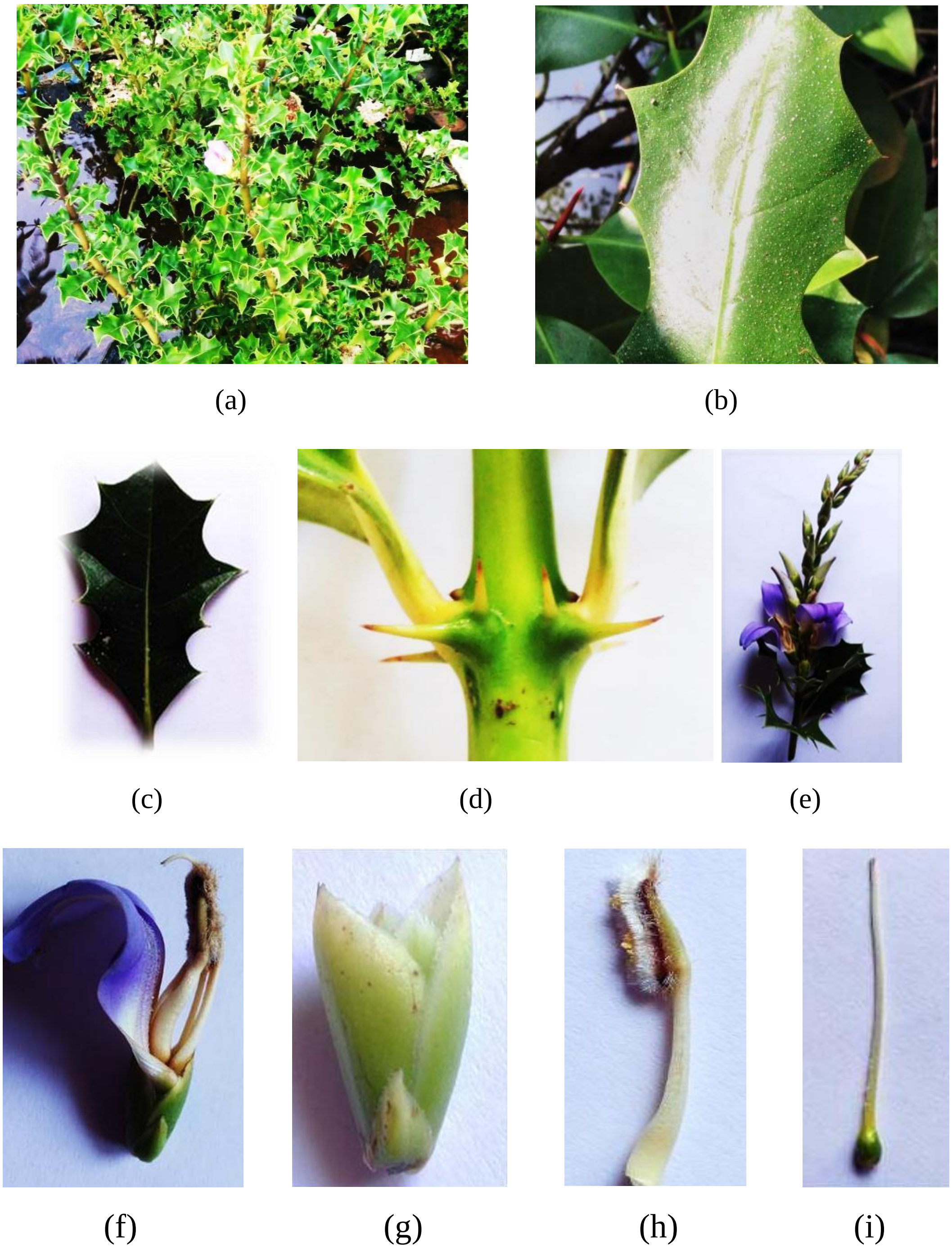


Plate 3.13 ***Acanthus ilicifolius*** (a) Habit (b) Leaf with salt secretion (c) Leaf (d) Axial spin (e) Inflorescence (f) Flower (g) Bracteoles (h) Stamen (i) Style

V. Family Lytheraceae

a. Genus *Sonneratia*

Key to *Sonneratia* species

1. Obovate leaf; round leaf apex;

   Petals white; stamens white………………***S.alba***

2. Ovate- elliptical leaf; broad leaf apex

   Petals purple; stamens purple…………..***S. caseolaris***

i. *Sonneratia alba* J. Smith (1816)

Common name	:	Mangrove apple
Local name	:	Nakshatrakandel
Distribution in Kerala	:	Kannur, Ernakulam and Alappuzha
Abundance	:	Very rare

Habit: evergreen tall trees. **Root:** pneumatophores long, strong, conical, hard, woody, branched. **Stem:** cream, grey to brown bark with slight vertical fissures. **Leaves:** simple, 5-10cm long, 3-7cm broad, elliptic to ovate, rounded leaf tip, leathery, opposite, petiole- short (0.5-1), pinkish. **Inflorescence:** solitary flowers, white, long pedicel, bud 1.8-2.6cm long. **Flowers:** bisexual, complete, regular, showy. **Calyx:** sepals 6, 0.5-1.2cm long x0.8-1cm broad, thick, leathery, greenish, fused at base, persistent. **Corolla:** 6petals, 1-2cm long, 0.2cm broad, polypetalous, linear, oblong, deciduous, white. **Androecium:** numerous white stamens;2.5-3cmlong, filaments white above, reddish below; anthers- bilobed, dorsifixed, extrorse. **Gynoecium:** 6 carpels, syncarpous, superior, ovary cup-shaped, numerous ovules, axile placentation; style is long (4-5cm), twisted, twice the length of stamens, terminal capitate stigma. **Fruit:** berry large, 3-4.5cm in diameter, green, fleshy, persistent star-shaped leathery calyx tube.

Table 3.15 District wise variation in morphometric measurements of *S. alba*

Characters	Districts		
	KNR	EKM	ALP
Leaf length	8.73± 1.32	7.68± 0.87	8.85± 0.97
Leaf width	5.72± 0.58	7.00± 0.35	5.22± 0.35
Petiole length	0.70± 0.22	0.63± 0.10	0.58± 0.05
bud length	2.12± 0.24	2.06± 0.43	2.00± 0.22
Sepal length	0.88± 0.29	0.95± 0.23	0.96± 0.22
Sepal width	0.83± 0.08	0.93± 0.12	0.90± 0.10
Petal length	1.57± 0.22	1.68± 0.24	1.57± 0.36
Petal width	0.20± 0.00	0.20± 0.00	0.20± 0.00
Stamen length	2.73± 0.22	2.75± 0.17	2.65± 0.13
Style length	4.50± 0.48	4.60± 0.32	4.93± 0.10
Fruit length	3.68± 0.54	3.85± 0.40	4.30± 0.24

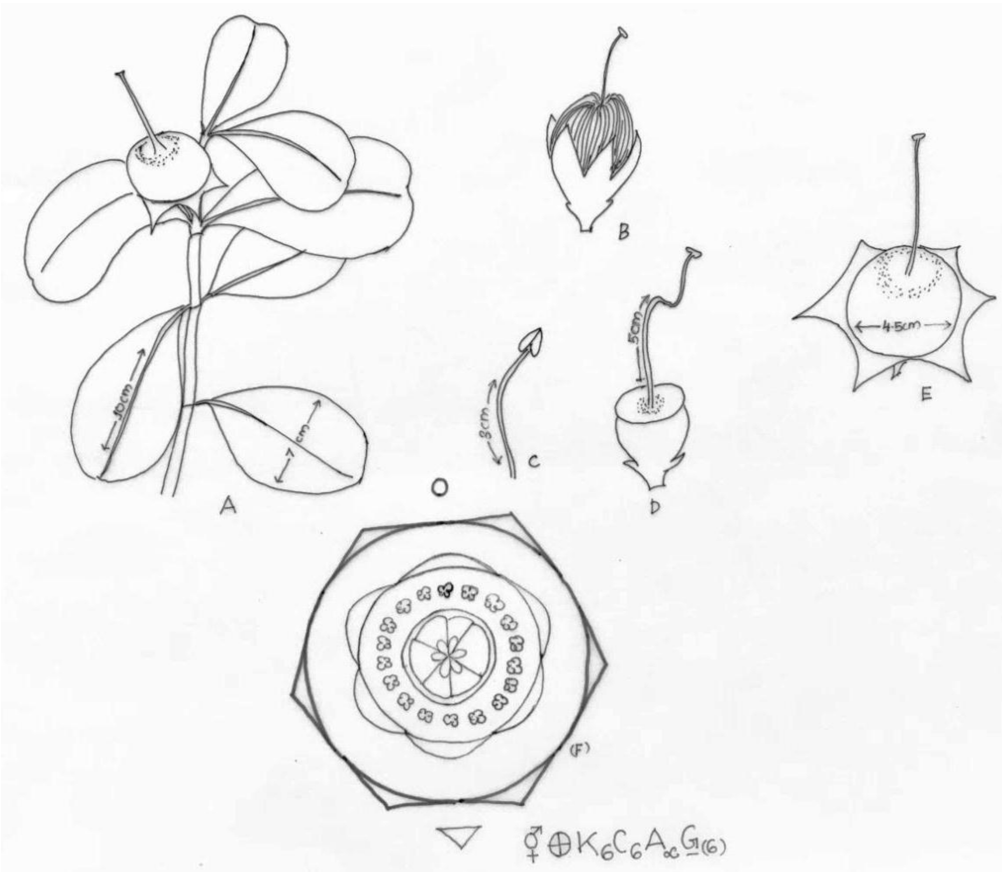


Figure 3.13 ***Sonneratia alba*** (A) Habit (B) Flower (C) Stamen (D) Ovary (E) Fruit (F) Floral diagram

(a) (b) (c)

Plate 3.14 ***Sonneratia alba*** (a) Habit (b) Flower (c) Fruit

ii. *Sonneratia caseolaris* (L.) Engler (1897)

Common name	:	Mangrove apple
Local name	:	Blathi, Chakkarakandel
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram.
Abundance	:	Common

Habit: medium - tall evergreen trees. **Root:** pneumatophores- conical, large, erect, branched, corky. **Stem:** pale green - pale brown with furrows. **Leaves:** simple, 4-12cm x 2-6cm, entire, ovate- elliptic, prominent reddish mid-rib, opposite – decussate, fleshy, dorsiventral petiole-short (1-1.2cm), pale green to reddish, pulvinous. **Inflorescence:** solitary, terminal, long peduncle, bud length 2-3cm. **Flowers:** reddish-purple, large, cup-shaped, showy, bisexual, complete, perigynous, pedicellate. **Calyx:** 6 sepals, 1.5-2cm x 1.5cm, entire, oblong- elliptic, inferior, fleshy, valvate, persistent. **Corolla:** 6petals, 1.5-2cm x 0.2-0.3cm, polypetalous, entire, reddish purple, inferior, deciduous. **Androecium:** stamens indefinite, long showy filaments (2.8-3.5cm), white above, reddish below, anthers round, tri- ridged, dorsifixed, extrorse. **Gynoecium:** carpels-6, syncarpous, ovary cup- shaped, numerous ovules, axile placentation, style 5-6cm long, single, terminal, persistent in fruits, stigma single, capitate. **Fruit:** green, stalked, globose berries, 4-5cm in diameter, persistent calyx and pointed style, germination epigeal.

Table 3.16 District wise variation in morphometric measurements of *S. caseolaris*

Characters	Districts									
	KSD	KNR	KZH	MLP	TRS	EKM	KTM	ALP	KLM	TVM
Leaf length	14.72± 14.90	10.08± 1.91	7.78± 2.41	5.50± 1.97	9.20± 0.70	10.82± 1.19	8.50± 1.52	9.23± 1.17	10.98± 0.94	7.27± 2.41
Leaf width	4.08± 1.24	12.48± 16.53	4.88± 0.76	5.10± 0.36	5.04± 0.21	5.30± 0.50	5.38± 0.48	5.04± 0.45	5.26± 0.77	8.40± 0.32
Petiole length	1.05± 0.10	1.10± 0.12	1.05± 0.10	1.18± 0.05	1.10± 0.12	1.15± 0.10	1.15± 0.10	1.13± 0.10	1.10 0.08±	1.13± 0.10
bud length	2.80± 0.19	2.92± 0.08	2.64± 0.15	2.74± 0.10	2.74± 0.10	2.90± 0.05	2.74± 0.18	2.80± 0.17	2.92 0.08±	2.72± 0.33
Sepal length	1.68± 0.22	1.82± 0.19	1.76± 0.15	1.76± 0.17	1.66± 0.14	1.86± 0.24	1.74± 0.26	1.80± 0.17	1.68 0.15	1.68± 0.13
Sepal width	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Petal length	1.85± 0.08	1.78± 0.06	1.77± 0.12	1.80± 0.05	1.65± 0.17	1.83± 0.05	1.62± 0.14	1.77	1.73± 0.05	1.53± 0.06
Petal width	0.25± 0.05	0.28± 0.05	0.23	0.25± 0.05	0.25± 0.05	0.30± .00	0.27 0.06	0.23± .00	0.28± 0.05	0.25± 0.05
Stamen length	3.05± 0.13	3.30± 0.24	2.90± 0.08	2.95± 0.06	3.15± 0.26	3.38± 0.15	2.95 0.06	3.29± 0.14	3.38± 0.13	2.95± 0.06
Style length	5.53± 0.41	5.80± 0.16	5.60± 0.16	5.73± 0.22	5.75± 0.13	5.85± 0.10	5.28± 0.10	5.75± 0.06	5.60± 0.16	5.36± 0.05
Fruit length	4.70± 0.24	4.80± 0.40	4.63± 0.25	4.50± 0.36	4.38± 0.21	4.78± 0.21	4.55 0.33	4.65± 0.24	4.65± 0.24	4.63± 0.13

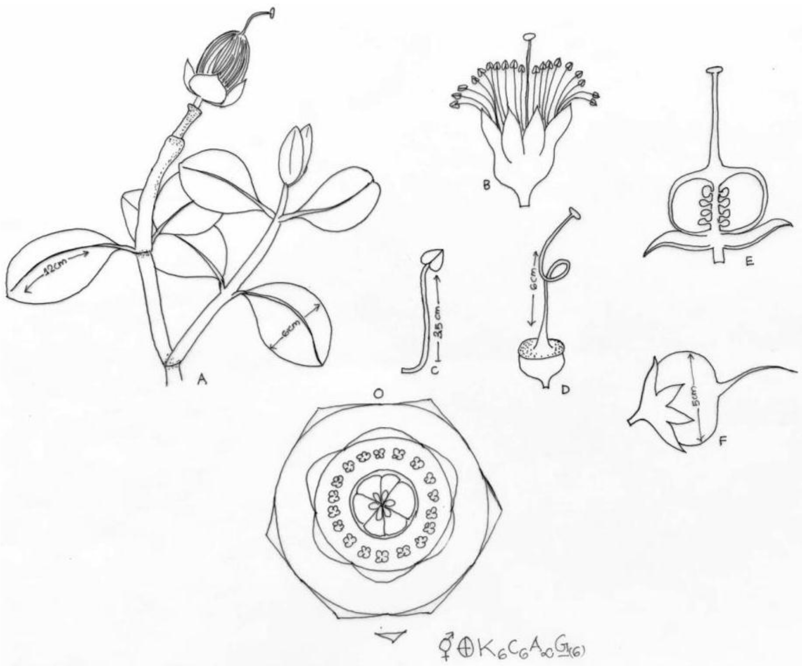


Figure 3.14 ***Sonneratia caseolaris*** (A) Habit (B) Flower (C) Stamen (D) Ovary (E) L.S of flower (F) Fruit (G) Floral diagram.

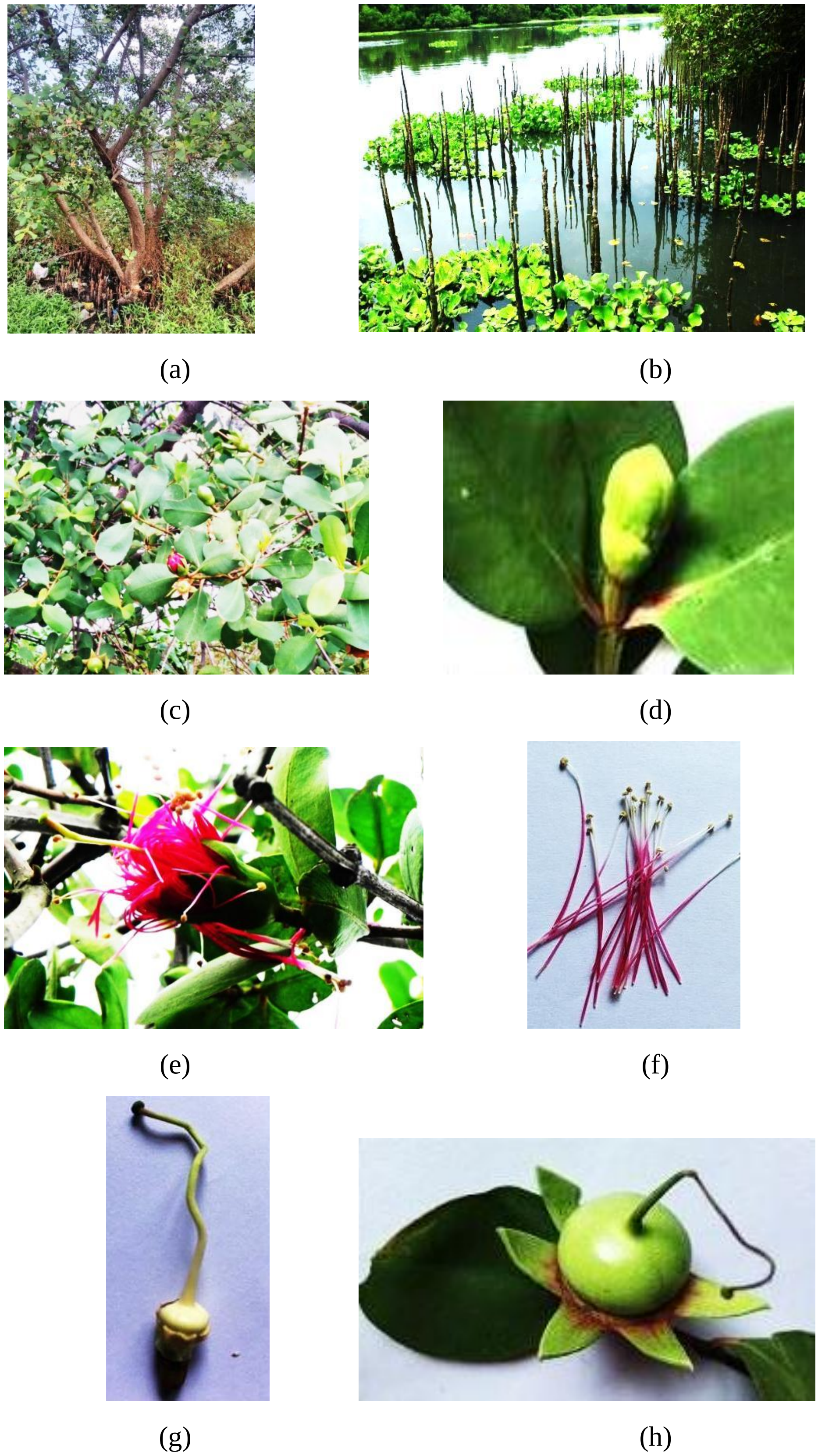


Plate 3.15 ***Sonneratia caseolaris*** (a) Habit (b) Roots (c) Flowering twigs (d) Bud (e) Flower (f)Stamens (g) Style (h) Fruit

VI. Family Myrsinaceae

a. Genus *Aegiceras*

i. *Aegiceras corniculatum* (L.) Blanco (1837)

Common name	*:*	Black mangrove, River mangrove
Local name	*:*	Pookandel, Puzhakandel
Distribution in Kerala	*:*	Kasaragod, Kannur, Kozhikode, Thrissur and Kollam
Abundance	*:*	Rare

Habit: shrub- small tree. **Root:** aerial roots not prominent. **Stem:** bark smooth, reddish brown to dark. **Leaves:** simple, 5-9cm x 3-5cm, elliptic to obovate, exstipulate, leathery, alternate; petiole pinkish red, 1-1.5cm long; leaf-tip slightly notched, cuneate base. **Inflorescence:** simple umbel, axillary, 15-20 flowers, peduncle 3-4cm long, pedicellate (1.5cm). **Flowers:** small, white, fragrant, simple, bisexual, zygomorphic, erect, pentamerous. **Calyx:** 5 sepals, 0.5cm x 0.5cm, polysepalous, coriaceous, persistent, twisted/ imbricate. **Corolla:** 5 petals, 0.7cm x 0.5cm, gamopetalous, entire, herbaceous, white, inferior, twisted aestivation. **Androecium:** 5 stamens, 0.3cm, opposite to petals; anthers sagittate, basifixed. **Gynoecium:** single loculed ovary, several ovules, free central placentation; single, terminal style (0.5-0.8cm) without stigma. **Fruit:** smooth, sharply curved capsules, 4-8cm long, green- reddish, cryptoviviparous.

Remarks: The species was rare in occurrence along Kerala coast. The length of pedicel (1.5cm) and stamen (0.3cm) were uniform in all districts. Other characters which showed uniformity in size throughout the districts were sepal length, sepal width, petal length and petal width.

Table 3.17 District wise variation in morphometric measurements of *A. corniculatum*

Characters	Districts				
	KSD	KNR	KZH	TRS	KLM
Leaf length	7.98± 1.36	7.10± 1.30	8.20± 0.44	8.06± 1.05	8.54± 0.21
Leaf width	4.26± 0.57	3.88± 0.55	4.30± 0.43	3.84± 0.48	4.40± 0.63
Petiole length	1.25± 0.21	1.38± 0.26	1.35± 0.13	1.48± 0.10	1.38± 0.13
Bud length	1.35± 0.24	1.40± 0.14	1.30± 0.14	1.40± 0.14	1.50± 0.08
Peduncle length	3.48± 0.41	3.74± 0.24	3.80± 0.10	3.72± 0.26	3.82± 0.19
Pedicel length	1.5	1.5	1.5	1.5	1.5
Sepal length	0.5	0.5	0.5	0.5	0.5
Sepal width	0.5	0.5	0.5	0.5	0.5
Petal length	0.7	0.7	0.7	0.7	0.7
Petal width	0.5	0.5	0.5	0.5	0.5
Stamen length	0.3	0.3	0.3	0.3	0.3
Style length	0.55± 0.06	0.65± 0.13	0.60± 0.08	0.80± 0.08	0.70± 0.14
Fruit length	5.96± 1.15	7.74± 0.28	7.20± 0.34	6.78± 0.34	7.42± 0.10

Figure 3.15 ***Aegiceras corniculatum*** (A) Habit (B) Flower (C) Calyx (D) Stamen (E) L.S of flower (F) Fruit (G) Floral diagram.

(a)

(b)

(c)

(d)

(e)

(f)

Plate 3.16 ***Aegiceras corniculatum*** (a) Habit (b) Flowering Twig (c) Leaf (d) Inflorescence (e) Flowers (f) Fruits

VII. Family Combretaceae

a. Genus *Lumnitzera*

i. Lumnitzera racemosa Willd. (1803)

Common name	:	Black mangrove
Local name	:	Kadakandel
Distribution in Kerala	:	Kasaragod, Alappuzha and Kollam
Abundance	:	Rare

Habit: shrub or evergreen trees, up to 8-10m. **Root:** pneumatophores few in numbers. **Stem:** bark grey – brown, fissured. **Leaves:** simple, 4.5-10cm long, 1.5-3 broad, broad obovate, notched tip, pointed base, pale green, succulent, fleshy, exstipulate, petiolate (0.5cm), cyclic. **Inflorescence:** cymose, 2-3cm long, axillary, buds 1-1.5cm long. **Flowers:** complete, white, erect, bisexual, actinomorphic, epigynous pedicellate, pentamerous. **Calyx:** 5 sepals, 0.5cm x 0.2 cm, gamosepalous, deep green, glabrous, fleshy, superior, persistent, imbricate. **Corolla:** 5 petals, 0.5-0.8cm x 0.5 cm, polypetalous, white, oblong lanceolate, deciduous, superior, imbricate. **Androecium:** 10 stamens, 5+5 arrangement; 0.8cm long, filaments white. **Gynoecium:** monocarpellary, 3 ovules, pendulous, inferior, style single (1-1.2cm), terminal, soft, white, stigma is absent. **Fruit:** single seeded drupe (2cm), green, woody, oblong, persistent calyx rim and style.

Table 3.18 District wise variation in morphometric measurements of *L. racemosa*

Characters	Districts		
	KSD	ALP	KLM
Leaf length	7.36± 1.71	8.72± 0.33	8.54± 0.22
Leaf width	2.00± 0.42	2.62± 0.13	2.66± 0.31
Petiole length	0.5	0.5	0.5
Infl. Length	2.40± 0.27	2.88± 0.25	2.80± 0.22
Bud length	3.68± 5.80	1.44± 0.10	1.42± 0.10
Sepal length	0.5	0.5	0.5
Sepal width	0.2	0.2	0.2
Petal length	0.72± 0.13	0.76± 0.05	0.68± 0.13
Petal width	0.5	0.5	0.5
Stamen length	0.8	0.8	0.8
Style length	1.13± 0.10	1.10± 0.12	1.15± 0.10
Fruit length	2	2	2

Remarks: The species was rare in distribution and was spotted only from Kasaragod, Alappuzha and Kollam district. Even though leaf size showed minute variation between districts, the petiole length exhibited uniformity. The length and width of sepals and petals were also uniform throughout the study site. The drupe was almost 2cm long in all the study area.

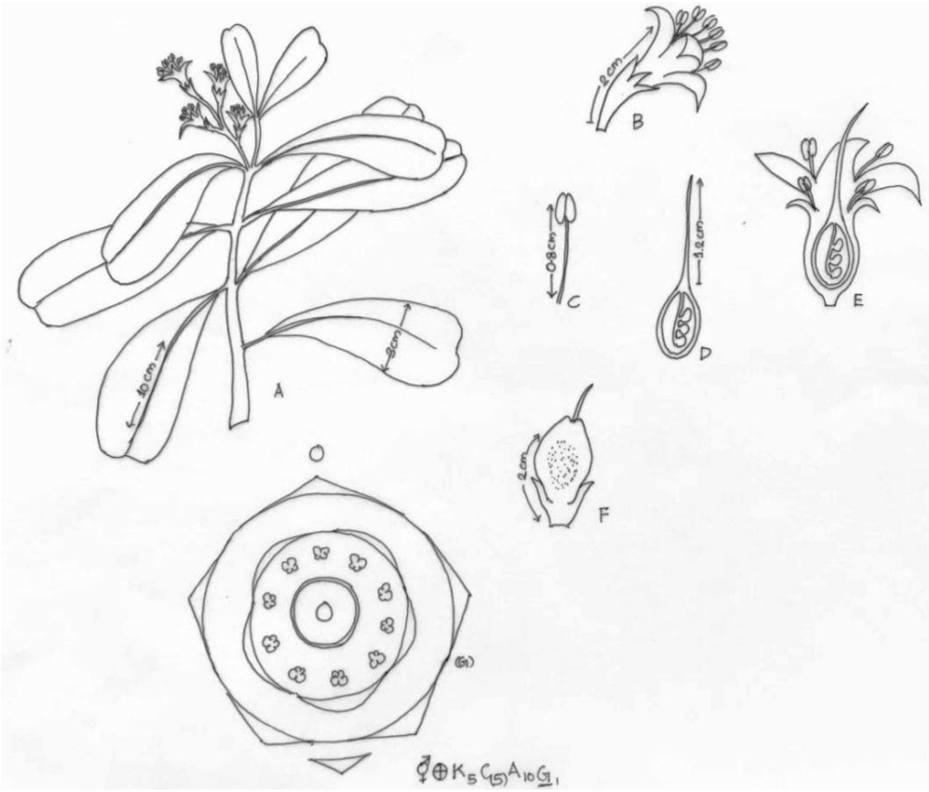


Figure 3.16 ***Lumnitzera racemosa*** (A) Habit (B) Flower (C) Stamen (D) Ovary (E) L.S of flower (F) Fruit (G) Floral diagram.

(a) (b)

Plate 3.17 ***Lumnitzera racemosa*** (a) Habit (b) Flowering twigs

VIII. Family Pteridaceae

a. Genus *Acrostichum*

i. *Acrostichum aureum* L. (1753)

Local name : Machitholu

Distribution in Kerala : Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram

Abundance : Very common

Habit: erect, bushy, rhizomatous fern, 1.5-2m tall. **Root:** stout woody rhizome, typical fibrous fern like roots. **Rachis:** arises from globose rhizome, circinately coiled and hairy in younger stages. **Fronts:** simple,19-22 in each rachis, 10-35cm long, 2-5cm broad, petiolate (2.5-3cm long), isobilateral, distinct mid rib, reddish when young, blunt leaf tip; mature fronds become sporophylls, bearing sporangia on the abaxial surface, sori densely produced on under surface, when mature turn brown.

Table 3.19 District wise variation in morphometric measurements of *Acrostichum aureum*

Characters	Districts								
	KNR	KZH	MLP	TRS	EKM	KTM	ALP	KLM	TVM
Front no.	17± 2	20±	22±2	18±2	21±1	19±1	20± 2	18± 2	18± 2
Front length	21.23 ± 2.57	25.08± 5.09	41.6± 3.16	26.08± 2.17	29.85± 4.32	25.97± 1.44	26.38 2.3	26.6± 2.99	30.83± 4.9
Front width	3.00± 1.02	3.54± 0.93	2.64± 0.36	4.12± 0.96	3.60± 0.70	3.18± 0.23	3.67± 0.73	2.80± 0.22	2.68± 0.26
Petiole length	2.63± 0.26	2.58± 0.17	2.50± 0.12	2.80± 0.28	2.60± 0.22	2.60± 0.27	2.80± 0.22	2.55± 0.24	2.48± 0.10

Remarks: The only fern member representing the true mangrove species. The species was common in most of the study sites. Malappuram and Ernakulam district represented profusely grown patches of *Acrostichum*. All the four morphometric measurements varied among districts.

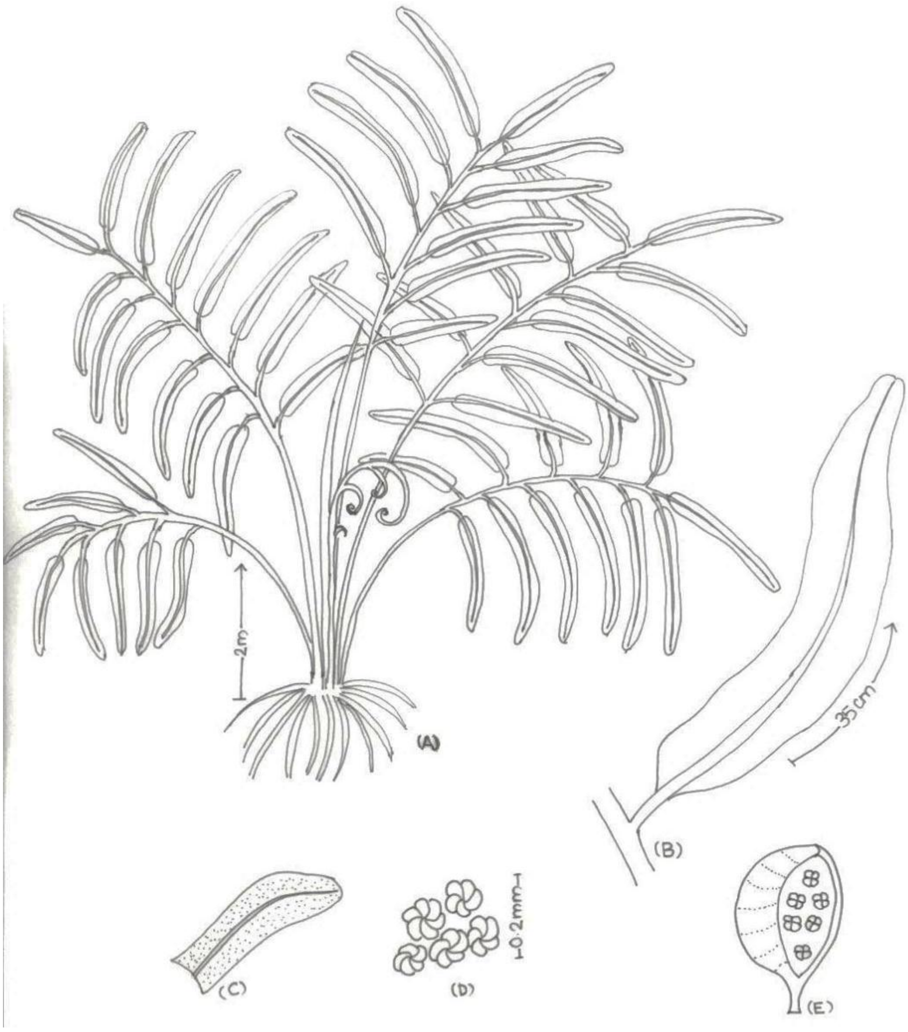


Figure 3.17 ***Acrostichum aureum*** (A) Habit (B) Front (C) Lower surface of front (D) Sori (E) Sporangium

(a) (b) (c)

Plate 3.18 ***Acrostichum aureum*** (a) Habit (b) Fronts (c) Leaflet tip

3.4.2 Mangrove Associates of Kerala

In the present study, 23 species of mangrove associates belonging to 15 families and 19 genera were identified from various mangrove habitats of Kerala (Table 3.21). Family Fabaceae (3sp.), Verbinaceae (3sp.) and Convolvulaceae (3sp.) were the dominant families. Among the 24 mangrove associates identified, *Derris trifoliate* and *Clerodendron inermi* were the most dominant species in Kerala.

Table 3.20 Mangrove associates along the Kerala Coast

Sl. No.	Family	*Species*	Sl. No.	Family	*Species*
1	Verbinaceae	*Premna latifolia*	13	Typhaceae	*Typha domingensis*
2		*Premna serratifolia*	14	Asclepiadaceae	*Calotropis gigantea*
3		*Clerodendron inermi*	15	Rubiaceae	*Morinda citrifolia*
4	Apocyanaceae	*Cerebra odollam*	16	Pandanaceae	*Pandanus tectorius*
5	Fabaceae	*Derris trifoliate*	17	Clusiaceae	*Calophyllum inophyllum*
6		*Derris scandens*	18	Cyperaceae	*Fimbristylis ferruginea*
7		*Pongamia pinnata*	19		*Mariscus javaniscus*
8	Convolvulaceae	*Ipomea pes-caprae*	20	Lecithidaceae	*Barringtonia racemosa*
9		*Ipomea violacea*	21	Poaceae	*Paspalum distichum*
10		*Ipomea campanulata*	22	Bignoniaceae	*Dolichandrone spathacea*
11	Malvaceae	*Thespesia populnea*	23	Combretaceae	*Terminalia catappa*
12		*Hibiscus tiliaceus*			

3.4.3 Characteristic identifying features of mangrove associates

I. Family: Verbinaceae

a. Genus: Premna

i. *Premna latifolia* Roxb. (1861)

Common name : Dusky Fire Brand Bark.

Local name : Munja

Distribution in Kerala : Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram

Abundance : Common

Habit: bushy shrubs- small trees. **Stem:** quadrangular, bark dark brown smooth. **Leaves:** simple, exstipulate, petiolate, opposite- decussate, ovate-oblong, reticulate venation. **Inflorescence:** corymbose panicles, axillary/terminal, densely pubescent, deciduous. **Flowers:** small, light greenish-dirty yellow, bisexual, zygomorphic, hypogynous. **Calyx:** campanulate, 5 dentate lobes, minute, glabrous inside. **Corolla:** petals infundibbular, gamopetalous, 5- lobed, dusty yellow, puberlent outside. **Androecium:** 4 stamens, didynamous, epipetalous, filaments glabrous, filiform, black, excerted anthers. **Gynoecium:** bicarpellary, syncarpous, 4 loculed, 1 ovule, style filiform, bilobed stigma. **Fruit:** drupaceous, succulent, globose.

ii. *Premna serratifolia* L. (1845)

Distribution in Kerala	:	Kasaragod, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: shrubs - small tree, up to 10m. **Stem:** green- brown bark, smooth/scaly. **Leaves:** simple, opposite, exstipulate, petiolate, elliptic-oblong, entire margin, glabrous above, puberulous beneath, reticulate venation. **Inflorescence:** corymbose panicled cyme, terminal. **Flowers:** small, white, bisexual, actinomorphic, hypogynous. **Calyx:** 5sepals small, fused to campanulate tube. **Corolla:** 5 petals, fused to form short corolla tubes, villious inside. **Androecium:** 4 stamens**,** didynamous, inserted below the throat of the corolla tube, ovate anther lobes. **Gynoecium:** bicarpellary, syncarpous, superior, 2-4 celled, 4 ovules, linear stigma, shortly bifid stigma. **Fruit:** drupe, spherical, dark red to black.

b. Genus: Clerodendron

i. *Clerodendron inermi* (L.) Gaertn. (1788)

Common name	:	Embret, wild jasmine, sorcerer's bush.
Local name	:	Puzhamulla
Distribution in Kerala	:	Kasaragod, Kannur, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam.
Abundance	:	Common

Habit: erect/ rambling shrub, 2-4m. **Stem:** bark greyish brown, slender, quadrangular, lenticellate. **Leaves:** simple, exstipulate, opposite decussate, elliptic-ovate, entire, petiolate, subcoriaceae, thick, glabrous above, slightly pubescent below, slender petiole. **Inflorescence:** axillary cyme. **Flowers:** white, bisexual, regular, zygomorphic, protandrous, pedicellate. **Calyx:** 5 sepals, fused to form narrow tube, cupular, leathery, glabrous, persistent. **Corolla:** 5petals, fused, 2.5-3 cm long. **Androecium:** 4 stamens, didynamous, filaments filiform, dark violet, versatile anthers. **Gynoecium:** bicarpellary, 2 loculed, filiform style, short bifid stigma. **Fruit:** drupe, glabrous, green –black, persistent calyx.

II. Family: Apocyanaceae

a. Genus: Cerebra

i. *Cerebra odollam* Gaertn.

Common name	:	Odollam Tree, Suicide tree
Local name	:	Othalanga
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: small trees. **Stem:** whorled arrangement of branches, produce white, milky latex. **Leaves:** entire, glossy, dark green, tapering base, acuminate apices; petiole short, pulvinous. **Inflorescence:** pseudoterminal cyme. **Flowers:** complete, regular, bisexual, hypogynous, white with a small yellowish center, star shaped, showy. **Calyx:** 5 sepals, linear, recurved, eglandular. **Corolla:** 5 petals, white, funnel shaped. **Androecium:** stamens 5, small, epipetalous, anthers lanceolate. **Gynoecium:** bicarpellary, 4 ovules. **Fruit:** similar to small mango, green fibrous shell encloses an ovoid white fleshy kernel.

III. Family: Fabaceae

a. Genus: Derris

i. *Derris trifoliate* Lour. (1790)

Common name	:	Common derris
Local name	:	Kammattivalli, Ponumvalli
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: evergreen woody climber. **Stem:** woody vine, dark brown, smooth bark. **Leaves:** compound, stalked pinnate leaves with 3 leaflets; leathery, elliptic-oblong, entire, sharp tipped, dark green. **Inflorescence:** terminal/ axillary racemes. **Flowers:** bisexual, zygomorphic, epigynous, glabrous, pale pink. **Calyx**: sepals fused to calyx tube, lobes poorly developed. **Corolla:** cream white to pinkish, 5 petals, typical pea-like flowers. **Androecium:** 10 stamens (9+1) arrangement, 9 fused to staminal tube, 1 free stamen. **Fruit:** disc-like flattened pods, green- brown, woody.

ii. *Derris scandens* (Roxb.) Benth. (1860)

Common name	:	Jewel Vine, Hog Creeper, Malay Jewelvine
Local name	:	Pannivalli, Ponnam valli
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: evergreen climber. **Stem:** woody, brown, lenticellate vines. **Leaves:** compound, alternate, imparipinnate; leaflets entire, elliptic- lanceolate, rounded base, cuneate apex, glabrous, short petioled. **Inflorescence:** axillary raceme, pea-like flowers, long pedicels. **Flowers:** pale rose, bisexual, zygomorphic, perigynous. **Calyx:** sepal fused to cup, green, obscure teeth. **Corolla:** long standard petal, ovateorbicular, pale rose- whitish. **Androecium:** stamens 10, (5+5), 5 long, 5 short. **Fruit:** pods dark brown, long, broad with narrow ends.

b. Genus: Pongamia

i. *Pongamia pinnata* (L.) Pierre (1899)

Common name	:	Pongam tree, Indian beech tree
Local name	:	Ungu
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: deciduous tree, up to 20m tall. **Root:** typical dicot root system. **Stem:** gray, smooth bark. **Leaves:** compound, imparipinnate, 5-9 leaflets, alternate, ovate-elliptical, acute tip, soft, shiny, glossy, deep green. **Inflorescence:** axillary racemes/ panicles. **Flowers:** fragrant, white/ pinkish, short stalked**. Calyx:** campanulate, truncate, finely pubescent. **Corolla:** white- pink, purple inside, 5 petals, standard obovate petal, oblique, obtuse keel**. Fruit:** pods smooth, ellipsoid, flattened, pointed beak, brown, thick leathery wall.

IV. Family Convolvulaceae

a.Genus: Ipomea

i. *Ipomea pes-caprae* (L.) R.Br. (1818)

Common name	:	bay hops, beach morning glory or goat's foot
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam
Abundance	:	Common

Habit: creeping herb, vein spreading on sandy coast. **Stem:** soft, tender vines, spreading, reddish. **Leaves:** simple, entire, alternate, bilobed, long petioled. **Inflorescence:** solitary flowers, axillary, pedicellate. **Flowers:** rose- purple, trumpet shaped, showy, bisexual**. Calyx: 5** sepals, fused, green**. Corolla:** 5 petals, fused to corolla tube, purple. **Androecium:** 5 stamens, epipetalous, filament short, at corolla throat, anthers bilobed, introrse**. Gynoecium:** bicarpellary, syncarpous, **Fruit:** round capsule, green- brown.

ii. *Ipomea violacea* L. (1753)

Common name	:	Beach moon flower
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: perennial, twining vine, 15-20 feet long. **Stem:** hardy vine, twisted, green-brownish. **Leaves:** entire, simple, heart shaped, petiolate, broader than long. **Flowers:** funnel shaped, white, 3-9cm long, complete, regular, bisexual, zygomorphic. **Corolla:** 5 petals, fused, funnel shaped, large, showy, white. **Fruit:** dry, dehiscent capsule

iii. *Ipomea campanulata* L. (1753)

Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur
Abundance	:	Rare

Habit: subshrub, scandent, climber, 10-20m long. **Stem:** stout, grey, twine. **Leaves:** entire, simple, petiolate, densely pubescent, ovate- cordate, alternate arrangement. **Inflorescence:** cyme, peduncle stout, shorter, puberulous; bracts deciduous, pedicel stout. **Flowers:** white, bisexual, complete, regular, zygomorphic. **Calyx:** campanulate, pubescent, persistent, green. **Corolla:** 5 petals, rounded, crisped margin, funnel shaped. **Androecium:** filaments hairy, inserted in corolla tube. **Fruit:** ovoid capsule, 4 valved, brown.

V. Family: Malvaceae

a. Genus: *Thespesia*

i. *Thespesia populnea* (L.) Sol. (1807)

Common name	:	Portia tree, Indian tulip tree, pacific rosewood
Local name	:	Poovarash, Pooparuthi
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Thrissur, Ernakulam, Alappuzha, Kollam
Abundance	:	Common

Habit: evergreen tree, 6-10m. **Stem:** bark greyish, brownish scales. **Leaves:** simple**,** petiolate, cordate shaped, acuminate apex, fleshy, shiny, alternate. **Flowers:** solitary, axillary, pedicellate, yellow-reddish orange. **Calyx:** densely appressed, campanulate, glabrescent outside. **Corolla:** 5 petals, broadly companulate, pale yellow, dark purple at center, obliquely obovate, twisted. **Androecium:** several stamens, pale yellow, fused to form tube. **Gynoecium: o**vary 5 capellary, syncarpous, superior, pistle long, enclosed in stamina tube, style long, stigma pointed. **Fruit:** capsules globose, slightly 5angular, disc-like calyx persistent, exudates bright yellow gummy substance when cut.

b. Genus: Hibiscus

i. *Hibiscus tiliaceus* L. (1753)

Common name	:	Sea hibiscus, beach hibiscus, coastal cottonwood
Local name	:	Thaiparuthi
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam
Abundance	:	Common

Habit: evergreen trees, up to 6-10m. **Stem:** long, flexible, spreading branches, bark pale greyish brown, soft hairs, lenticels appear as small corky dots. **Leaves:** simple, heart shaped, prominent veins, broader than long, olive- green, glabrous above while, velvety white to greyish, pubescent below, lamina deeply lobed at base, pointed at apex, caducous, spirally arranged. **Inflorescence:** terminal cyme, bracteate. **Flowers:** yellow, large, showy, bisexual, complete, actinomorphic. **Calyx:** epicalyx, green. **Corolla:** 5 petals, bright yellow, obovate, twisted aestivation. **Androecium:** light yellow, fused together to form a distinct tube enclosing the pistil, stigmas deep crimson purple. **Fruit:** capsule, ovoid, persistent calyx.

VI. Family: Typhaceae

a. Genus: *Typha*

i. *Typha domingensis* Pers. (1806)

Common name	:	Bulrush, Reedmace, Cumbungi, Southern cattail
Local name	:	Potta
Distribution in Kerala	:	Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam
Abundance	:	Common

Habit: emergent macrophyte, up to 6m tall. **Leaves:** linear, slender, distichous, vertical, arise from central meristem, sheathing base, simple, alternately arranged, arenchymatous. **Inflorescence:** Numerous unisexual flowers integrate to form a spike. **Male flowers:** distal end of spike, pair of stamens with tuft of hairs. **Female flowers:** below male flowers, densely packed, stigmas brown. **Fruit:** seeds small, hairy.

VII. Family: Asclepiadaceae

a. Genus: Calotropis

i. *Calotropis gigantea* (L.) Dryand. (1811)

Common name	:	Crown flower, milk weed, swallows wort, bowstring hemp
Local name	:	Erukku
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: large shrubs. **Stem:** bark yellowish grey, longitudinal fissured. **Leaves:** entire, opposite, sessile or sub-sessile, light greenish, ovate, cordate base, thick, leathery, soft white hairs. **Inflorescence:** umbel, dirty-white- lavender flowers, terminal position. **Flowers:** complete, bisexual, zygomorphic, pentamerous, waxy. **Calyx:** 5 sepals, valvate. **Corolla:** 5 petals, gamopetalous, thick, leathery, valvate, raised crown like structure. **Androecium:** 5 stamens, attached to stigma head-gynostigium. **Gynoecium:** 2 carpels, syncarpous, style fused to stigma head. **Fruit:** follicle, compressed, seeds tufted with long silky hair.

VIII. Family: Rubiaceae

a. Genus: *Morinda*

i. *Morinda citrifolia* L. (1753)

Common name	:	Indian mulberry
Local name	:	Manjappavatta, manjanathi
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Kottayam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: evergreen shrub/ small tree, 5-10m. **Stem:** spongy, greyish yellow bark. **Leaves:** simple, opposite, oblong to lanceolate, large, dark green, leathery. **Inflorescence:** globular, irregular head, terminal/ axillary. **Flowers:** tubular, scented, white, produced in globose heads. **Calyx:** truncated rim, green, valvate, superior. **Corolla:** 5 petals, white, gamopetalous, tubular throat, inserted into globular head, valvate, superior. **Androecium:** 5 stamens scarcely exerted. **Gynoecium:** polycarpellary, syncarpous, parietal placentation, style long, bifid stigma. **Fruit:** syncarpous/ globose drupe, green, succulent, pungent aroma.

IX. Family: Pandanaceae

a. Genus: Pandanus

i. *Pandanus tectorius* Parkinson (1773)

Common name	:	Screw pine
Local name	:	Kaitha
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: evergreen, spiny tree, up to 4-8m. **Root:** prop roots. **Stem:** unbranched up to of 3-6m, then forks into branches. **Leaves:** long, dark green, saw-like margins, spirally arranged, sweeping crown, spines large, white/very pale. **Inflorescence:** racemosa, covered by spathaceous bracts. **Flowers:** monoecious. **Male flowers:** small, fragrant, short lived, stamen numerous, densely packed. **Female flowers:** ovary rudimentary, pistil numerous, coherent, ovary superior. **Fruit:** The fruits are globose, covered with phalanges. The outer fibrous husk of phalanges makes them buoyant. Seeds 2-8 in numbers.

X. Family: Clusiaceae

a. Genus: *Calophyllum*

i. *Calophyllum inophyllum* Lam. (1785)

Common name	:	Ball tree, Indian laurel, Beach touriga
Local name	:	Punna
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: evergreen tree, up to 25m tall, low- lying branches, irregular canopy. **Stem:** outer bark thick, grey, fissured; inner bark soft, firm, fibrous, sticky white latex. **Leaves:** entire, smooth, polished, thick, leathery, obovate-oblong, prominent midrib, fine parallel veins run to the margin. **Inflorescence:** terminal raceme. **Flowers:** sweetly scented, white, bisexual, regular, complete. **Calyx:** 4 petals, **Corolla:** 4-8 petals, free, white, whorled arrangement. **Androecium:** numerous stamens, yellow, grouped into four bundles. **Fruit:** drupes, round, green, hardy.

XI. Family: Cyperaceae

a. Genus: Fimbristylis

i. *Fimbristylis ferruginea* (L.)Vahl (1805)

Common name	:	Rusty sedge
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: erect, perennial grasses, up to 20-80cm tall. **Root:** rhizomes short, creeping. **Leaves:** leaf blades narrow, linear, green, 10-20cm long, each one ends in inflorescence. **Inflorescence:** umbel, 5-10 spikelets. **Flowers:** rusty brown, densely packed, spikelets ovoid or oblong, glumes boat- shaped, one nerved, subacute keel, stamens 3, 2.5mm long filaments, linear anthers, style long, bifid, ciliated with papillose stigma. **Fruit:** nuts yellow, smooth, obovoid with short stalk.

b. Genus: Mariscus

i. *Mariscus javaniscus* Houtt.

Common name	:	Javanese flatsedge
Distribution	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: erect, tufted perennial grass. **Root:** rhizome short. **Leaves:** many, linear, acuminate, scabrid margins, prominent midrib, coriaceous, green- brown, sheathing base. **Inflorescence:** large, compound, 40-80 cm long culms. **Flowers:** densely spicate spiklets, oblong-lanceolate, acute, glumes distichous, broadly ovate, apex acute, green- pale brown. Stamens 3, stigmas 3. **Fruit:** black-brown coloured nuts, obovate, trigonous,

XII. Family: Lecithidaceae

a. Genus: Barringtonia.

i. *Barringtonia racemosa* (L.) Roxb. (1826)

Common name	:	Powder- puff tree.
Distribution	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: small trees. **Stem:** straight, unbranched up to 1m, crown of branches, bark greyish brown. **Leaves:** simple, large, thin, leathery, finely toothed, petiolate, prominent midrib and veins, alternately arranged. **Flowers:** white to pinkish, bisexual, complete, regular. **Calyx:** 2/3 sepals, large, irregular, enclosing buds. **Corolla:** petals pinkish, oblong-ovate to lanceolate. **Fruit:** pear shaped 4- angled, single seed.

XIII. Family: Poaceae

a. Genus: Paspalum

i. *Paspalum distichum* L. (1759)

Common name	:	Knotgrass, eternity grass, ginger grass
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: perennial weed grasses, creeping, up to 50 cm. **Root:** fibrous adventitious roots. **Leaves:** blades flat, 3-15cm long, ciliate base, acuminate tip. **Inflorescence:** raceme, peduncles short, culms sub compressed, dark nodes, sheaths loose, keeled, papillose margins, dark green. **Flowers:** spikelets solitary, lower glume absent, upper glume elliptic, acute tip, pale green, imbricate; upper florets bisexual, 3 stamen, pale yellow anther, ovary oblong, stigma pink.

XIV. Family: Bignoniaceae

a. Genus: Dolichandrone

i. *Dolichandrone spathacea* (L.f.) K. Schum. (1899)

Common name	:	Mangrove trumpet tree
Distribution in Kerala	:	Kannur, Ernakulam, Alappuzha,
Abundance	:	Rare

Habit: moderate sized, deciduous tree. **Stem:** bark greyish brown. **Leaves:** compound, imparipinnate, opposite, exstipulate, rachis long, leaflet 5-7, opposite, petiolate, elliptic, acuminate apex, entire, glaborous. **Inflorescence:** corymb, erect, terminal. **Flowers:** bisexual, white, large. **Calyx:** spathaceous, acuminate tip. **Corolla:** white, long, slender, funnel shaped. **Androecium:** 4 stamens, didynamous. **Gynoecium:** ovary sessile, ovule many, long style, bilobed stigma. **Fruit:** capsule, purple- brown, ribbed.

XV. Family: Combretaceae

a. Genus: *Terminalia*

i. *Terminalia catappa L.* (1967)

Common name	:	Country almond
Local name	:	Thallitenga
Distribution in Kerala	:	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Thiruvananthapuram
Abundance	:	Common

Habit: semi-deciduous, medium- large sized trees. **Stem:** straight, cylindrical trunk with grey brown bark. **Leaves:** simple, entire, large, alternate, leathery, green- yellow-red. **Inflorescence:** axillary spike. **Flowers:** small, white/ cream flowers; bisexual-unisexual, male flowers more in numbers, female flowers- base of the spike. **Calyx:** 4/5, united, calyx tube adnate to ovary, valvate, persistent. **Corolla:** 4/5 petals, polypetalous, small, alternate to sepal, valvate. **Androecium:** 8/10 stamens, double the number of petals, curved filaments. **Gynoecium:** monocarpellary, single ovule, pendulous placentation, inferior. **Fruit:** sessile, laterally compressed, oval-shaped drupe.

i. Premna serratifolia

ii. Premna latifolia

iii. Clerodendron inermi

iv. Cerebra odollum

v. Derris scandens

vi. Ipomea pes-caprae

vii. Ipomea violacea

viii. *Thespesia populnea*

ix. Calotropis gigantea

x. Morinda citrifolia

xi. Pandanus tectorius (habit)

xii. Leaf crown

xiii. Fimbristylis ferruginea

xiv. Mariscus javaniscus

Plate 3.19 (i-xiv) Mangrove associates identified from Kerala

3.4.3 Molecular characterisation of selected mangrove species

The Mat K and rbcl are two chloroplast genes used in molecular characterisation of plant species. They are ideal tools in resolving taxonomic ambiguity among plant families and species. In the present study two mangrove genera; *Aegiceras* and *Acanthus* exhibited variability and thus molecular sequence analysis was carried out to resolve the issue.

i. Molecular characterisation of *Aegiceras* spp.

Aegiceras represents two mangrove species; *A. corniculatum* and *A. floridum. Aegiceras corniculatum* commonly known as the black mangrove is considered as least concerned species as per the IUCN red list. The species was found to be rare in Kerala coast and was spotted along the districts of Kasaragod, Kannur, Kozhikode, Thrissur and Kollam. *A. floridum* is considered as near threatened species as per IUCN red list. This species was spotted during the present survey and was also not reported from Kerala in the earlier studies. Both the species have simple, alternate, entire leaves and characteristic umbel inflorescence with numerous white flowers. The fruits are much longer and curved in *A. corniculatum* while smaller and straight fruits are characterized by *A. floridum.* In the present study few plants specimens of *Aegiceras* along the Kannur district were marked with smaller and straight fruits which led to misperceptions in taxonomic characterisation. Hence molecular tools were accepted to resolve the ambiguity.

The DNA barcoding using universal mat K and *rbcL* gene for *Aegiceras* spp. revealed a band at 1kb in the DNA ladder (denoted as BN2). The gene sequences obtained for the *mat K* and *rbcL* genes were deposited in Gene bank and the accession numbers obtained were KP976101.1 and KP976098.1 respectively. The phylogenetic tree revealed two separate clusters for *rbcL* and *mat K* genes and exhibited more than 90% similarity with *A. corniculatum* species (Figure 3.19). The *rbcL* gene sequence of BN2 sample showed more than 93% similarity with *Aegiceras corniculatum.* Even though the *matK* sequence of BN2 sample formed a separate cluster, the sequence also exhibited resemblance to *A. corniculatum*. Thus the BN2 sample was recognised as *Aegiceras corniculatum* and the morphological variations could be due to certain environmental factors.

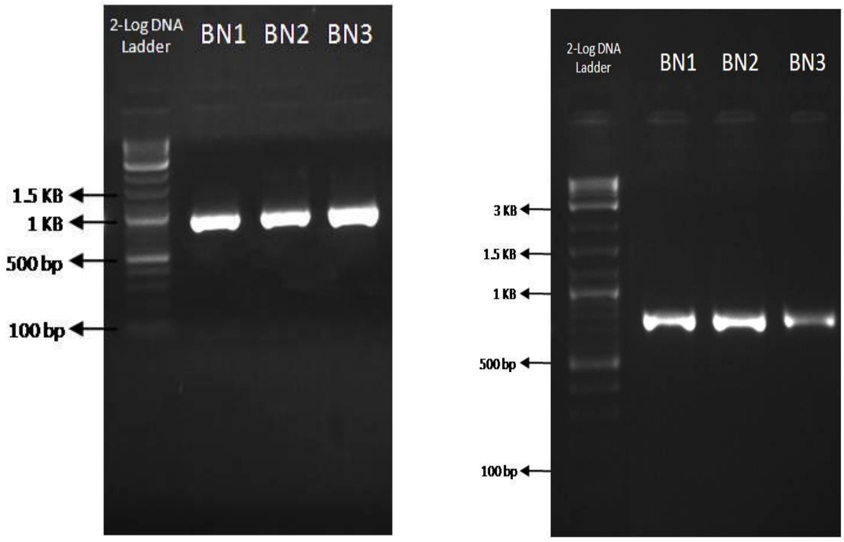


Figure 3.18 PCR product of *Mat K* and *rbcL* gene of *Acanthus* and *Aegiceras* spp.

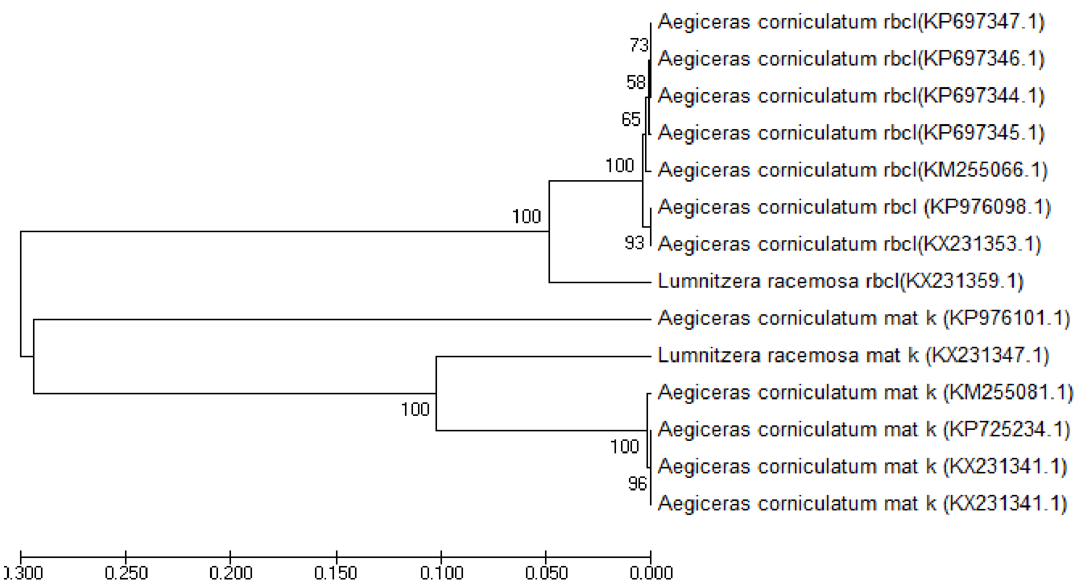


Figure 3.19 Phylogenic tree of *Aegiceras* spp.

ii. Molecular characterisation of *Acanthus* spp.

The genus *Acanthus* belongs to the family Acanthaceae with three species of mangroves: *A. ilicifolius, A. ebracteatus* and *A. volubilis.* Of these, *A. ilicifolius* and *A. ebracteatus* were reported from Indian mangroves as well as from Kerala in earlier studies. Later on the species *A. ebracteatus* were not reported from the mangrove habitats of Kerala and was considered to be extinct from the coast. Both the species of *Acanthus* are known as Holly leaved mangroves and described in detail in earlier studies (Tomlinson, 1986). The key identifying features of the two species is the flower colour; blue to purplish blue flowers are characteristic features of *A. ilicifolius* while pure white flowers are displayed by *A. ebracteatus*. In the present study white coloured flowers were encountered from Ezhome (Kannur). To establish the conclusive inference the molecular analysis of the two species were carried out using *mat K* and *rbcL* genes.

i. *Acanthus ebracteatus*

ii. *Acanthus ilicifolius*

Plate 3.20(i, ii) Species of *Acanthus*

The accession numbers obtained for the gene sequence for *mat K* and *rbcL* for *A.ilicifolius* (KP976099, KP976098) and *A. ebracteatus* (KP976097, KP976100) respectively. The *mat K* gene sequence of both *A. ilicifolius* (KP976099) and *A. ebracteatus* (KP976097) were 97% and 99% identical to the earlier submitted gene sequence of *A. ilicifolius* in National Center for Biotechnology Information. Similarly the *rbcl* sequence of both the species (KP976098, KP976100) showed 100% identity to *A. ebracteatus.*

The molecular analysis could not provide a conclusive taxonomic differentiation between the two species both plant samples were considered as two distinct phenotypes of *Acanthus* spp. since the morphometric measurements did not mark variation between the two species, the variations in the flower could possibly be due to strong convergent evolution of many characters to the stressful mangrove environment. Further studies have to be undertaken to resolve the existing controversy in classifying the species.

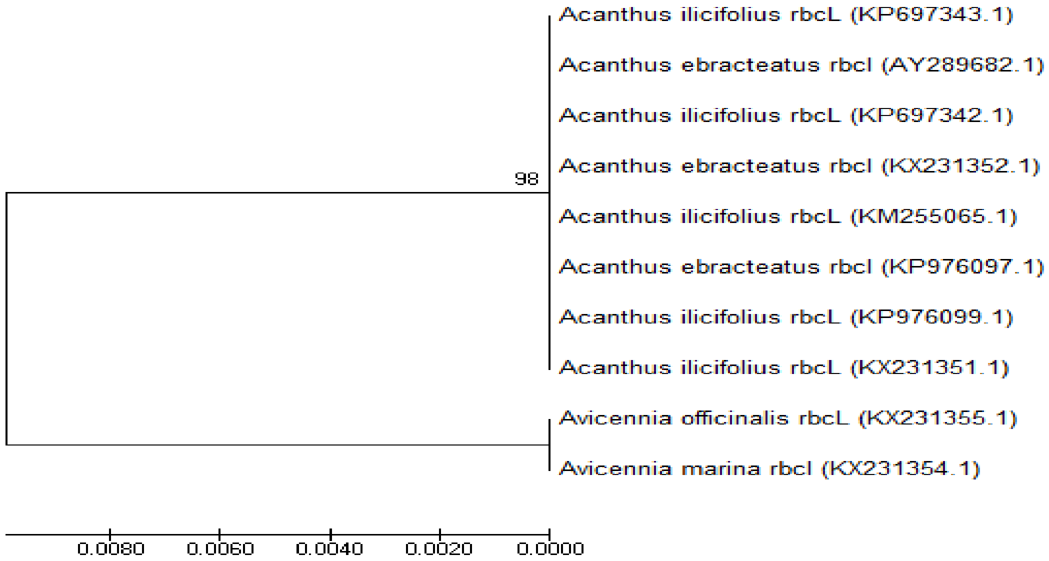


Figure 3.20 Phylogenic tree of *Acanthus* spp. for *rbcL* gene

3.5 Discussion

3.5.1 Species composition and morphometric variations

Among the 18 species of mangroves identified in the present study, only a single member represents the fern Class Filicopsida and all the other species belonged to Class Magnoliopsida. Rhizophoraceae and Avicenniaceae are the two families with only mangrove species. The other mangrove representing families were Euphorbiaceae, Acanthaceae, Combretaceae, Lytheraceae and Myrsinaceae.

i. Family Rhizophoraceae

The family Rhizophoraceae derived its name from the type genus Rhizophora and is the only family with mangrove species alone. Earlier taxonomic classifications grouped the family under order Cornales (Cronquist 1968; Thorne 1968). Later Takhtajan (1980) and Dahlgren (1988) placed it under order Mrytales. The family displays close resemblance to Combretaceae, Rubiaceae and Tiliaceae (Airy Shaw, 1966), while Behnke, 1988; Dahlgren 1988 marks its close relation to Erythroxylaceae. As per the angiosperm phylogenetic grouping (APG) system based on molecular characteristics, the family is placed under the order Malphigiales. The members of the family are woody trees favouring the water front regions of intertidal zone. The members have prominent stilt root/ prop roots/ knee roots/ buttress and exhibit viviparous mode of reproduction. The family includes four genera: *Rhizophora, Bruguiera, Ceriops* and *Kandelia.* The present study identified all the four genera from various mangrove habitats of Kerala. The genus Rhizophora is a pantropical species and was first reported by Linnaeus in 1953. Globally, ten species of the genus along with natural hybrids was reported by Spalding et al., 2010. *R. apiculata, R. mucronata, R. stylosa* and *R.* x *lamarckii* were reported from Indian mangroves (Singh and Garge, 1993; Dagar et al., 1993; Naskar, 2004; Selvam et al., 2004; Kathiresan et al., 2008) while a new hybrid species *R.* x *annamalayana* was reported by Kathiresan and Rajendran (2005) from the Pichavaram mangroves. The present study identified only two species of *Rhizophora*; *R. apiculata* and *R. mucronata* from Kerala. *R. mucronata* was observed along mangrove habitats of Kasaragod, Kannur, Kozhikode, Thrissur, Ernakulam, Alappuzha and Kollam while *R. apiculata* was found from Kasaragod, Kannur, Kozhikode, Ernakulam, Kottayam, Alappuzha and Kollam. The present study could not spot both the species from Malappuram and Thiruvananthapuram districts while Neethu and Harilal (2018) and Grinson et al. (2018) reported the occurrence of *R. mucronata* in Malappuram district. The morphometric measurements of *R. mucronata* revealed larger leaf size in Thrissur and Ernakulam, while all other districts represented more or less similar size ratio. The average length of mucron was highest in Kannur and lowest in Alappuzha, while most of the other characters did not exhibit much variation among the districts. The leaf size of *R. apiculata* was much larger in Kannur and Ernakulam. Most of the floral measurements exhibited higher values in Kannur and Ernakulam districts, however not much variation was observed among other districts. Within the two species of *Rhizophora,* the leaf size, mucron length, peduncle length, pedicel length and fruit length were higher for *R. mucronata.* The flowers of *R. mucronata* were slightly larger than *R. apiculata* and size variations in various floral measurements are clearly depicted in Table 3.21. Duke and Bunt (1979) identified spots on the ventral surface of leaves of *R. apiculata* of Indo- Malaysia, but such characters were not observed in Kerala mangroves.

Tomlinson (1986) reported six species of *Bruguiera* and grouped those under two categories; one with large solitary flowers and the other with many small flowers arranged in inflorescence. The present survey identified three species of *Bruguiera*; *B. cylindrica, B. gymnorrhiza* and *B. sexangula*. The most common species was *B. cylindrica* and was spotted from all the districts except Malappuram, Kottayam and Thiruvananthapuram. The leaf length to breadth ratio of Bruguiera was highest in Thrissur followed by Ernakulam and Kasaragod. The sepal width, petal width and bristle length did not exhibit variation among districts. Large sized fruits were noted in Kannur. *B. gymnorrhiza* was dominant along southern zone and was observed only from Malappuram in northern zone. The large leaf size and flower size were observed in Ernakulam. The morphometric charters such as sepal width, petal width, bristle length and the stamen length did not exhibit variation among the five districts. The fruit size was larger in Ernakulam followed by Kollam, Alappuzha, Kottayam and Malappuram. *B. sexangula* was rare in occurrence and was identified only from four districts (Kasaragod, Ernakulam, Kottayam and Alappuzha). The overall morphometric values were greater in Ernakulam district however negligible variations were recorded in other districts. Among the three species of Bruguiera, *B. gymnorrhiza* large sized leaves, flowers and fruits followed by *B. sexangula* and *B. cylindrica* (Table 3.22).

Table 3.21 Distinguishing features of species of family Rhizophoraceae

Characters	*R.mucronata*	*R.apiculata*	*B.gymnorrhiza*	*B.cylindrica*	*B.sexangula*	*K. candel*
Leaf length	12.5-16.2	12.3-16	8.2-12.2	7.5-9.8	7.5-12	8.4-15.8
Leaf width	7.5-8.9	4.6-6.5	3.2-4.5	2.4-3.2	2.8-3.5	2.5-4.8
Leaf shape	ovate- elliptic	ovate- lanceolate	elliptic oblong	ovate- lanceolate	ovate- lanceolate	oblong- lanceolate
Leaf apex	acuminate	acute	acute	Acute	Acute	Blunt
Leaf base	cup shaped	-	cuneate	-	Cuneate	-
Leaf mucro	present	present	absent	absent	Absent	absent
Mucro length	0.3-0.9	0.2-0.7	-	-	-	-
Petiole length	3.8-4.8	3.2-4.2	2-2.6	1.4-2.2	1.5-2.5	0.8-1.9
Infl. type	cyme	cyme	solitary	cyme	Solitary	Cyme
Infl. position	axillary	axillary	axillary	axillary	Axillary	axillary
No.of flowers	4	2	1	3	1	4
Bud length	1.2-1.8	1-1.6	2-3.2	1.5-2	1.9-2.6	1.3-2
Peduncle length	1.5-5.8	0.3-0.8	-	1.4-2	-	4-5.9
Pedicel length	1.3-2.1	sessile	1.8-2.1	0.4-0.6	1.5-1.9	0.4-0.9
Calyx Colour	light green	creamy white	reddish	light green	Yellowish	Green
Calyx lobes	ovate	ovate	acicular	tubular	Acicular	lanceolate
Sepal length	1.2-1.9	0.6-1.3	2-3.2	1.5-2	1.9-2.5	2-3
Sepal width	1.2-1.6	0.8-1.2	0.2-0.3	0.2	0.2	0.3-0.5
Corolla colour	white	white	white, turn brown	white	yellow, turn brown	white
Petal length	1.4-1.9	0.6-1	1.5-2.5	0.5-0.8	1.5-2	2-2.5
Petal width	0.9-1.2	0.3-0.5	0.5	0.5	0.5	0.4-0.8
Bristle length	-	-	0.3	0.2	0.3	-
Stamen no.	8	11-12	26-32	16	20-24	34+
Stamen length	1-1.2	0.8-1.1	0.5	0.3	0.4	0.7-1.2
Style length	0.1	0.1	1.4-2	0.3-0.4	1-1.5	1-1.2
Ovary	inferior	inferior	inferior	inferior	Inferior	inferior
Fruit length	39-49	45-52	15-17.6	13-15	14.6-15.6	37-45

Kandelia was considered as a monotypic genus for a long time. The genus was reported from India by Tomlinson (1986), Banerjee et al. (1989), Naskar and Mandal (1999), Kathiresan (2008). However various recent studies on molecular phylogeny (Huang and Chen, 2000; Chiang et al., 2001) marked the presence of another species; *K. obovata.* This species is not reported from India and the present investigation also encountered only *K. candel* from Kerala coast along ten districts except Thiruvananthapuram. The species along Kannur district were more healthy and aged trees, while those at southern zones were of emerging populations the species. The leaf size ranged from 8-15cm x 2.5-4.8cm along various districts. None of the morphometric parameters recorded uniformity in size among the nine districts. The species *Ceriops tagal* was first reported by Wight in 1872, followed by Gamble in 1915. The species was considered to be extinct from Kerala coast and very scanty reports were available regarding the species since then. There after the species was reported from Kollam district by Mini Mohandas et al. (2012) and Vidyasagaran and Madhusoodanan (2014). The present study also observed the species along Kollam district (Vincent Island).

ii. Family Avicenniaceae

The family includes 10 species of *Avicennia* (Spalding et al., 2010) of which only three species are reported from India and Kerala. The present study also identified three species; *A. marina*, *A. officinalis* and *A. alba* from Kerala. *A. officinalis* was the most common species in all districts while *A. alba* was noted only in Kollam and was rare in occurrence. *A. marina* was spotted along Kasaragod, Kannur, Kozhikode, Ernakulam and Kollam. The average leaf lengths recorded were higher in Kozhikode. The species exhibited dimorphism in leaf character along Kannur and Ernakulam district. The leaves were larger (3-10cm x 3-5.5cm), green in certain parts of the two districts, while the other group of trees exhibited much smaller (3-5cm x 3-3.5cm) and yellowish green leaves (Plate 3.21). Many of the floral character such as sepal length, sepal width, stamen length and length of style were uniform in all the five districts.

Plate 3.21 Leaf variation in *Avicennia marina*

The species *A. alba* was rare in occurrence along the Kerala coast and was spotted only from Kollam district (Ayiramthengu) while *A. officinalis* was most commonly distributed mangrove species in all districts.

Table 3.22 Distinguishing features of *Avicennia* spp.

Characters	*A. officinalis*	*A.marina*	*A. alba*
Leaf length	5.3-11	3-10.5	9.2-12
Leaf width	3-7.2	3-5.5	1.5-2
Leaf shape	Ovate- oblong	Elliptic-oblong	Lanceolate
Leaf apex	obtuse	acute	Acuminate
Petiole length	1-2	0.5-1.5	1-1.8
Infl.type	Compound spike	Compound spike	Compound spike
Infl.position	Axillary/ terminal	terminal	Axillary/ terminal
No. of flowers	10-12,large	15-18, medium	8-32, small
Calyx Colour	green	green	Green
Calyx lobes	Broad, acute	Broad, elliptic	Broad, ovate
Sepal no.	5	5	5
Sepal length	0.4-0.5	0.4	0.3-0.4
Sepal width	0.5	0.4	0.4
Corolla colour	yellow	Light orange -yellow	Orange yellow
Petal no.	4	4	4
Petal length	0.3-0.5	0.3-0.5	0.3-0.4
Petal width	0.5-0.7	0.3-0.4	0.2-0.3
Stamen no.	4	4	4
Stamen length	0.3	0.3	0.3
Style length	0.4	0.4	0.4
Position of ovary	superior	superior	Superior
Fruit shape	flattened, short apical beak	spherical to ovoid, short beak	conical, extended terminal beak
Fruit length	1.5-2.5	1.5-3	2.5-3.5
Fruit width	2-3	2-2.5	1.5-2

The morphometric measurements revealed large sized leaves and fruits along Kannur and Ernakulam district while most of the other floral characters were same in all districts. Among the three species of *Avicennia*, larger leaves and flowers were observed for *A. officinalis* followed by *A. marina* and *A. alba* (Table 3.23). While the fruits were much longer for *A. alba* than other two species where the fruits were much spherical with shorter apical beak.

iii. Family Euphorbiaceae

The members of Euphorbiaceae are characterized by the presence of milky latex. Two mangrove species under genus *Excoecaria* was identified during the study. The genus name is derived from the Latin word "excaeco" meaning making blind. Around 40 species of the genus are identified along the tropical region, of which only two are widely spread mangrove species. Both *E. agallocha* and *E. indica* were identified from Kerala, of which *E. agallocha* was common in occurrence and was noted from all districts except Thiruvananthapuram. *E. indica* had restricted distribution and was spotted only Kottayam and Alappuzha. The leaf size of *E. agallocha* was greater in Ernakulam and Kollam districts and smaller in Kasaragod. The inflorescence length also varied along districts and larger inflorescence were noted along southern districts than north. The female flowers and the mature fruits of *E. indica* were only noticed along Kottayam and Alappuzha. The species lack much information on taxonomic features and is marked as data deficient by IUCN. Recently Ragavan (2014) provided elaborate report on the morphometric features of the species from Andaman and Nicobar Island.

iv. Family Lytheraceae

The genus *Sonneratia* was named after Pierre Sonnerat. Earlier the species was placed under the separate family Sonneratiaceae which included two genera; *Sonneratia* and *Duabanga.* But recent classifications placed the two genera in separate monotypic subfamilies under family Lythraceae. Ten species of *Sonneratia* were identified globally (Spalding et al., 2010), of which four are recorded in India (Singh and Garge, 1993; Dagar et al., 1993; Naskar, 2004, Kathiresan, 2008). The present floral survey identified two species; *S. caseolaris* and *S. alba*. The later was rare in occurrence and was spotted only from Kannur, Ernakulam and Alappuzha districts. The morphometric measurement recorded only minute variation in various characters among the three districts. *S. caseolaris* were more common and marked its presence in all the ten districts. The leaf size was greater in Kasaragod followed by Kannur and Ernakulam, while reduced leaf size were observed in Thiruvananthapuram and Malappuram. The variations in the floral measurements were negligible and even the sepal width displayed a uniformity in all districts. Among the two species *S. caseolaris* exhibited proportionally higher leaf size and other floral characters.

Table 3.23 Distinguishing features of *Sonneratia* spp.

Characters	*S. caseolaris*	*S. alba*
Leaf length	4-12	5-10
Leaf width	2-6	3-7
Leaf shape	Ovate-elliptical	Obovate
Leaf apex	Broad, not narrow	Round
Leaf mucron	Absent	absent
Petiole length	1-1.2	0.5-1
Infl. type	Solitary	solitary
Infl. position	Terminal	terminal
No. of flowers	1	1
Calyx Colour	Green	green
Calyx lobes	Oblong elliptic, Tubular	Oblong elliptic, tubular
Sepal no.	6	6
Sepal length	1.5-2	0.5-1.2
Sepal width	1.5	0.8-1
Corolla colour	Purple	white
Petal length	1.5-2	1-2
Petal width	0.2-0.3	0.2
Stamen no.	Numerous, pink	Numerous, white
Stamen length	2.8-3.5	2.5-3
Style length	5-6	4-5
Position of ovary	Superior	superior
Fruit	Globose berry	Globose berry
Fruit width	4-5	3-4.5

v. Other Families

The genus *Aegiceras* is the single mangrove representative from the family Myrsinaceae. Even though two species of *Aegiceras; A. floridum* and *A. corniculatum* are reported globally, only the later species was identified from Kerala. Earlier thick stands of mangrove vegetation were reported along the Kerala coast and *A. corniculatum* was a most common species of mangrove prevailing here. But the present study observed the loss of the species from various mangrove habitats and was recorded only from Kasaragod, Kannur, Kozhikode, Thrissur and Kollam. The species was not observed along central Kerala and marked its dominance in northern zone. The Kollam district displayed much healthier growth of the species in the Ayiramthengu region and was clearly portrayed in the morphometric measurements. Large sized leaf, flowers and fruits were evident in Kollam district than other districts.

The genus *Lumnitzera* belongs to the family Combretaceae. The generic name was assigned in honour to the Hungarian botanist Ivan Lumnitzer and the species name racemosa means "arranged in cluster" with reference to the characters of inflorescence. Even though three species of *Lumnitzera* is reported globally (Spalding et al., 2010) and 2 spp. from India (Singh and Garge, 1993; Dagar et al., 1993; Naskar, 2004, Kathiresan, 2008), only a single representative of the genus was marked from Kerala in the present study. *L.racemosa* was identified along the Kasaragod, Alappuzha and Kollam districts. The morphometric variation was not evident among the three districts and many of the characters (petiole length, sepal length, petal and sepal width) were uniform in all habitats.

The family Acanthaceae includes a wide range of tropical plants, of which only four species under the genus *Acanthus* are considered as true mangroves. The mangrove representatives of *Acanthus* are: *A. ilicifolius, A. ebracteatus*, *A. volubilis* and *A. xiamensis.* Even though all the three species are reported from Indian mangroves (Singh and Garge, 1993; Dagar et al., 1993; Naskar, 2004, Kathiresan, 2008) the species *A. volubilis* is not yet identified along Kerala coast. On the other hand *A. ilicifolius* is the most common species in the mangrove habitats of Kerala. The morphometric variation in leaf size marked larger leaf area in mangroves of

Thrissur, Ernakulam and Alappuzha. Most of the floral characters did not exhibit much variation between districts.

As per the reports of World Atlas of Mangroves (Spalding et al., 2010) the family Pteridaceae is the only fern family and represented three mangrove species globally (*A. aureum, A. danaeiifolium* and *A. speciosum*). Even though the two species *A. aureum* and *A. speciosum* were reported along Indian mangroves, only *A. aureum* was only spotted in Kerala. The species was identified from the mangrove habitats of all districts except Kasaragod. The number of fronts per plant varied from 16-22 in numbers and the leaf let length varied from 10-35cm. The morphometric measurements of leaflet width and petiole length did not show much variation. The species were more evident in the degrading habitats mangrove of most districts.

3.5.2 Taxonomic ambiguity of *Acanthus* species

The mangroves are taxonomically well documented from the past; however they are also subjected to frequent revisions during the course of time. The classification between true mangroves and mangrove associates were of great controversy from the beginning. Besides these ambiguities, many of the convergent characters have made it difficult in either identifying the specific species or classify them under respective families. Several traits such as pollen morphology, embryology etc. may not exhibit variations related to habitat change. However various environmental factors to a great extent, influences morphological characters making it challenging task in tracing the evolutionary history of the species. Thus development of various molecular methods has proved helpful in solving taxonomic ambiguities as molecular markers unlike morphological markers are not prone to environmental variations.

The genus Acanthus is an Old World genus belonging to the family Acanthaceae. It is easily distinguished from other mangrove species by the presence of spiny leaves, terminal spike inflorescence, bracteoles (2) and uniform anthers (Duke, 2006). Polidoro et al. (2010) reported four species of Acanthus; *A. ilicifolius, A. ebracteatus, A. volubilis* and *A. xiamenensis*. Out of these, *A. xiamenensis* is endemic to China and all other species are reported along Indian coast. Wang and

Wang (2007) have considered *A. xiamenensis* as *A. ilicifolius* due to lack of taxonomic identity. Kathiresan (2010) also opined that taxonomic distinction between two species is still not clear in India. For instance both the species are not clearly identified and reported mistakenly in many studies. Even though Remadevi and Binoj Kumar (2000) reported the occurrence of this species from mangroves of Aroor (Alappuzha) and contented that the specimens indexed as *A. ilicifolius* in Indian herbarium are actually *A. ebracteatus*. No other reports revealed its presence along Kerala mangroves and were questioned by Anupama and Sivadasan (2004). In the present study the species was encountered from mangrove habitats of Ezhome, Kannur district. Many of the earlier studies have reported the occurrence of A. ebracteatus from various mangrove habitats of Kerala; however the reports lack species description. After a long gap of time Ragavan et al. (2014) provided a detailed taxonomic description of both *A. ilicifolius* and *A. ebracteatus* from the Andaman and Nicobar Islands.

In the present study two species of *Acanthus* was spotted along Kerala coast; *A. ilicifolius* and *A. ebracteatus*. Even though morphometric variation among the two species revealed no differences except in flower colour. However both the species exhibited serrated leaves with axial spines and presence of bracteoles, it was difficult in distinguishing the species without flowers. Barker (1986) also reports that both the species have similar vegetative characters and the difference between them is the presence or absence of bracteoles. But these bracteoles are often shed after anthesis, making it wary in identification of the two species. Thus molecular tools were adopted for further clarification in identification of the species. The two potential genes mat *K* and *rbcl* were used in DNA barcoding. The *mak* K genes of both the species were identical to the sequences of *A.ilicifolius*, already submitted to the gene bank while the rbcl gene sequences of both the species exhibited similarity to *A. ebracteatus.* The molecular analysis could not draw a conclusive taxonomic differentiation between the two species and a critical conclusion was also not derived based on the existing literature as very limited information is only available regarding the morphological variations of mangrove species along Kerala. The variations in the habitats and stress full mangrove environments could be the possible reasons contributing to convergent evolution of many morphological characters. However it is recently reported that the two genes, *mat K* and *rbcl* does not support resolution in species of *Acanthus* and *Bruguiera* (Surya and Hari, 2017).

3.5.3 An overview of mangrove species of Kerala

The mangrove taxonomy needs much attention as many of the species are poorly identified and wrongly classified in many of the reports. The taxonomic studies by Tomlinson (1986) reported 114spp. of mangroves and associates globally, of which only 54 spp. (20 genera, 16 families) are considered as true mangrove species. Spalding et al. (2004) reported a range of 30-40 species of true mangroves which included further grouping as 'core mangrove' species such as *Rhizophora apiculata, Kandelia candel, Ceriops tagal, Bruguiera gymnorrhiza, Aegiceras corniculatum* and *Sonneratia caseolaris.* At present 73 species are considered as true mangroves which includes 38 spp. of core mangroves as per the classification of World Atlas of Mangroves, 2010 (Spalding et al., 2010).

The present study identified 18spp. of true mangroves and 23spp. of associated flora along the ten districts of Kerala. Basha (1992) reported 18spp. of true mangroves and 23spp. of semi mangroves. Kathiresan (2008) reported 64 spp. of mangroves and associates from Kerala, while Khaleel (2008) identified 14 true mangroves and 40 mangrove associates from North Malabar. Anupama and Sivadasan (2004) identified mangroves species (15spp.) and associates (49spp.) in Kerala. Gopikumar et al., 2008 identified 28 floral components from mangroves of Puthuvypin, which included true mangroves (8), semi mangroves (5), grasses (5), fern (1) and herbs and climbers. The occurrence of various species of mangroves and associates are also reported from Kerala by many authors from long time and the number of species assorted to each category vary with authors and are not constant (Table 3.25). The earlier reports of Thomas et al., 1974 reported 6spp. along the Thiruvananthapuram district. The present survey also spotted less number of mangroves (3spp) namely *Avicennia officinalis, Sonneratia caseolaris* and *Acrostichum aureum* along Thiruvananthapuram district. While Grison et al. (2018) reported only the presence of *Sonneratia caseolaris*. In contrast to this, Neethu and Harilal (2018) reported 10spp. of true mangroves from the district. The species included *Aegiceras corniculatum, Avicennia officinalis,* *Bruguiera cylindrica, B. gymnorrhiza, Excoecaria agallocha, E. indica, Lumnitzera racemosa, Rhizophora apiculata, R. mucronata* and *Sonneratia caseolaris.* Similarly the report by Mini et al. (2014) highlighted the occurrence of 14spp. of true mangroves from the same district. The species listed by them were quiet doubtful as many of the species such as *Phoenix sylvestris, Aegiceras corniculatum, Acanthus ebracteatus* were neither spotted in the present study nor reported in earlier studies from Thiruvananthapuram district.

Table 3.24 Review on mangrove species reported from Kerala

Species	1	2	3	4	5	6	7	8	9	10
Acanthus ebracteatus	-	-	-	-	+	-	-	-	-	-
A. ilicifolius	+	+	+	+	+	+	+	-	-	+
Acrostichum aureum	+	+	-	+	+	-	+	-	-	+
Aegiceras corniculatum	-	+	+	+	+	-	+	+	+	+
Avicennia alba	-	-	-	+	-	-	-	-	-	-
A. marina	-	+	+	+	+	-	-	+	+	+
A. officinalis	-	+	+	+	+	+	+	+	+	+
Bruguiera cylindrica	-	+	+	+	+	-	+	+	+	-
B. gymnorrhiza	+	-	+	-	+	+	-	+	+	+
B. parviflora	-	+	-	-	+	-	-	-	-	+
B. sexangula	-	-	+	+	+	-	-	+	+	+
Ceriops tagal	-	-	-	-	+	-		+	+	-
Excoecaria agallocha	-	+	+	-	+	+	+	+	+	+
E. indica	-	-	+	-	+	-	-	+	-	-
Heritiera littoralis	-	-	-	-	+	-	-	-	-	-
Kandelia candel	-	+	+	+	+	+	-	-	+	-
Lumnitzera racemosa	-	+	+	+	+	-	-	+	-	+
Nypa fruticans	-	-	-	-	+	-	-	-	-	-
Phoenix sylestris	-	-	-	-	+	-	-	-	-	-
R. apiculata	+	+	+	+	+	-	-	+	+	+
R. mucronata	+	+	+	+	+	-	-	+	+	+
Sonneratia alba	-	+	+	+	+	-	-	+	+	+
S. apetala	-	-	-	-	+	-	-	-	-	-
S. caseolaris	-	+	+	+	+	+	-	+	+	+
Total	**5**	**14**	**15**	**14**	**23**	**6**	**6**	**14**	**13**	**14**

1. Thomas et al., 1974; 2. Anon, 2002; 3.Anupama and Sivadasan, 2004; 4.Radhakrishnan & Gopi, 2006; 5.Mini et al., 2014; 6.Arun & Shaji, 2013; 7.Sheela Francis, 2013; 8.Vidyasagaran & Madhusoodanan, 2014; 9.Grinson et al., 2017; 10. Anon, 2018

The mangroves of Thrissur were studied by many during the course of time (Saritha and Tessy, 2011; Sheela, 2013; Vidyasagaran and Madhusoodanan, 2014). The present study identified 9spp. of true mangroves. The studies by Anon (2002) and Saritha and Tessy (2011) reported only 5spp. Many species such as *R. mucronata, B. cylindrica, Kandelia candel, S. caseolaris* etc. spotted in the present survey were missing in their reports. The Malappuram district had seven species of mangroves. The species of *Avicennia, Acanthus, Bruguiera, Kandelia, Excoecaria* and *Sonneratia* were evident in Malappuram. The species *Rhizophora mucronata* and *Aegiceras corniculatum* reported in earlier studies (Anon, 2002), were not spotted in the present study. The Kozhikode mangrove habitats had representations of 11spp. and could identify two species, *R. apiculata* and *B. cylindrica* which were not reported in the earlier studies of Anon (2002) and Anon (2014). The larger extend of mangrove cover were noted along Kannur district and were inhabited by 12spp. Many studies are reported from the Kannur district revealing the mangrove species composition. Vidyasagaran and Madhusoodanan (2014) reported 15spp. from Kannur. Twelve species of true mangroves were identified from the mangrove habitats of Kasaragod. The present floral survey identified better representation of mangroves in Northern part of Kerala. *R. mucronata, A. officinalis, A. ilicifolius, A. aureum, E. agallocha, S. caseolaris, K. candel* were common and abundantly distributed throughout Kerala coast. Even though *S.alba, B. sexangula,* and *R. apiculata* were also found in all three zones of Kerala; they were rare and restricted in distribution. *Aegiceras corniculatum* and *Avicennia marina* were abundant in Northern parts and in Puthuvypin (Central Kerala) while was rare in Southern part and was confined only to the Ayiramthengu region f Kollam. B. gymnorrhiza was found to be rare in northern and southern part, while was abundant in central Kerala. *Lumnitzera racemosa* was rare in north (only represented in Kasaragod) and south (Alappuzha, Kollam) Kerala while was completely absent in central part. *Ceriops tagal* and *Excoecaria indica* was present only in south Kerala.

The present study identified 23spp. of mangroves associates and the major genera were *Premna, Clerodendron, Cerebra, Derris, Thespesia, Ipomea, Morinda, Pandanus* and *Fimbristylis*. However species like *Syzygium travencoricum, Crinum* *defixum*, *Flagellaria indica*, *Samadera indica*, *Aegle marmelos* and many other species reported earlier was not encountered in present investigation. The number of mangrove associates reported from various part of Kerala showed great variations. Radhakrishanan and Gopi (2006) identified 18spp. of mangrove associates. Arun and Shaji (2013) reported 8spp. of associated flora from Kumbalam Islands, which included *Bacopa monnieri* as one of the associate. Sheela (2013) reported 9 mangrove associates from Poyya backwaters while the number of species reported by Vidyasagaran and Madhusoodanan (2014) were 33spp. from various mangrove habitats of Kerala. Both *Acanthus ilicifolius* and *Acrostichum aureum* were included under mangrove associates in their study. Sahadevan et al., 2017 also reported 32 spp. of mangrove associates from Puthuvypin. Acrostichum aureum was considered as associate and the list also included many of the halophytes such as *Diplachne fusca*, *Phragmites karka*, *Millettia pinnata*, *Bacopa monnieri* etc. The confusion in differentiating between mangrove, mangrove associates and other halophytes have led to the miss placement of species under respective categories and thus the total number of species reported is not constant and varies in each studies. For example, *Hernandia nymphaeifolia* and *Clerodendron inermi* were reported as mangrove associates by Pillai and Sirikolo 2001; Saenger 2002; Thomson and Evans 2006 while many others (Parani et al., 1998; Satyanarayana et al., 2002; Tomlinson 1986) classified these species as true mangroves. The major two species *Acrostichum aurum* and *Acanthus ilicifolius* were under dispute for a long period of time regarding their placement as mangroves or mangrove associates. Many of the international, national and even regional studies grouped these species differently (Table. 3.25). The present study grouped the two species under true mangroves based on the classification of World Atlas of Mangroves (Spalding et al., 2010).

Table 3.25 Review on taxonomic position of species of Acanthus and Acrostichum

Species	True mangrove	Mangrove associate
Acrostichum aureum	Tomlinson (1986); Duke (1992); Lin (1999); Peter and Sivasothi (1999); Giesen et al. (2007); Spalding et al. (2010)	Saenger et al. (1983); Tansley and Fritsch (1905); Chang (1997); Kathiresan and Bingham (2001); Jayatissa et al. (2002); Mu et al. (2007); Saritha and Tessy (2011); Vidyasagaran and Madhusoodanan (2014); Sahadevan et al. (2017)
Acanthus ilicifolius	Saenger et al. (1983); Chapman (1984); Tansley and Fritsch (1905); Parani et al.(1998); Lin (1999); Satyanarayan et al. (2002); Mu et al. (2007); Giesen et al. (2007);Spalding et al. (2010); Saritha and Tessy (2011); Sahadevan et al. (2017)	Tomlinson (1986); Chang (1997); Peter and Sivasothi (1999); Jayatissa et al. (2002);Wang et al. (2003); Vidyasagaran and Madhusoodanan (2014)

Chapter 4

Distribution and Zonation pattern of Mangroves of Kerala

Contents

4.1 Introduction

4.1.1 Zonation

The spatial distribution of mangroves is referred to as the zonation of mangrove species. Even though it is the striking feature of most mangroves, it is not universal as the zonation pattern is affected by various environmental factors. The possible causes of the zonation pattern have been debated extensively in the literature by Macnae (1968), Chapman (1976), Snedaker (1982) and Tomlinson (1986) and based on this, different classification of mangrove forest have been hypothesized during the course of time. The most accepted classification was put forward by Lugo and Snedaker (1974), in which the mangrove forests were classified to six types; fringe forests, riverine forest, overwash forest, basin forest, dwarf forest and hammock forest as given below (Figure 4.1).

Later Cintron and Novelli (1984) modified this classification and based on the topography and hydrology, broadly categorized three types of mangrove forest: fringe, riverine and basin forest. Further, classification based on water level, wave energy and pore water salinity were put forward by Gilmore and Snedaker (1993) and identified 5 distinct types of mangrove forests: mangrove fringe forests, overwash mangrove islands, riverine mangrove forests, basin mangrove forests and dwarf mangrove forests.

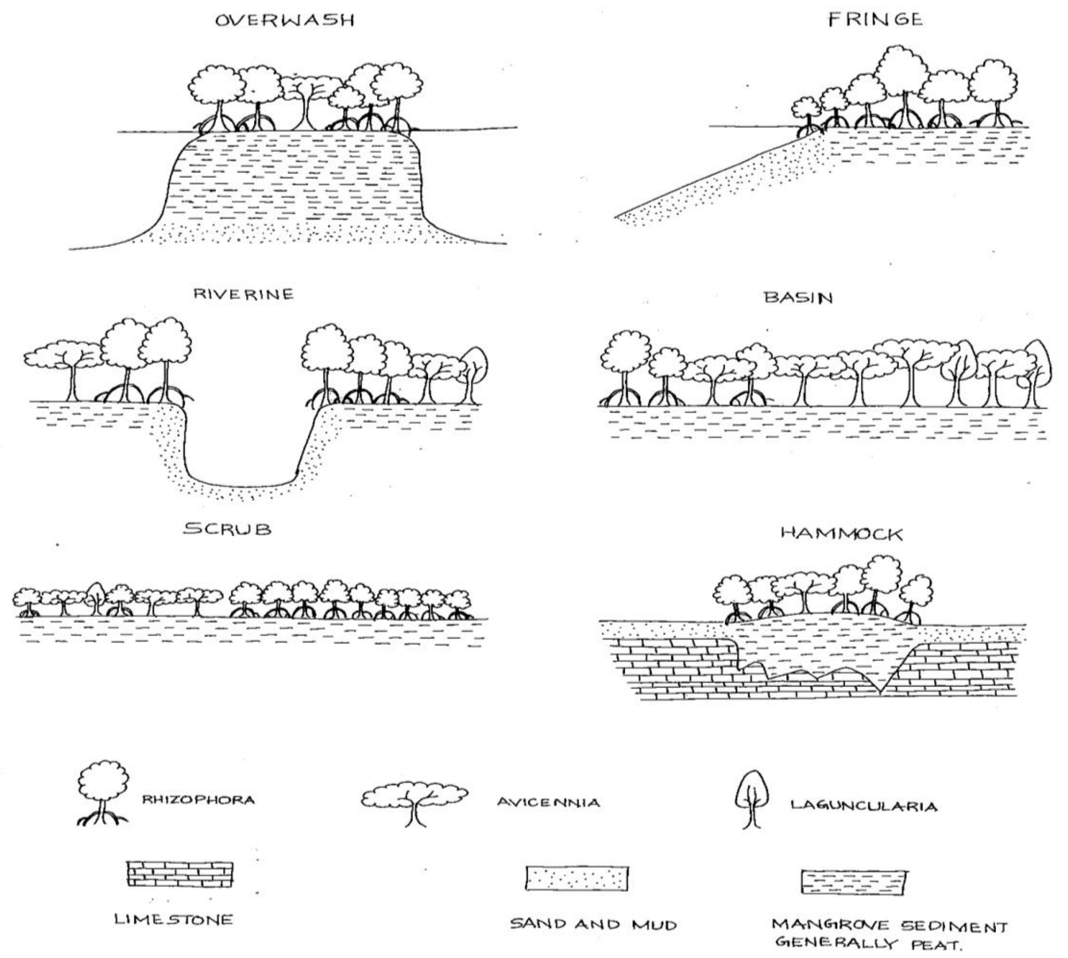


Figure 4.1 Different types of mangrove forests (modified from Lugo and Snedakar, 1974)

Thom (1984) put forth another classification based on geophysical, geomorphological and biological processes in mangrove ecosystem. According to this classification the geophysical factors such as changes in sea level, climatic conditions and tidal properties of a region and the geographical factors such as character of sedimentation, dominance of particular processes like wave, tide or river and micro topography of the area are the dynamic factors controlling the zonation pattern. Based on these factors Thom identified five different environmental setting for mangrove ecosystems (Figure 4.2).

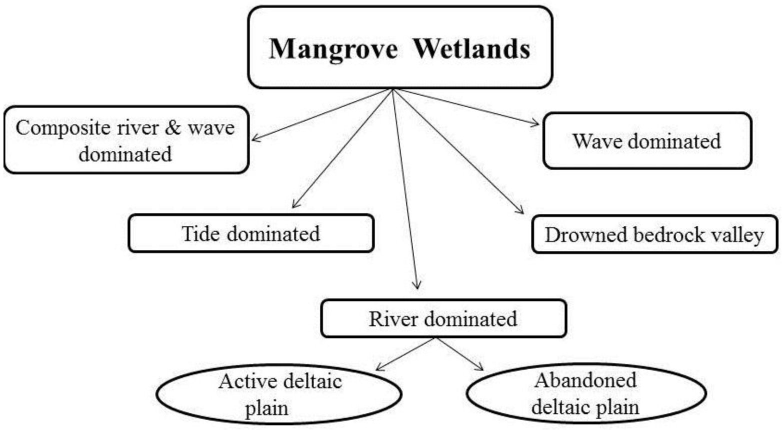


Figure 4.2 Different types of mangrove wetlands by Thom (1984)

River-dominated mangrove wetlands are characterized by high inflow of fresh water and sediment discharge, but low tidal range. They usually lead to formation of deltas by the deposition of river-borne sediments. Mainly two types of deltas are formed in such habitat: active deltaic plain and the abandoned deltaic plain. The active deltaic plain usually does not support salt-tolerant plants like mangroves to grow due to high amount of fresh water discharge while the abandoned delta supports extensive growth of mangroves as the flow of the river water is not very strong here. The micro-topography such as land elevations and frequency of tidal inundation further determines the distribution of mangrove species in the abandoned delta. New areas for mangrove growth is always available in river- dominated mangroves due to the continuous large scale deposition of sediments. Krishna and Godavari mangroves (Andhra Pradesh), Pichavaram and Muthupett mangroves (Tamil Nadu) are typical examples of river- dominated mangroves. The tide-dominated mangrove wetlands where high tidal range and strong bidirectional tidal currents are dominant physical forces controlling the mangrove vegetation. Large amounts of sea water with high velocity are brought into the mangroves during the high tide and the water currents help in the dispersion of sediments brought by rivers leading to the elongation of islands and formation of shoals. Usually funnel shaped river channels are formed and are fed by tidal creeks separated by large tidal flats. These tidal flats and islands and shoals have extensive mangroves due to low wave energy. Sunderbans and Mahanadi mangrove wetlands are typical examples.

Wave-dominated mangrove wetlands are characterized by higher wave energy at the shoreline and relatively low amount of river discharge. Sandy ridges and barrier islands are formed in these wetlands enclose broad, elongated lagoons bordered by mangroves. This type of wetland is found along the coasts of Mexico, Brazil and other middle and South American countries. Composite river and wave dominated mangrove wetlands display high wave energy and high river discharge resulting in formation of extensive sand sheets supporting extensive mangrove growth. Drowned bedrock valley is defined by a bedrock valley system, which has been drowned by a rising sea level. This open estuarine system cannot be filled by marine or river depositions. Relatively small river deltas are formed at the heads of the valley where the mangroves may flourish in fine sediments. The mangroves of Gulf of Kutch, Gujarat exhibit this type of vegetation.

4.1.2 Effects of anthropogenic activities on mangrove habitats

Mangrove habitats are highly dynamic and unstable, thus are always at a high risk of various natural phenomenon such as coastal erosion, storms, wave actions, changes in sediment and hydrological factors. Thus mangroves have developed various adaptive features to withstand these unfavourable circumstances while the impacts of human interference have taken a toll of these ecosystems. Various anthropogenic activities such as urban expansion, developments of ports and industries, aquaculture ponds, unsustainable timber extraction had all lead to large scale degradation of these mangrove habitats which is mainly due to the ever exploding global population that has increased the quest for land, food and other resources. Over the past 100 years there has been considerable decline in mangrove area, which is remarkably portrayed in Asian mangrove habitats during the last 50years. These ecosystems are studied globally by many and had identified various causes for the mangrove degradation which vary considerably from country to country. White and Cruz-Trinidad (1998) highlight the conversion of mangrove ecosystems to aquaculture ponds and urban expansion and industrial development as main causes of mangrove loss in Philippines. While in Malaysia, the main causes were conversion of mangrove lands for rubber and oil palm plantation, aquaculture and port development (Chan and Salleh, 1987). As these ecosystems serves as the best nursery grounds, these are mainly converted to shrimp ponds in Thailand (Plathong and Sitthirach, 1998), Vietnam (Hong and San, 1993), Ecuador (Hamilton, 2011) whereas the land is utilized for agriculture in Thailand (Barbier, 2004) and for swamp rice cultivation in West Africa (Sylla, 1994).

The increasing population has led to demographic shift in human inhabitation from inland to coastal areas, causing disturbances to all the coastal ecosystems with mangroves being the prime victim to such alterations. Even though global warming and impacts of climate change on mangroves are current debates at present, there are also various other threats that streaks out localized mangrove vegetation. Mangroves are cleared on large scale for construction of ports, harbours, industries and tourist resorts. It is difficult to figure out the loss of mangrove area due to urbanization, industrial and infrastructural developments as these activities are highly localized and less transparent compared to large scale conversions for aquaculture and agriculture practices. Besides the direct loss due to reclamation activities, many of the mangrove habitats face widespread mortality due to alterations in drainage patterns. Construction of various roads, jetties, bund walls etc. cuts off the tidal flow leading to a permanently ponded condition in many mangrove habitats. All these alterations have resulted in fragmentation of various mangrove habitats causing loss/changes in species composition, zonation pattern and ecological conditions of mangrove habitats.

The Kerala mangroves are not an exception to such developmental activities and are fatally affected by the same resulting in great loss of mangrove cover. Thus, the present day mangroves exist as fragment patches fringing the estuary and coastal areas. As this wanton destruction continues, even the available limited stocks of mangroves in Kerala are under risk and require optimal counter measures for their conservation and restoration. Only cursory approach has been laid out to understand the district wise mangrove cover and zonation patterns as most of the earlier studies were based on the floral diversity and ecological aspects of mangroves of Kerala. The information on district wise mangrove cover and zonation patterns are lacking from Kerala coast for more than a decade, are a prerequisite for the conservation and management programmes. Thus the present study provides the scientific information on these aspects for even localised mangrove patches of Kerala.

4.2 Review of literature

4.2.1 Mangrove degradation and causes

Duke et al. (2007) opined that the mangrove loss is occurring at an alarming rate and if it continues being unnoticed, 100% of the mangroves could be lost in near future. According to Ellison and Farnsworth (1997) and Kairo et al. (2001) the main cause for mangrove loss is habitat destruction. Spalding et al., 1997 and Spiers, 1999 opines that half of the world mangroves are already destroyed mainly due to heavy population and development pressures and to some extend due to frequent storms. A better knowledge on the extent of global mangroves will not only help in estimating the carbon stocks in mangrove vegetation but would provide a base for identifying the degree of degradation. For tracing the loss in mangrove area, even small patches are to be identified and mapped rather than mapping only the dense mangroves of the world.

The mangroves of India are unique in their variability and rich biodiversity but are also subjected to sever degradation due to various developmental activities (Upadhyay et al., 2002). The recent assessment of mangrove cover in India is 4921km^2 (FSI, 2017) ie 3% of the global mangrove area. The mangrove cover of India is discussed in detail in chapter 1. The mangrove vegetation showed a decline of 59.18km^2 between the years of 1972-75 and 1980-82 as per the reports of National Remote Sensing Agency, India (1983). Later a decline of 40% of mangrove area was reported by MoES (1990), of which 26% is lost along east coast, 44% along west coast and 32% along Andaman and Nicobar islands (Jagtap et al., 1993; Naskar,2004).Sahu et al. (2015) reported mean annual change of 24.25 ± 82.57 km^2 of area based on the mangrove area reported by Forest Survey of India since 1987-2013.Except Andhra Pradesh and Andaman and Nicobar islands, most of the other states displayed an increase in area due to initiation of various restoration programmes. The 2004 tsunami had a greater impact on mangroves of Andaman and Nicobar Island while various agriculture development activities led to the decline in mangrove in Andhra Pradesh. The mean annual increase in area was estimated to be 28.16 ± 50.58 km^{2}in Gujarat, 1.91 ± 11.14km^{2}in Maharashtra and 0.91 ± 1.57 km^{2}in Goa respectively (Sahu et al., 2015).

The main causes for degradation of mangrove forest are: developmental activities, aquaculture and agriculture expansion, unsustainable extraction of timber, over-grazing, pollution, natural calamities and climate change. The anthropogenic activities are the prime causes of degradation. The causes and extent of degradation also varied among each mangrove habitat. Even though Sundarban has not reported in reduction in mangrove cover over a long period of time (Giri et al., 2007), the ENVIS center (2004) identifies some of the major issues in this vegetation are increasing human pressure, conversions and over- exploitation of fisheries occurring along the localized parts of this vast ecosystem. Das et al. (l987) reported the larger extent of destruction of Hooghly- Matlah estuary due to aquaculture practices. Other major threats to the system are acidic soil (soil rich in pyrite being converted to sulphuric acid); pollution due to industrial discharge (Chaudhuri and Choudhury, l994); erosion and embankment. Erosion in estuarine mouths results in flooding of human settlement areas as result embankments are constructed which further reduces the water movement into the system. Greater reduction in population of *Nypa fruticans* and *Heritiera fomes* are reported due to reduction in fresh water entry (ENVIS, 2004).

The major reasons for mangrove degradation in Bhitarkanika mangroves are identified to be human pressure, conversion of paddy cultivation etc. (Ministry of Environment and Forests, India, l990) and for forest resources such as fodder, firewood, house and other construction materials (Chadha and Kar, 1999). They also reported greater extend of grazing activities in Mahanadi Delta, Balasore coast and Jagatshinghpur district, where the people shift to cattle farming after the crop harvesting period. Nearly 70,000 cattle are found along estuaries, feeding on mangrove vegetation especially *Avicennia* species. The local communities are greatly dependent on this protected area for firewood and household construction materials (stem and leaves of *Phoenix, Heritiera, Lumnitzera, Xylocarpus* and *Avicennia* etc.). Indian Space Research Organisation (l992) reported the clearing of large areas of mangroves for aquaculture purposes in the Hatamundia reserved forest. Both natural and anthropogenic threats are faced by mangroves of Andhra

Pradesh. Banerjee et al. (l998) the major natural factor as cyclonic floods, heavy siltation rates while reclamation for agriculture and aquaculture practices, felling for firewood and constructions and other developmental activities are the external human factors that causes damage to these mangroves. Banerjee et al., l998 reported the extraction of tons of mangrove would for coal production while Prasad et al. (l997) reported the conversion of mangrove lands to Casuarina plantation for salt manufacturing.

The mangroves of Gujarat are considered as most degraded mangroves and designated as "open scrub mangroves" by Blasco (l975).Gulf of Kachchh and Khambhat mangroves are subjected to heavy exploitation due to unsustainable extraction of firewood and over grazing. The changes in flow pattern of rivers due to construction of series of dams in various rivers has also affect mangrove vegetation in the state. Thivakaran (l998) also reports the damage due to oil pollution as another major threat. The state of Maharashtra was occupied by luxuriant mangrove vegetation till l670, but at present remains as the victims of rapid urbanisation. A large portion of mangroves are cleared for construction of roads (Bhosale and Mulik, 1991) and the remaining part is subjected to heavy pollution domestic and industrial effluents especially along the Thane and Mahim creek (Kadam, l992; Rao et al., l991).

Mangroves of Karnataka coast are not an exception to the aftermaths of human development. Pollution being the major cause in combination with tree felling, encroachment for agricultural or aquaculture operations has affected these mangroves. Even though mangroves of Pichavaram are well studied for a long time, almost 75% of the green cover had already been destroyed by now. Out of the remaining mangrove area only 10% has dense vegetation. Kathiresan (2002) opined that high salinity, low level of available nutrients and poor microbial counts are the major causes of the natural degradation while poor tidal flushing was highlighted as an important cause by M.S. Swaminathan Research Foundation, Chennai. Pichavaram mangrove forest is surrounded by 11 villages, colonized with more than 2000 families within 3km radius from the forest areas and the overexploitation of mangroves resources by the local communities is the major threat identified in this ecosystem (Kathiresan, 2000). The mangroves of Pichavaram and Muthupet areas face the problem of overgrazing especially during monsoon season during which the propagules are set. The propagules and young seedlings of *Avicennia* spp. are reported to be overgrazed by cattle in these regions, resulting in reduced regeneration. Ramachandran et al. (l998) reported localized degradation along the Andaman and Nicobar Islands (2,379 m^2 within 7 years). Even though land conversion for human settlements, agricultural; exploitation for fisheries, encroachment and tourism activities are evident in these ecosystems, the extent of anthropogenic activities is less compared to other mangrove habitats of India.

It is clearly evident in various study that the mangrove cover in India had undergone sever decline. However various natural calamities like storms, cyclones and tsunami has highlighted the importance of mangroves in protecting the coastal area. Understanding the value of mangroves, various conservation and restoration programmes are implemented with the involvement of local community. As a result around 4195.28ha of area has been restored along four states of South India namely; Andhra Pradesh (1,978ha), Tamil Nadu (840ha), Karnataka (1,244.5ha) and Kerala (134.78ha) during 2002-2006 period.

4.2.2 Mangrove cover of Kerala

At present, the mangroves of Kerala exist as discrete patches along the small pockets of backwaters which once extended more than 7,000 hectares (Ramachandran and Mohanan, l987). But a large portion of mangrove area in Kerala has been reclaimed for harbours, ports, prawn farming, coconut and rice cultivation (Silas, 1987) and the major reason for such extensive clearing is identified as result of increasing population pressure (Masteller, 1996). Due to lack of scientific knowledge of this ecosystem, they were always considered as waste land and breeding grounds for mosquitoes in most part of Kerala. This has resulted in large scale clearance for agriculture purpose especially for rice and coconut production. But the local people are unaware of the fact that the mangrove cleared lands become more acid sulphate rich soils which ultimately reduces the agriculture yield (Scott, 1989). Yet another example is the construction of Thanneermukkom barrage, to prevent seawater intrusion into the Vembanad estuary for paddy cultivation in the reclaimed lands resulting in reduces salinity in concomitant to the over-dominance of freshwater throughout the year. Subsequently the mangroves fringing the Vembanad estuary are severely affected.

The earlier reports highlighted dense mangrove vegetation along Kerala coast ~700km^2(Blasco, 1975; Ramachandran and Mohan, 1987). However due to extended human interferences the mangrove cover has drastically been reduced. Basha (1991) reported 1671ha of mangrove cover, spread over 10 districts of Kerala. Along the ten districts, Veli, Quilon, Kumarakom, Cochin, Chettuva, Nadakkavu, Edakkad, Pappinissery, Thalassery, Kunjimangalam and Chiteri, were identified as mangroves that requires conservation and rehabilitation(Suma, 1995).As per the reports of Kurien (1994) the mangrove cover has further been reduced to 1095ha. The studies by Forest Survey of India (FSI, 2017) shows that mangroves are facing large scale destruction and are greatly confined to river mouths and tidal creeks. The study also points out comparatively higher rates of destruction in the southern districts of Kerala than north. Based on remote sensing data and field observations Mohanan (1997) reported 4,200 ha of mangrove area. Forest survey of India has been mapping the mangrove area of Kerala since 1987. However in the study only the major dens mangroves of Kasaragod, Kannur and Ernakulam districts are considered. FSI reported negligible mangrove cover since 1987 to 2001. The mangrove cover of 8km^2 was observed in 2003 which showed a rapid decline to 5km^2 in 2005 (FSI, 2006). A gradual increase in mangrove cover was noticed in 2015 and the current area of mangrove in Kerala is 9km^2(FSI, 2017). Out of the 9km^2, 5km^2 is recorded as moderately dense and 4km^2 as open mangrove. Similarly the mangroves of Kasaragod, Kannur, Kozhikode and Malappuram were studied by Radhakrishnan et al. (2006) and reported approximately 3,500 ha of area.

Table 4.1 Review on district wise mangrove area (ha) in Kerala

Districts	1	2	3	4	5	6	7	8	9
Trivandrum	23	-	15	23	28	-	-	-	27
Kollam	58	-	15	58	-	-	-	-	53
Alappuzha	90	-	25	90	-	-	-	-	103
Kottayam	80	-	20	80	-	-	-	-	99
Ernakulam	260	89	250	260	600	200	200	200	615
Thrissur	21	41	25	21	30	-	-	-	40
Malappuram	12	-	100	12	26	-	-	-	37
Kozhikode	293	23	200	293	-	-	-	-	120
Kannur	755	939	3500	755	-	600	600	600	746
Kasaragod	79	-	50	79	315	100	100	100	110
Total (ha)	1671	1092	4200	1671	1100	900	900	900	1953

1. Basha (1991), 2.Kurien et al. (1994), 3.Mohanan (1997), 4. Muraleedharan et al. (2006), 5. Vidyasagaran & Madhusoodanan (2014), 6.FSI (2015), 7.Kerala Forest Department (2016), 7.FSI (2017), 8. Neethu & Harilal (2018).

The extent of mangrove vegetation was first reported by Basha in 1991 (Table 8.1). Out of the 14 districts of Kerala, he identified mangroves along 10 districts with highest area of mangroves under Kannur (755ha) followed by Kozhikode (293 ha) and Ernakulam (260 ha). Later Kurien et al (1994) studied mangroves along four districts and reported a considerably higher mangrove cover along Kannur (939ha) and Thrissur (41ha) compared to earlier reports. While there was a decline in mangrove cover in Ernakulam (89ha) and Kozhikode (23ha) districts respectively. However the studies by Mohanan (1997) showed greater extent of mangrove area (4200ha) throughout the ten districts of Kerala. The data released by Muraleedharan et al. (2006) was centered upon the reports of Basha (1991). Later in 2014, Vidyasagaran and Madusoodanan reported 1100ha of mangroves along five districts, but missed out the largest chunks of mangroves along Kannur and Kozhikode districts. The reports by FSI were focused on only three districts and the remaining districts were marked with spares and negligible open mangroves. However the most recent reports by Neethu and Harilal (2018) reported comparatively higher area of mangroves (1953ha).

Reviewing the earlier works very few reports are available on the mangrove vegetation cover throughout Kerala coast. Scanty reports are available on regional or localized areas of particular districts, especially of those with dense mangrove cover. Most of the open mangroves and fragmented patches are neglected and left unnoticed resulting in wide lacunae in mangrove studies of Kerala.

4.2.3 Zonation and various factors affecting zonation pattern

The zonation of intertidal habitats with thick vegetation usually exhibit bands of monospecific vegetation occurring parallel to shoreline. While in narrow mangrove belts, definite zonation pattern cannot be marked along the shoreline and a mosaic pattern may be displayed. Distinct spatial pattern of mangroves on a global scale were studied by many scientists (Davis, 1940; Macnae, 1968; Lugo and Snedakar, 1974; Chapman, 1976; Matthijs et al., 1999; Sorrell et al., 2000 and Krauss et al., 2008). Still debates are ongoing regarding the underlying causes for distinct zonation patterns exhibited by mangroves. Davis (1940) opined that the succession pattern of individual species of mangroves results in specific zonation pattern. But this hypothesis was not accepted by many (Macnae, 1966; Bunt and Stieglitz, 1999; Upadhyay et al., 2007 and Hinrichs et al., 2009) and they opined that there is no general pattern exhibited by mangroves and it exhibits different patterns based on the various factors such as strong freshwater influences. This hypothesis was not investigated for Kenyan mangroves and was questioned by McKee (1993) and Youssef and Saenger (1996). The coastal mangrove forests of Tanzania along the east coast of Africa exhibit typical zonation pattern (Walter, 1971) whereas in Mozambique a clear zonation is not evident (Macnae and Kalk, 1962). Classical zonation was first described by Davis (1940) along southwest Florida, but many of the extensive dwarf mangroves of southeast Florida lack this zonation pattern and a randomly intermingled clustering was observed by Snedaker and Stanford (1976). Saenger et al. (1999) studied the zonation of mangroves in Mobbs Bay, Australia in relation to the physicochemical characteristics of the substrate and canopy cover. He identified three environmental gradients influencing the zonation pattern of mangrove species in low salinity sites. Canopy cover, height above the water table and sulphide concentration in the sediments were the three gradients which either alone or in combination influenced the zonation. He also suggested that the cumulative interaction between these gradients and tolerance limits of each species to these gradient resulted in the specific segregation of species.

Most of the early works from the western hemisphere were based on land building role of mangroves and suggested that the zonation is the spatial expression of plant succession. Curtiss (1888) described the land formation by *Rhizophora mangle* gradually laying foundation for other species. Similarly many other investigations were carried out on the land building role of the *R. mangle* by Harshberger, 1914; Harper, 1917 and Davis, 1940. Later Savage (1972) stated that *Avicennia germinans* exhibited similar land building and stabilization property as that of *Rhizophora mangle.* But these descriptions lacked scientific information on general ecology due to insufficient field and experimental work to verify their conclusions. Davis (1940) identified the existence of zones within a mangrove habitat with a forward zone leading into the sea thus it cannot be considered as a climax forest or an association. He opined that mangrove vegetation is composed of a number of seral communities arranged in fairly definite zones with the pioneer community of Rhizophoracean members to the tropical forest climax association. During the course of succession, *Rhizophora mangal* was considered to be the pioneer species to build and colonize new land (primary succession). The arching prop root system traps the debris and soil to which the viviparous propagules are laid (Curtiss, 1888). The development of these propagules leads to further accretion of soils (Davis, 1940) which severs as the substratum for the *Avicennia germinans*. The plant succession basis for explaining the zonation was considered logical and scientifically appealing. Chapman (1976) gave the most definitive syntheses of successional zonation.

Lugo (1980) opined that various factors such as sea-level rise/fall, topography, sedimentation rate and tidal energy results in steady-state migration of mangroves towards or away from the sea. Even though, coastal geomorphology play a major role in development of mangroves and may possibly be the reason for regional differences in zonation patterns but it could not provide a satisfactory explanation for the intertidal zonation patterns. Thus other hypotheses such as dispersal dynamics, seed predation, physiological tolerance and interspecific competition were more acceptable as it offer clear explanations for mangrove zonation. In addition to zonation, species richness, canopy height, basal area, tree density, age/size class distribution and understory development are also characteristic features attributing to the mangrove forest structure. Based on size and composition in mangroves of Florida, Lugo and Snedaker (1974) defined six mangrove forest types: riverine, overwash, fringe, basin, scrub and hammock. This classification was broadly accepted and it reflected differences in geomorphology and hydrology. Tomlinson, 1986 reported that various factors such as temperature, tidal amplitude, rainfall, catchment area, freshwater seepage and frequency of cyclones influence the species richness in that particular habitat. Ball, 1998 opined that the zonation patterns shows difference depending on geographic location of river, seasonal rainfall patterns, catchment size and the response of the species to salinity gradients. *Rhizophora mucronata* is found toward the seaward zone and are absent towards the high salinity landward zone as they prefer soft, water-saturated substrate with low salinity soil (Macnae and Kalk, 1962).

Davis (1940) and Smith (1992) studied the zonation patterns in many geographically different regions and reported that the difference in zonation patterns is influenced by the large variation in species composition. The patterns in Florida and the Caribbia, shows that *R. mangle* (red mangrove) occupy the seaward zone, followed by *A. germinans* (black mangrove) and *L. racemosa* (white mangrove) in the most landward position. While a contrasting pattern can be observed in northeastern Australia (Queensland). Here the pattern is much more complex due higher number of species and shows reverse from that in Florida with *Avicennia* spp. in the seaward position and *Rhizophora* spp. in the landward position. Local scale variations in mangrove zonation can also be identified along estuaries in response to differences in freshwater input. Davis, 1940 proposed that the zonation reflects the land building and plant succession in that particular habitat. But this view was not accepted by many as the evidence shows that mangroves respond to coastal propagation rather than causing succession (Thom 1967). However Woodroffe (1982) and McKee and Faulkner (2000) opined that mangroves play a major role in building land vertically in sediment-poor environments by the deposition of organic matter. The geomorphology (the geological and physical factors) such as the river flows, tides and waves play a major role in the formation, overall structure and zonation pattern of mangrove habitats (Thom, 1982; Semeniuk, 1985; Woodroffe, 1992).

The presence/ absence of understory species are yet another structural characteristic of mangrove forests. Most of the herbaceous plant species do not grow under the closed canopy in the mangrove forests due to salinity, flooding stresses and low light penetration. Usually the understory is formed in open canopy and is mainly composed of mangrove seedlings and juveniles. The mangrove zonation patterns were studied by many during the course of time: Van Steenis, 1957 (Indonesia); Macnae, 1968 (East Africa); Macnae, 1969; Bunt, 1982; Elsol and Saenger, 1983 (Australia); Johnstone, 1983 (Papua New Guinea); Gallin et al., 1989 and Beeckman et al., 1990 (Gazi Bay, Kenya); Amarasinghe and Balasubramaniam, 1992 (Sri Lanka); Ruwa, 1993 (Kenyan open coast) and so on. Macnae (1966) studied the zonation pattern of Eastern Australia and identified six zones parallel to shore, namely landward fringe, landward *Avicennia, Ceriops* thickets, *Bruguiera* forests, *Rhizophora* forests, seaward fringe (*Avicennia* and *Sonneratia).* Such patterns were also identified by Bunt and Williams (1981) along the mangrove of open coasts but were not common in riverine forest as well as more variable and complex intertidal environments. The variation in tidal inundation, salinity and other edaphic factors across the intertidal region was responsible for mangrove zonation pattern (Snedaker, 1982 and Smith, 1992). While the partial influence of various biotic factors on zonation pattern was explained by Ball, 1980 and Smith, 1987. Quantification or statistical testing of mangrove zonation patterns was also done by Dale, 1999. Smith, 1992 studied the mangroves of Indo- West Pacific and identified the occurrence of *Aegiceras, Avicennia* and *Sonneratia* towards lower intertidal zones; *Bruguiera* and *Rhizophora towards* mid-intertidal areas; *Heritiera, Xylocarpus* and numerous other species in the higher intertidal regions. Matthijs et al., 1999 studied the relationship between soil redox state, sulphide concentration, salinity and spatial patterns of mangrove species distribution along the mangroves of Gazi Bay (Kenya). The effects of mangrove zonation and the physicochemical parameters of soil in the macro benthic faunal distribution along the mangroves of Kadolkeel, Srilanka were studied by Navodha and Upali (2014). Joao et al. (2014) studied the mangroves of Santos, Brazil. The mangrove forest occupies 71km^2 with *Rhizophora mangle, Avicennia schaueriana* and *Laguncularia racemosa* as dominant species. The study demonstrates the structural diversity of the forest, but no specific zonation pattern was identified by the author. Sinfuego and Buot, 2014 studied the mangrove zonation and its utilization by local people in Ajuy and Pedada Bays, Philippines. All the ten plots studied were grouped into four zones based on the dominant species and the species richness in the Panay Island was low.

The zonation of Indian mangroves were studied by Rao and Sastry 1972; Blasco, 1977 and Singh et al., 1986. Dagar et al. (1991) and Singh and Garge (1993) studied the mangroves of Andaman and Nicobar islands and used the terms proximal, middle and distal zones for describing the zonation patterns. Mohanan, 1997 also studied the zonation patterns in mangroves and reported that the species with large propagule size are the early colonizers occurring towards the water front region while the smaller propagules are drifted towards more interior. Kannupandi and Kannan, 1998 studied the mangroves of Pichavaram and reported mixed vegetation of larger trees of *Rhizophora* and *Avicennia* species. Blasco et al. (1992) studied the species distribution in Sundarban mangroves in response to flooding. The mangroves of Sundarbans were also studied in detail by Chaudhuri and Choudhury (1994) and Hussain and Acharya (1994) but their works emphasized more on the species composition and the possible relationships between them and the physical environment, while lacked detailed information on zonation patterns. While the use of remote sensing technology by Choudhury et al. (1994) resulted in better understanding of forest structure. The zonation pattern of Sundarban mangroves were also studied by Aaron et al. (2000) and the analysis was based on elevation, salinity, physico- chemical characteristics of soil determining the species distribution. The zonation pattern with respect to the tidal amplitude were studied by Selvam and Karunakaran (2004) and opined that the area with higher tidal amplitude resulted in larger mangrove area. The tidal amplitude in Sundarban mangroves is about 4 to 5m receiving a macro tide during the spring tide thus the water penetrates up to 90 km from the shoreline resulting in larger area of mangroves in Sunderbans. While Pichavaram mangroves receive comparatively lower tide (64cm during spring tide) with limited tidal water penetration resulting in lower mangrove cover. Satyanaryana et al., 2002 studied the mangrove floristic and zonation patterns of Coringa, Kakinada Bay, East Coast of India and identified 15 true mangrove species, 6 associates and 6 marsh grasses. Yuvraj et al., 2017 studied the distribution and zonation pattern of mangroves in Shoal Bay creek in Andaman Islands and identified 2912.97ha of mangroves with varying distribution from small patches to dense forest types. The study reported the occurrence of various zones from the seaward to landward end such as seaward fringes, tall dense *Rhizophora*, *Rhizophora-Ceriops* dense, *Xylocarpus* mixed, *Bruguiera* clumps and landward back mangroves. Dense *Rhizophora* community (1688.72 ha) dominated the entire creek and exhibited strong zonation. The studies on Kerala mangrove reported from the past are mainly based on floral diversity and ecological aspects and very limited information are available on mangrove cover and zonation patterns.

4.3 Methodology

4.3.1 Distribution and zonation pattern

All Kerala floral survey along various mangrove habitats of Kerala was carried out to identify the species diversity, extent of mangrove cover and the major threat factors. Mangrove patches along 117 sites in ten districts, extending from Manjeswaram (12^0 42' 44″ N, 74^0 53' 14″ E) to Veli (8^0 30' 35″ N, 76^0 53' 25″ E) was analysed. The entire study area was divided into three zones: the northern zone (Kasaragod, Kannur, Kozhikode, Malappuram and Thrissur), central zone (Ernakulam, Kottayam) and the southern zone (Alappuzha, Kollam and Thiruvananthapuram). The detailed description of the study area is given in Chapter 2. Quadrat method was used to estimate different tree structural variables such as density (stems ha^{-1}), relative density, frequency, relative frequency and abundance (Cintron and Schaffer-Novelli, 1984). Five quadrats of the size 5mx5m ($25m^2$) were laid on each site considering the representatives and accessibility. The plant species were identified and counted to obtain the quantitative data. The zonation pattern were studied by laying line transects perpendicular to the water front as per the standard references of Lugo and Snedaker (1974) and Chapman (1975).

The structural variables such as density, relative density,

Density = Number of individuals of a species / ha.

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total no. of quadrats of occurrence}}$$

$$\text{Relative density} = \frac{\text{No. of individuals of a species} \times 100}{\text{Total no. of individuals of all species}}$$

$$\text{Percentage frequency} = \frac{\text{No. of quadrats of occurrence} \times 100}{\text{Total no. of quadrats studied}}$$

$$\text{Relative basal area} = \frac{\text{Basal area of the species} \times 100}{\text{Basal area of all species}}$$

4.3.2 Tidal Data

The tidal data were collected from the predicted astronomical tide: http://www.incois.gov.in/portal/osf/tide.jsp from Data and Information Management Group, Indian National Center for Ocean Information Services, MoES, Government of India. The high tide and low tide data were collected from various tide gauges maintained by INCOIS, throughout Kerala and pooled to obtain district wise average tidal data.

4.3.3 Mapping of mangrove area

The field sites along ten districts were selected with the help of a Global Positioning System (Magellan ® Triton 200/300) after collecting information from local administration. An approach was thus developed based on analysis of Landsat imageries for extracting mangrove forests area of the state. Multi-temporal medium resolution IRS P6 LISS III imagery was used to obtain comprehensive coverage and analysis of the current mangrove conditions. The imageries of the year 2017 were used for the study. All data were geometrically rectified to UTM coordinates using image-to-image registration. Rectification was based on a nearest neighbor resampling routine with less than one pixel root-mean-square error in all instances. Extracted data was cross checked with Google satellite images. The geometrically rectified images were then subjected to segmentation process based on three parameters; scale, colour and shape (Giri et al., 2007). After image segmentation, the data set obtained from the field survey was used to create training data for the classification of IRS LISSIII imagery. GIS tools were used to classify the mangrove cover of the study area. About 200 plus sample GPS locations used to creates digital signatures to extract the pixel values of the mangrove cover. All those GPS sample location were also used for ground truthing. The vectorised data was used to calculate the area of mangrove cover in Kerala. ERDAS software was employed for imagery processing.

4.3.4 Threat analysis

Even though mangrove destruction is evident in localised areas in all districts, the degree of mangrove loss (in area) could not be calculated as most of the sites lacked the scientific information on the past as well as current mangrove cover. Since no authentic reports are available for most of the mangrove sites, a descriptive research approach was carried out using SWOT analysis. The SWOT is the acronym of Strengths, Weaknesses, Opportunities and Threats (Pearce and Robinson, 1988). The analysis reflects the internal strength and weaknesses of a particular environment and various opportunities and threats faced by the system. The analysis included direct field observations, secondary data collection from various departments, published research as well as newspaper articles and direct questionnaire with local communities.

4.3.5 Data Analysis

Diversity indices are used to measure the changes in the diversity of a community. The software PRIMER v.6 (Clarke and Gorley 2006) was employed to compute the various indices as Shannon index (H’), Margalef index (d) and Pielou’s index (*J*’) and Simpson index (D).

i. Shannon index (Shannon and Weaver, 1963)

$$H' = \frac{3.3219(N\log - \Sigma ni - \log ni)}{N}$$

Where, H' = the species diversity in bits of information per individual

N = total number of individuals in the collection

ni = the proportion of individuals of each species belonging to the ith species of the total number of individuals (number of individuals of the ith species)

Σ = summation

ii. Margalef's index (Margalef, 1968)

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

Where, d = species richness

S = total number of species

N = total number of individuals

iii. Pielou's index (Pielou, 1966)

$j' = H'/\log_2 S$ or $H'/\ln_2 S$

Where, J' = evenness

H' = species diversity

S = total number of species

iv. Simpson's index (Simpson, 1949)

$D = 1/\lambda$

Where, $\lambda = \Sigma Pi2$

$Pi = ni/N$

Where, ni = number of individuals of i, i_2 etc.

N = total number of individuals.

4.4 Results

4.4.1 Distribution and diversity of Mangrove species in Kerala

The all Kerala floristic survey was carried out along 117 study sites along 10 districts, extending from Manjeswaram (12^0 42' 44″ N, 74^0 53' 14″ E) to Veli (8^0 30' 35″ N, 76^0 53' 25″ E). Altogether 18spp. of true mangroves were identified from the three zones, of which 15 spp. were present in Kollam, exhibiting highest species diversity, followed by Alappuzha district representing 14sp. Ernakulam district was marked with 13sp of true mangroves followed by Kannur and Kasaragod districts (12 sp.) respectively. Thiruvananthapuram represented least species diversity with only 3sp. of mangroves namely *Avicennia officinalis*, *Sonneratia caseolaris* and *Acrostichum aureum*.

The Shannon index showed a higher value for Kollam (3.749) followed by Alappuzha (3.715) and Kannur (3.52). Even though the mangrove cover in Kottayam was low compared to Thrissur, the district represented better species diversity with H'=3.23 (Table 4.2). The least value for Shannon index was observed for Thiruvananthapuram (1.442). Similar to the Shannon index, the Margalef species richness were also highest for Kollam (d'=3.219*)* and lowest for Thiruvananthapuram (d'=0.7035). Alappuzha (3.049), Kannur (2.966), Ernakulam (2.8) and Kasaragod (2.479) showed a decreasing trend in species richness. The Pielou’s evenness and the Simpson’s dominance also recorded higher values for Kollam (J’=0.9595, λ’=0.917) followed by Kannur (J’=0.9817, λ’=0.9074), ALP (J’=0.9759, λ’=0.9189), Ernakulam (J’=0.9724, λ’=0.9046) and Malappuram (J’=0.9614, λ’=0.8341) respectively. Thus the present observation indicates that Kollam, Alappuzha and Kannur districts represented better mangrove vegetation than other districts and Thiruvananthapuram district represents least diversity and richness with very sparse mangrove distribution.

Table 4.2 Diversity indices of mangroves in various districts of Kerala

Districts	S	H'	d'	J'	λ'
Kasaragod	11	3.224	2.351	0.9706	0.8859
Kannur	12	3.52	2.966	0.9817	0.9074
Kozhikode	11	3.305	2.479	0.9553	0.8866
Malappuram	7	2.699	1.576	0.9614	0.8341
Thrissur	9	3.039	2.068	0.9585	0.8673
Ernakulam	13	3.486	2.8	0.9724	0.9046
Kottayam	10	3.23	2.308	0.9724	0.887
Alappuzha	14	3.715	3.049	0.9759	0.9189
Kollam	15	3.749	3.219	0.9595	0.917
Thiruvananthapuram	3	1.442	0.7035	0.9097	0.5982

S No. of Species, *H'* Shannon index, *d'* Margalef species richness, *J' Pielou's* evenness, *λ'* Simpson's dominance

A clear differentiation in species distribution was observed along northern, central and southern regions of Kerala. Species like *Rhizophora mucronata, Avicennia officinalis, Acanthus ilicifolius, Acrostichum aureum, Excoecaria agallocha, Sonneratia caseolaris,* and *Kandelia candel* were common in all the three regions, but species like *Sonneratia alba, Lumnitzera racemosa, Bruguiera sexangula* and *Rhizophora apiculata* were found to be rare in occurrence. *Aegiceras corniculatum* and *Avicennia marina* species were abundant in northern region but were found to be very rare in central (Puthuvypin, Ernakulam) and southern Kerala (Ayiramthengu, Kollam). *Aegiceras corniculatum* was completely absent in central zone and was represented only at Ayiramthengu region of Kollam in the southern zone. Among the three species of *Bruguiera; B. gymnorrhiza,* was copiously seen in central Kerala, but was rare along northern and southern regions of Kerala. *Lumnitzera racemosa, Sonneratia alba, Excoecaria indica, Avicennia alba* and *Ceriops tagal* were the other rare species of Kerala. *Lumnitzera racemosa* was observed only in the Kasaragod district of northern zone; Alappuzha and Kollam districts of southern zone while was completely absent in the central part. On the other hand, *Excoecaria indica* was absent in northern zone and was recorded from Alappuzha in southern zone and Ernakulam and Kottayam in the central zone. Both *Avicennia alba* and *Ceriops tagal* had representations only in the Ayiramthengu and Thekkumbhagam islands of Kollam and completely absent in other regions.

4.4.2 Distribution pattern of Mangroves based on tree density

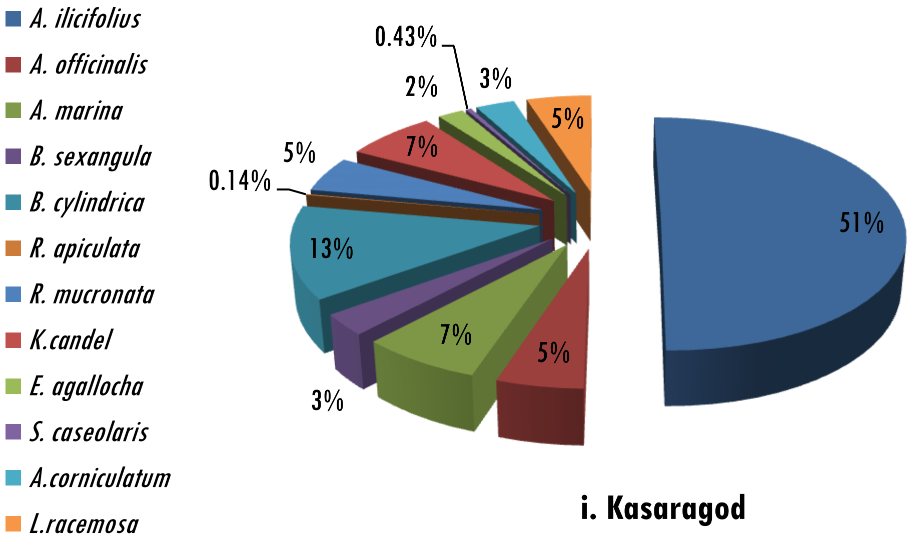
Avicennia officinalis marked their presence in all the ten districts, while the percentage of tree density was higher for *Acanthus ilicifolius* in all district except Thiruvananthapuram (Table 4.3). In Thiruvananthapuram, *Acrostichum aureum* represented higher percentage of tree density (93%).

Table 4.3 Distribution pattern of mangroves (% tree density)

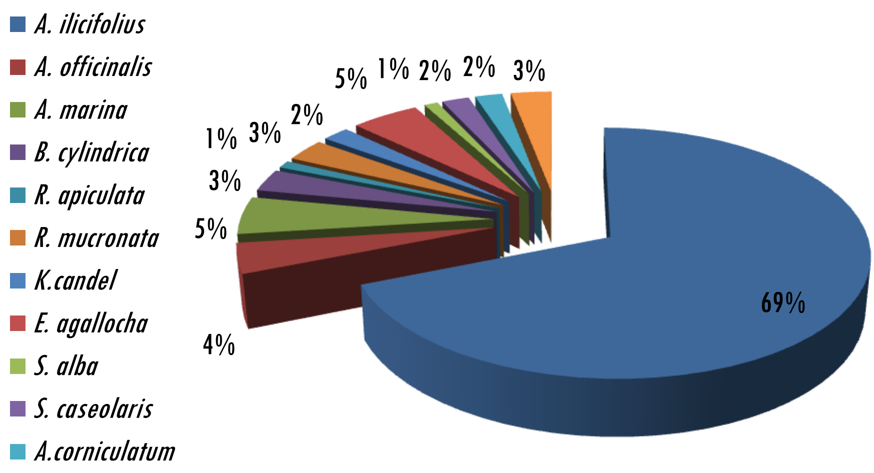
	Districts									
Mangrove Spp.	Kasaragod	Kannur	Kozhikode	Malappuram	Thrissur	Ernakulam	Kottayam	Alappuzha	Kollam	Thiruvananthapuram
Acanthus ilicifolius	51	69	70	72	67	50	27	63	54	-
Avicennia officinalis	5	4	6	9	16	6	1	2	1	6
Avicennia marina	7	5	2	-	-	0.1	-	-	26	-
Avicennia alba	-	-	-	-	-	-	-	-	0.32	-
Ceriops tagal	-	-	-	-	-	-	-	-	0.4	-
B. gymnorrhiza	-	-	-	1	-	3	4	2	0.08	-
B. sexangula	3	-	-	-	-	0.25	16	1	-	-
B. cylindrica	13	3	3	-	2	11	-	2	1	-
R.apiculata	0.14	1	0.12	-	-	0.4	2	2	2	-
R.mucronata	5	3	1	-	5	6	-	5	5	-
Kandelia candel	7	2	1	1	0.11	1	0.22	2	0.24	-
E.agallocha	2	5	5	3	3	14	3	4	3	-
E. indica	-	-	-	-	-	-	4	5	-	-
Sonneratia alba	-	1		-	-	0.7	-	0.01	-	-
S. caseolaris	0.43	2	0.36	5	1	0.4	2	3	0.08	1
Aegiceras corniculatum	3	2	1	-	1	-	-	-	0.56	-
Lumnitzera racemosa	5	-	-	-	-	-	-	2	2	-
Acrostichum aureum	-	3	11	9	5	7	41	7	0.03	93

i. Northern zone

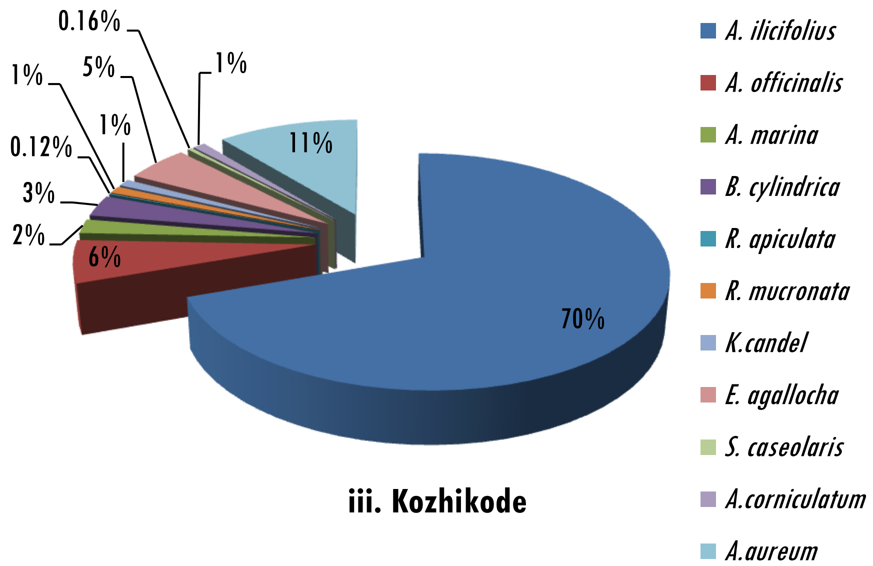
Kasaragod represented 10 mangrove species, of which *Acanthus ilicifolius* was most dominant species contributing 51% of tree density (Figure 4.3). *A. ilicifolius* was followed by *B. cylindrical* (13%), *A. marina* (7%), *Kandelia candel* (7%), *R. mucronata* (5%) and *A. officinalis* (5%) respectively. The least tree density was exhibited by *R.apiculata* (0.14%) and *S. caseolaris* (0.43%). Similar to Kasaragod, *A. ilicifolius* was most dominant species (69%) in Kannur followed by *A. marina* (5%) and *Excoecaria agallocha* (5%) and least density by *R.apiculata* (1%) and *S. caseolaris* (1%) (Figure 4.3, ii). Kozhikode and Malappuram had 11 and 7 species of mangroves respectively. The tree density of *A. ilicifolius* was marked higher in both districts with 70% (Kozhikode) and 72% (Malappuram). This was followed by *Acrostichum aureum* and *Avicennia officinalis* in both districts (Figures 4.3, iii & iv). *S. caseolaris* showed lower density in Kozhikode (0.36%) while it was much greater in MLPM (5%). Similar to other districts of northern zone, Thrissur also exhibited higher tree density for *Acanthus ilicifolius* (67%) followed by *Avicennia officinalis* (16%), *R. mucronata* (5%) and *S. caseolaris* (5%) respectively (Figure 4.3, v). Even though species of *Aegiceras corniculatum* and *Kandelia candel* were observed in the district, these species portrayed lower density (1%, 0.11%).



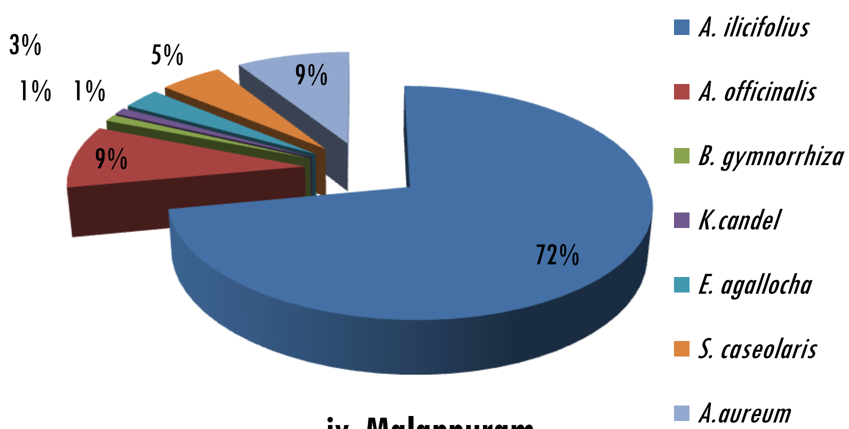
i. Kasaragod



ii. Kannur



iii. Kozhikode



iv. Malappuram

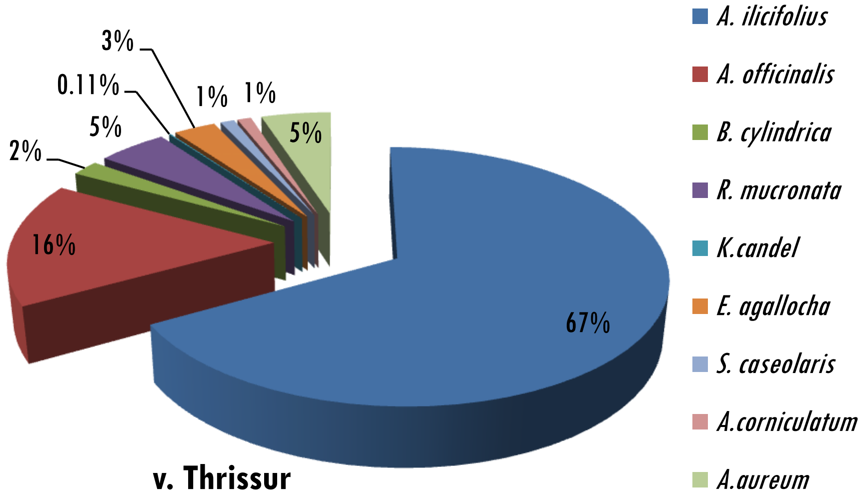
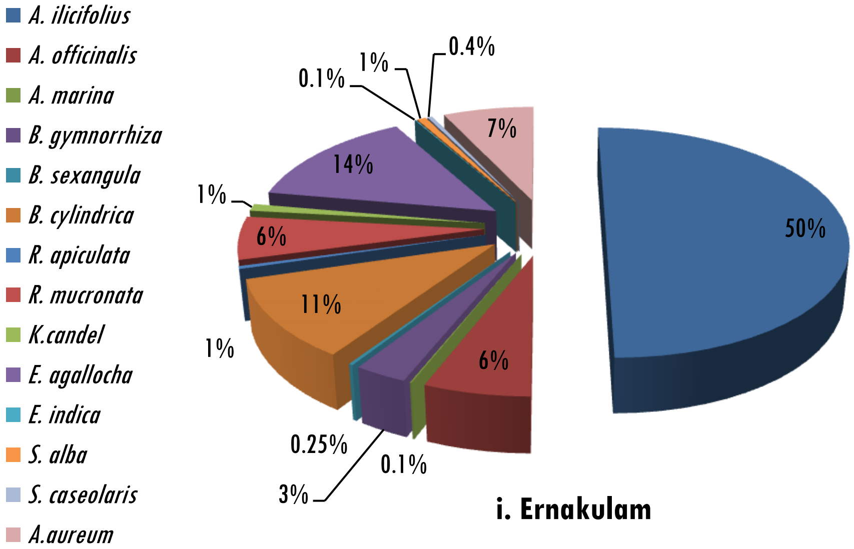


Figure 4.3 (i-v) Percentage tree density of mangroves in various districts of northern zone

ii. Central zone

Ernakulam and Kottayam districts representing the central zone had 12 and 10 species of true mangroves. *A. ilicifolius* (50%) marked the dominance in Ernakulam (Figure 4.4, i.) while *Acrostichum aureum* (27%) was dominant in Kottayam (Figure 4.4, ii). *E. agallocha* (14%), *B. cylindrical* (11%), *Acrostichum aureum* (7%) and *R. mucronata* (6%) followed the decreasing trend in tree density in Ernakulam. Species of *Avicennia marina* (0.1%) and *S. alba* (1%) were rare in Ernakulam while it was completely absent in Kottayam district. *B. sexangula* which was rare/ absent in other districts, marked higher tree density (16%) in Kottayam.



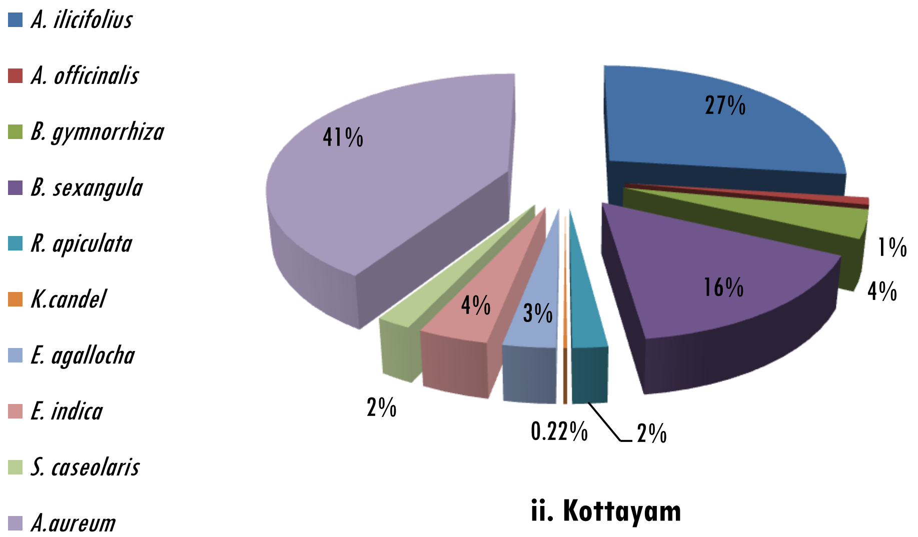


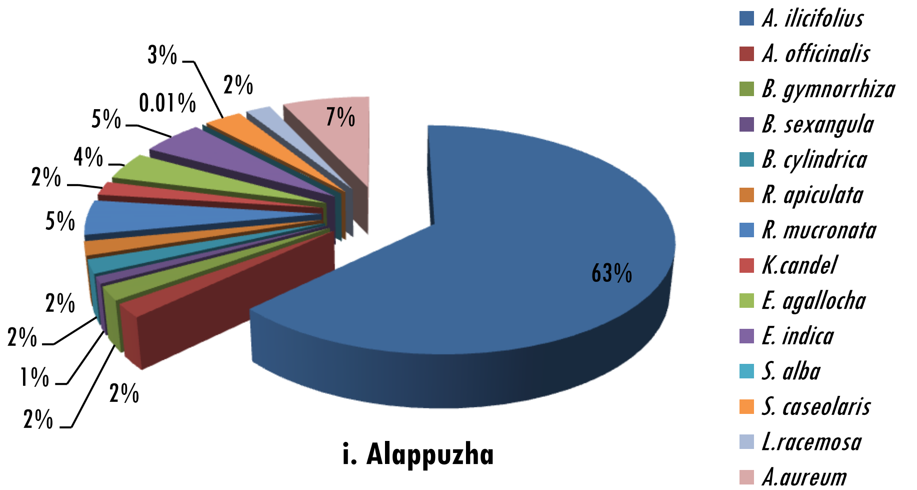
Figure 4.4 (i, ii) Percentage tree density of mangroves in various districts of central zone

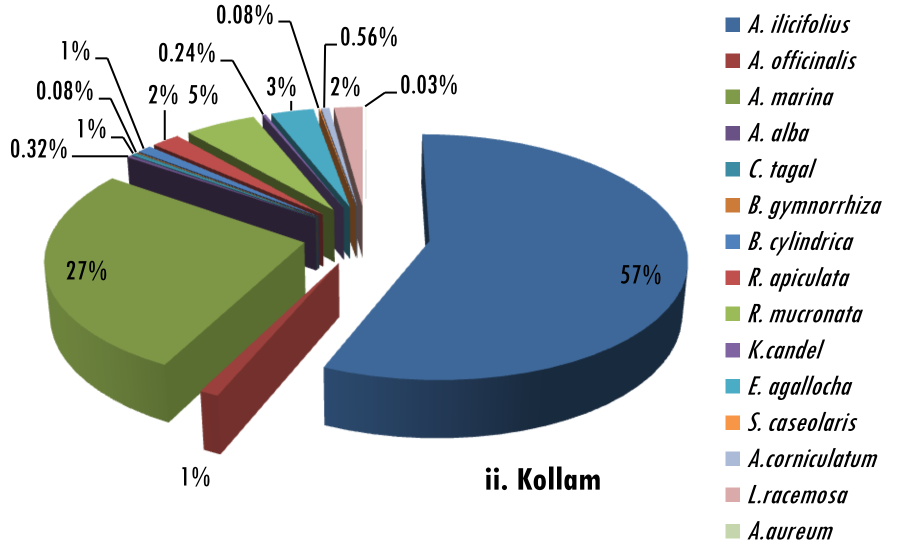
iii. Southern zone

The highest species diversity was observed in Kollam (15sp.) and Alappuzha (14sp.) districts of southern zone of Kerala. Alappuzha and Kollam districts marked the dominance of *Acanthus ilicifolius* (63% and 54% respectively) while the species was not observed in Thiruvananthapuram district (Figures 4.5, i, ii & iii). Many of the rare species like *Avicennia alba* (Kollam-0.32%), *Ceriops tagal* (Kollam-0.4%), *Bruguiera sexangula* (Alappuzha-1%), *Rhizophora apiculata* (Kollam-2%, Alappuzha-2%), *Aegiceras corniculatum* (Kollam-0.56%), *Lumnitzera racemosa* (Kollam-2%, Alappuzha-2%) exhibited lower tree density compared to their presence in northern zone.

4.4.3 District wise zonation pattern

In the present study, the zonation pattern varied from locality to locality as the mangrove stands were sparse and existed as isolated patches. Majority of the districts represented patchy mangrove vegetation except few stands in the shoreline from Mahe to Dharmadom, Pazhayangadi, Ezhimala, Payyannur, and Edakkad and so on. The district wise distribution and zonation pattern of mangroves are discussed below.





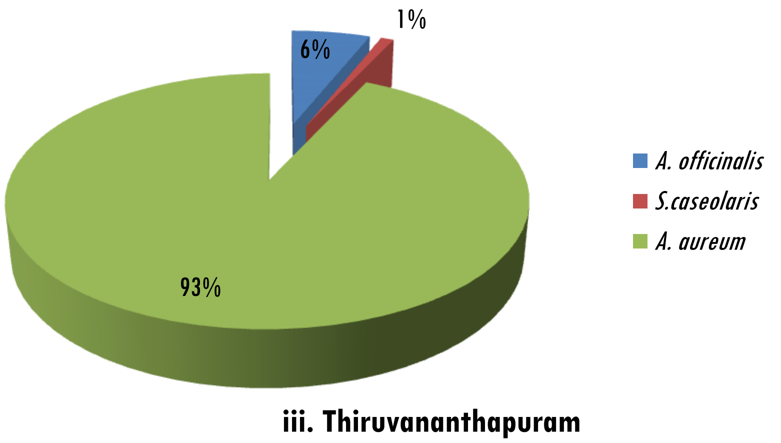


Figure 4.5 (i-iii) Percentage tree density of mangroves in various districts of southern zone

i. Kasaragod

Kasaragod district has better representation of mangrove species, even though the mangrove cover is comparatively less. The mangroves along twelve transects extending from Manjeswaram (12° 42' 44 ″N, 74° 53' 14″E) to Kavai (12° 5' 5 ″ N, 75° 10' 34" E) were studied (Figures 4.6- 4.10). Patchy and fringing type of mangroves were identified in all transect along Manjeswaram, Uppala – Muttom, Kumbala North, Kumbala South, Mogral puthur, Chandragiri, Neeleswaram, Achanthuruth, Kottapuram, Kariyamkodu, Edayilakadu and Kavai. The tidal range exhibited an average of 0.56m during low tide to 1.31m during high tide. All the 11 transects except Manjeswaram (coastal) were estuarine type with most of the mangroves confined to the upstream regions of Kayals of Kumbala, Mogral Puthur and backwaters at Pallam. Comparatively larger patches were observed along Pallam backwater and along the southern bank of Kumbala. *Acanthus ilicifolius* formed the most dominant under canopy stands followed by *Avicennia marina* and *Kandelia candel*. *Lumnitzera racemosa*, *Rhizophora mucronata* and *Avicennia officinalis* were the other dominant species in the district. Mogral puthur, Kariyamkodu and Edayilakadu area had occasional patches of *Aegiceras corniculatum* along the midstream regions.

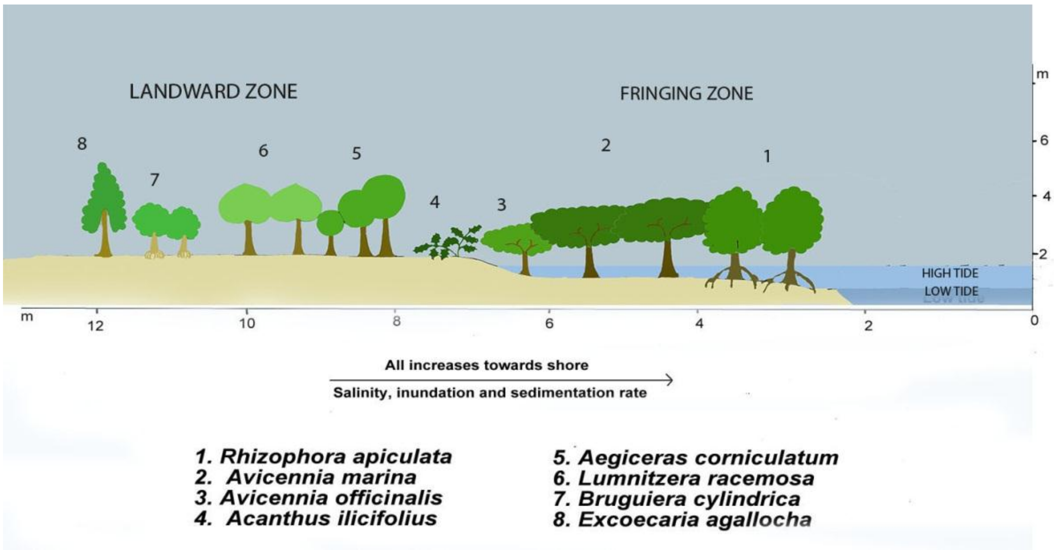


Figure 4.6 Zonation along the transect of mangrove vegetation of Edayilakadu, Kasaragod

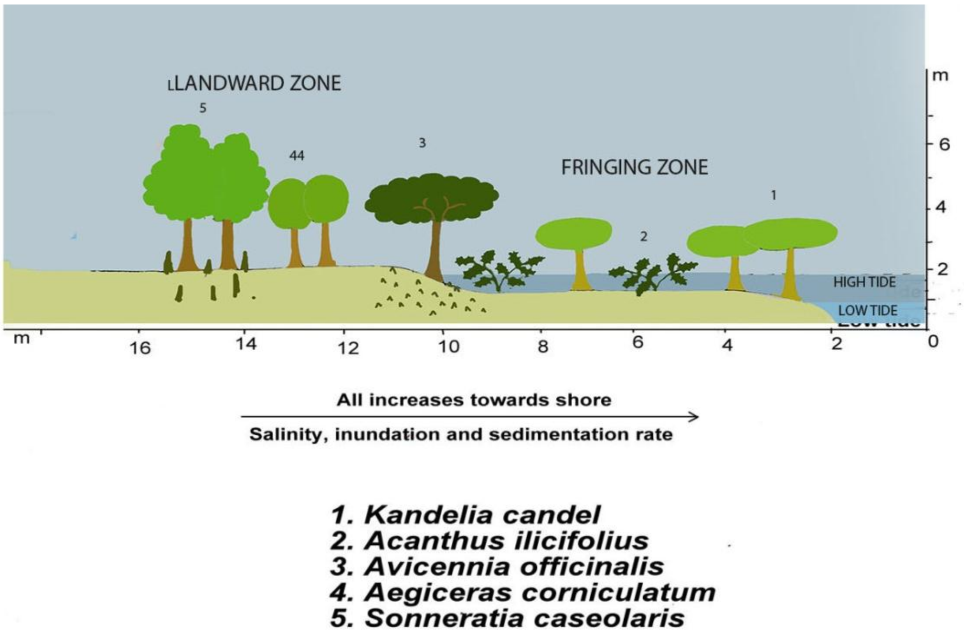


Figure 4.7 Zonation along the transect of mangrove vegetation of Kariyamkodu, Kasaragod.

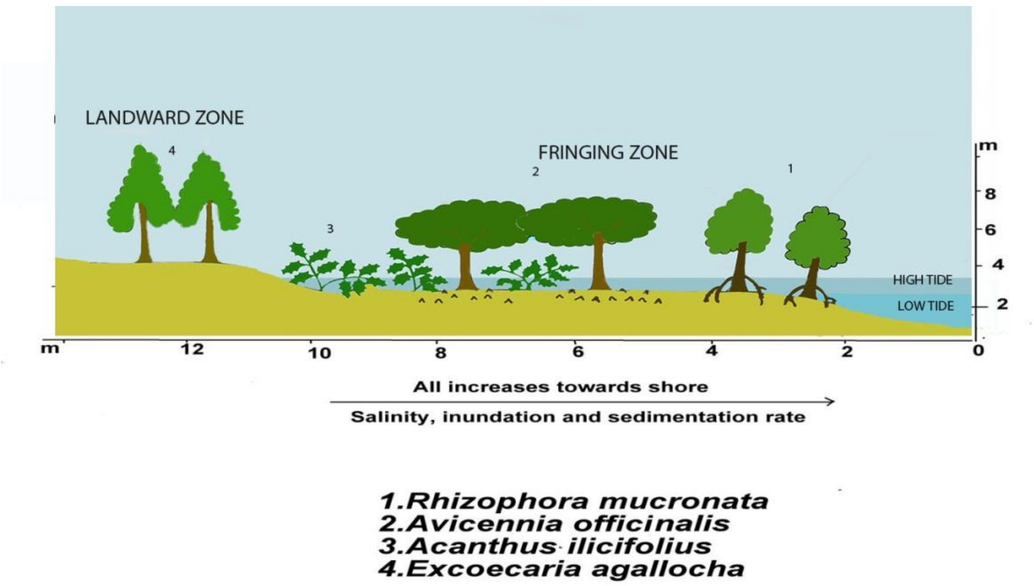


Figure 4.8 Zonation along the transect of mangrove vegetation of Kumbala, Kasaragod.

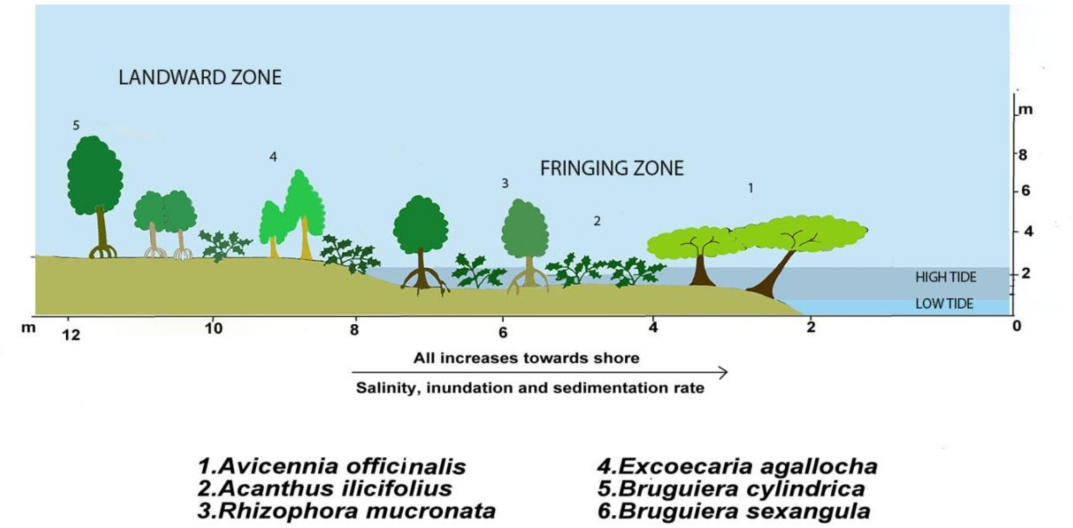


Figure 4.9 Zonation along the transect of mangrove vegetation of Manjeswaram- Kasaragod.

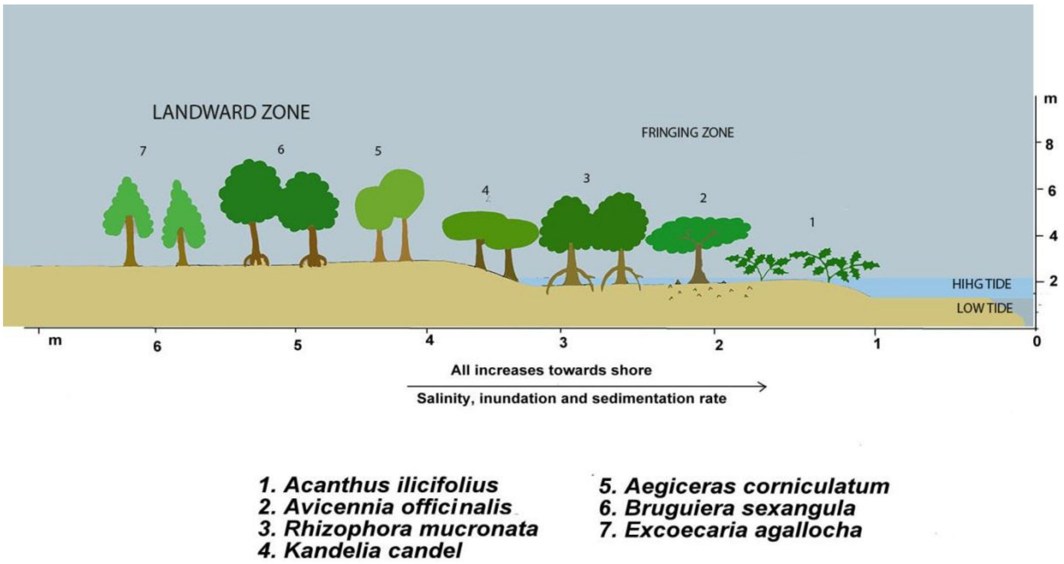


Figure 4.10 Zonation along the transect of mangrove vegetation of Mogral puthur, Kasaragod

The fringing, intermediate and the landward zones were replaced by different species in different sites along the district. *Rhizophora mucronata* occupied the fringing zone in most of the sites (Edayilakadu and Kumbala) while it was replaced by *Acanthus ilicifolius* in Mogral puthur, *K. candel* in Kariyamkodu and *Avicennia officinalis* in Manjeswaram. Species of *Bruguiera* (*B. cylindrical* and *B. sexangula*) and *E. agallocha* occupied the landward region along all the sites in the district. *Bruguiera sexangula* which was absent in other districts of northern zone was identified from the Manjeswaram and Mogral puthur regions. Mangroves of Edayilakadu, Kariyamkodu, Kumbala, Manjeswaram and Mogral puthur exhibited fringing type of mangrove forest. The degree of destruction of mangrove habitats were less in Kasaragod district compared to other parts of Kerala. However small scale destruction was seen in areas like Manjeswaram and Kumbala. Management and conservation programs of mangroves were also active in the district.

ii. Kannur

Luxuriant mangrove forests, almost 80% of the total mangrove forest cover of Kerala occurs in this district. Mangroves were spotted along 18 transects from Pazhayangadi (12° 1' 20"N, 75° 16' 4.36"E) to Korapuzha (11° 21' 20.19"N, 75° 44' 49.81"E). Out of the 18 sites studied, 14 sites were estuarine type (Pazhayangadi, Pappinissery, Valapattanam, Ramapuram, Chempallikundu/Vialapra, Ezhome, Perumba, Kandankali, Cherukunnu, Madakara, Thavam, Koduvalli, Thalassery and Korapuzha); 3 of the sited were landward type (Kunjimangalam, Edattu and Edakkad) and only Dharmadam was coastal type in nature. The average tidal variation ranged from 0.67m (low) to 1.36m (high).

Of the 18 true mangrove species identified during the present study, 12 species were present in this district. Even though the district is blessed with verdant mangrove diversity, the pattern of diversity was different from that of Kasaragod district. *Acanthus ilicifolius* was the dominant species followed by *Avicennia marina* and *Excoecaria agallocha.* Majority of the sites marked the presence of *Rhizophora* spp. and *Avicennia* spp. towards the fringing zone. *Acanthus ilicifolius* occupied the intermediate zone and gradually proceeded towards the landward region occupied by *B.cylindrica*, *Aegiceras corniculatum*, *Acrostichum aureum* (Chempallikundu, Cherukunnu Ezhome, and Pazhayangadi). While the landward region was mainly inhabited by *Sonneratia caseolaris* in Dharmadam, Koduvalli, Kunjimangalam and by *Kandelia candel* in Madakara. The extent of fringing zone was limited in Cherukunnu transect and exhibited more of landward zone inhabiting more number of mangrove species (Figure 4.12).

Mangroves of Dharmadam were coastal type, having an extended fringing zone occupied by species of *S. alba* and *R. mucronata* (Figure 4.13). The fringing zone gradually proceeded towards mixed zone of *A. marina, S. caseolaris* and *A. officinalis.* The landward transition was completely absent in this site. In Pazhayangadi, the fringing and landward zones were of lesser extend and an expanded mixed intermediate zone of *A. ilicifolius*, *Avicennia marina*, *A. officinalis* and *Aegiceras corniculatum* was evident (Figure 4.18). The transect of Edakkad, exhibited a mixed mangrove vegetation of *Acanthus ilicifolius*, *Avicennia officinalis* and *Excoecaria agallocha* occupying the landward regions (Figure 4.20). The fringing and intermediate zones were absent in this site. Mainly fringing mangrove forest were witnessed in most of the sites in Kannur district (Chempallikundu, Dharmadam, Ezhome, Koduvalli, Madakara, Pazhayangadi, Valapattanam and Thavam) while Edakkad, Cherukunnu, Kunjimangalam and Edattu exhibited Hammock type of mangrove forest.

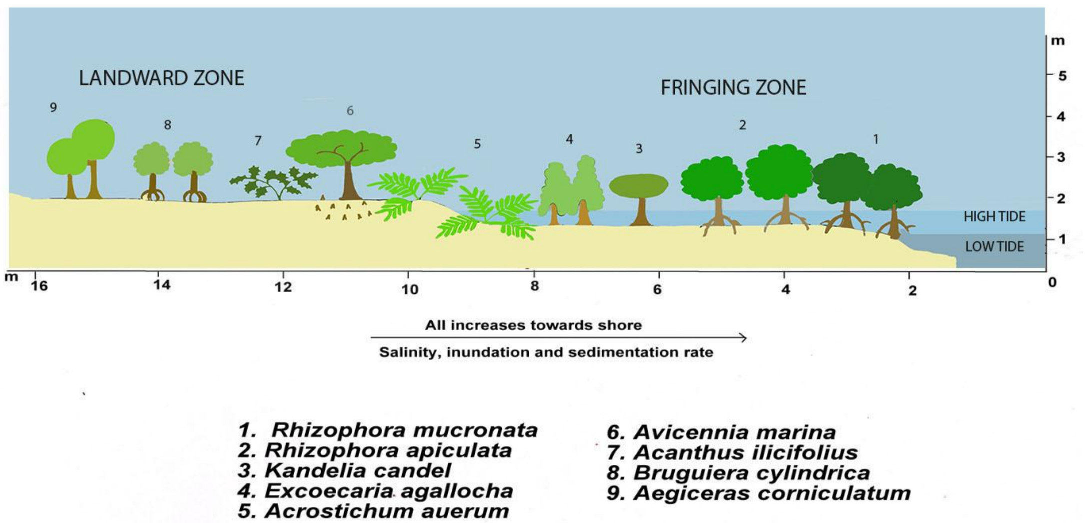


Figure 4.11 Zonation along the transect of mangrove vegetation of Chempallikundu, Kannur

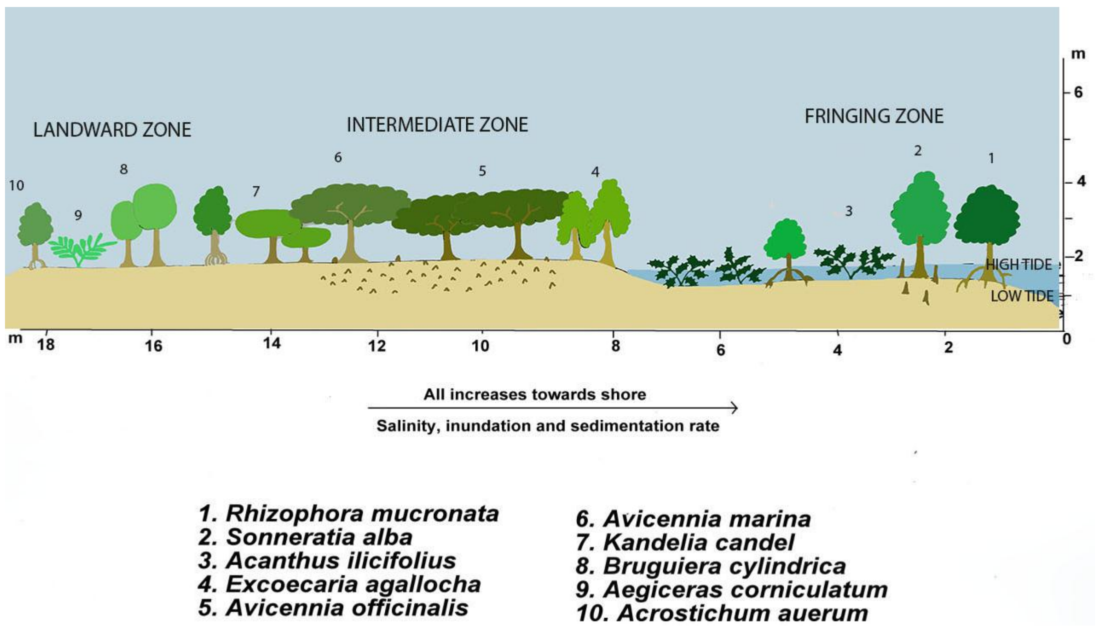


Figure 4.12 Zonation along the transect of mangrove vegetation of Cherukunnu, Kannur

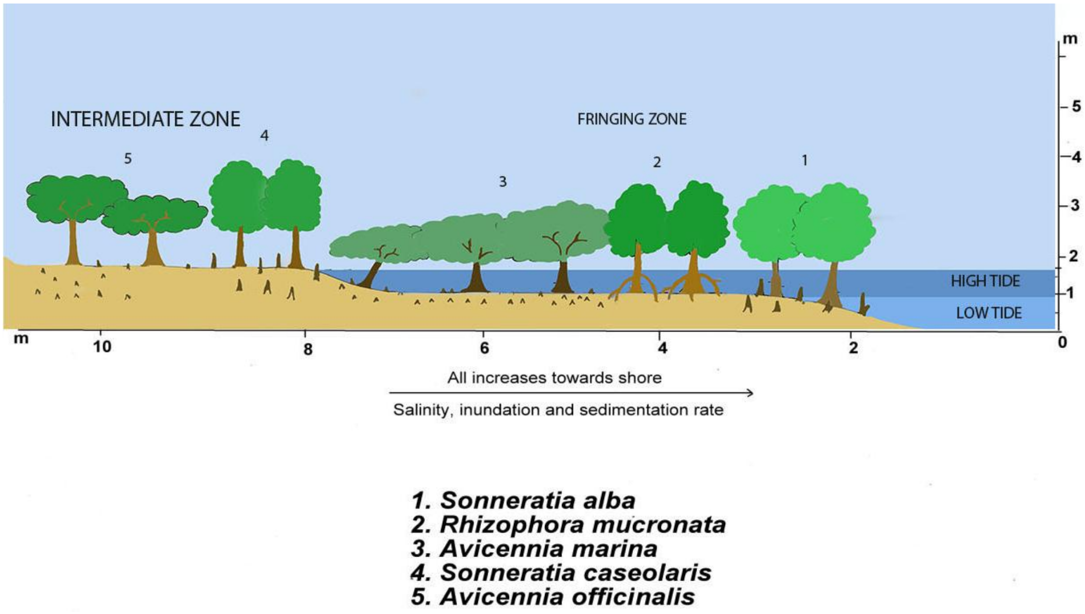


Figure 4.13 Zonation along the transect of mangrove vegetation of Dharmadam, Kannur

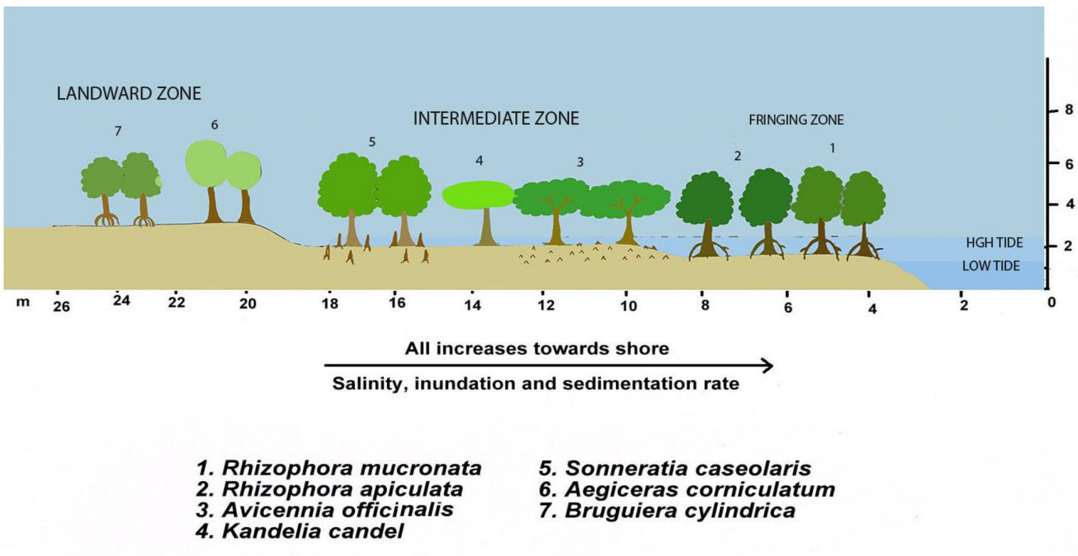


Figure 4.14 Zonation along the transect of mangrove vegetation of Ezhome, Kannur

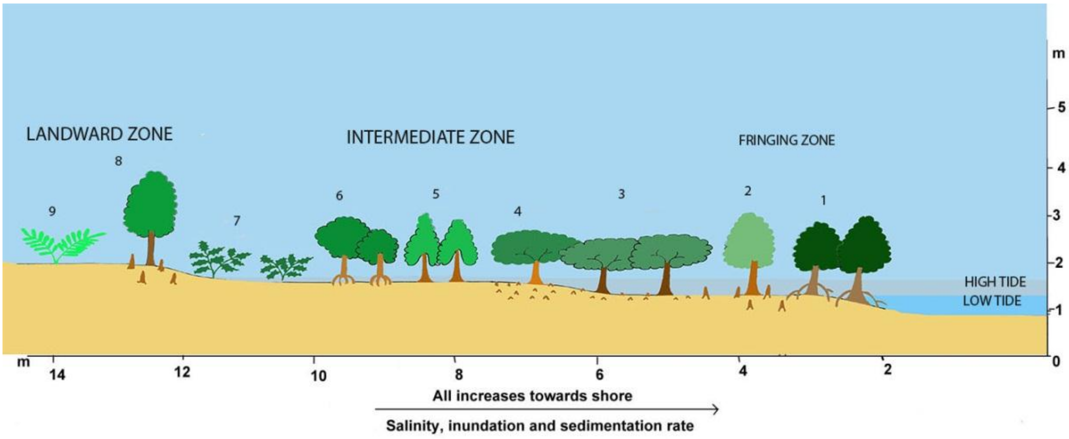


Figure 4.15 Zonation along the transect of mangrove vegetation of Koduvalli, Kannur

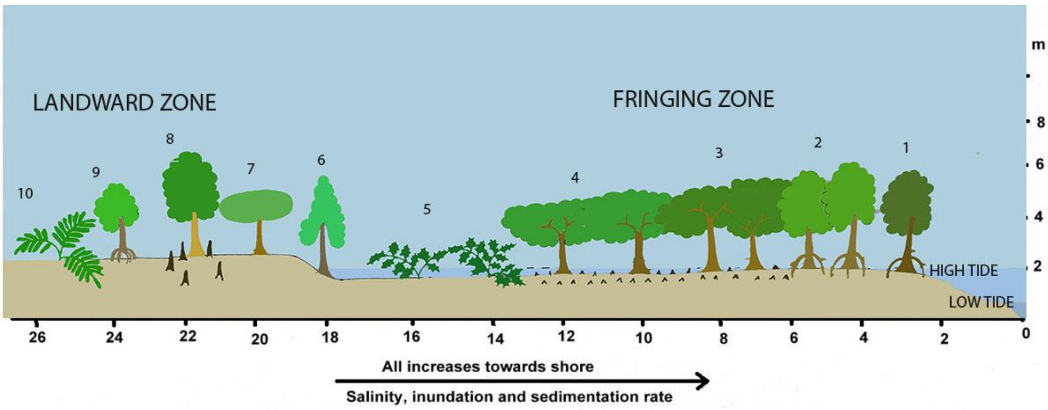


Figure 4.16 Zonation along the transect of mangrove vegetation of Kunjimangalam, Kannur

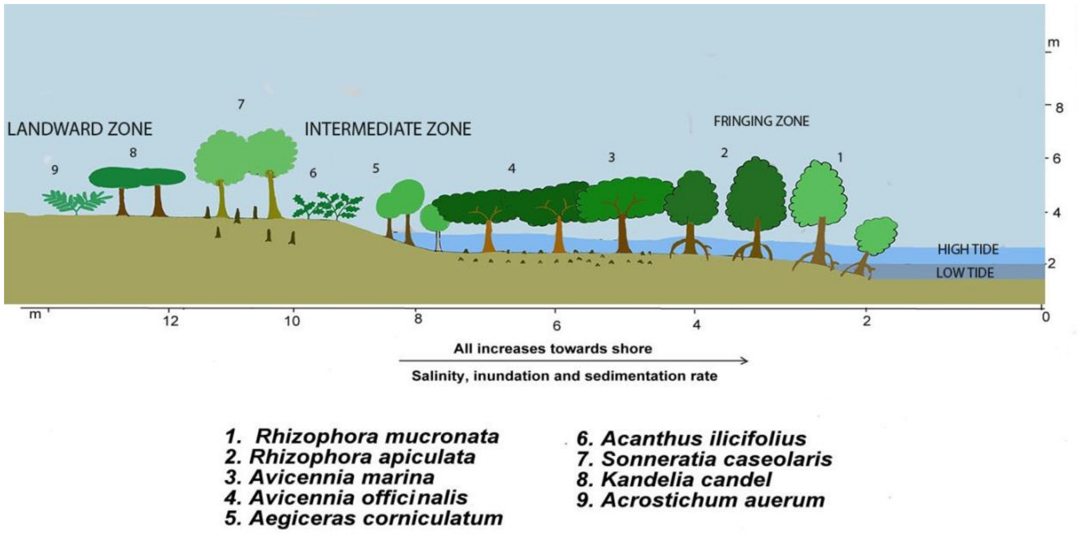


Figure 4.17 Zonation along the transect of mangrove vegetation of Madakara, Kannur

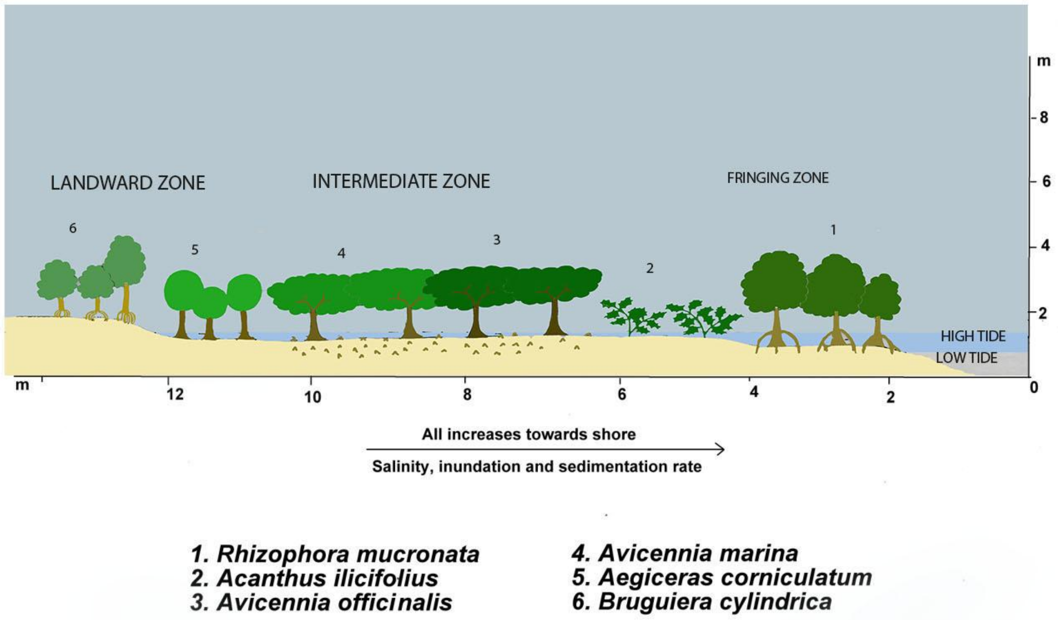


Figure 4.18 Zonation along the transect of mangrove vegetation of Pazhayangadi, Kannur

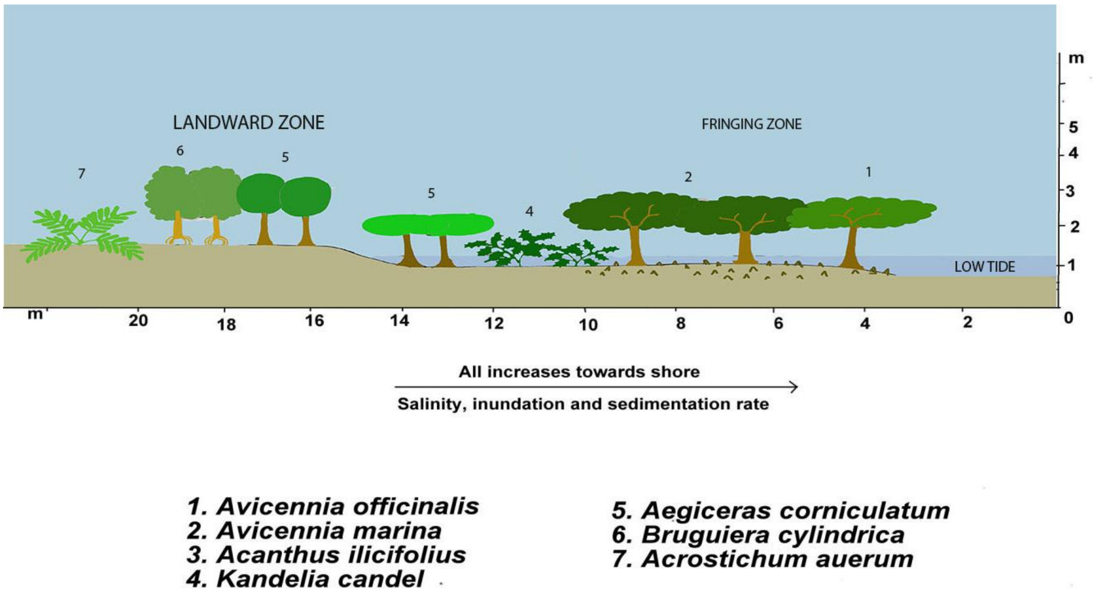


Figure 4.19 Zonation along the transect of mangrove vegetation of Valapattanam, Kannur

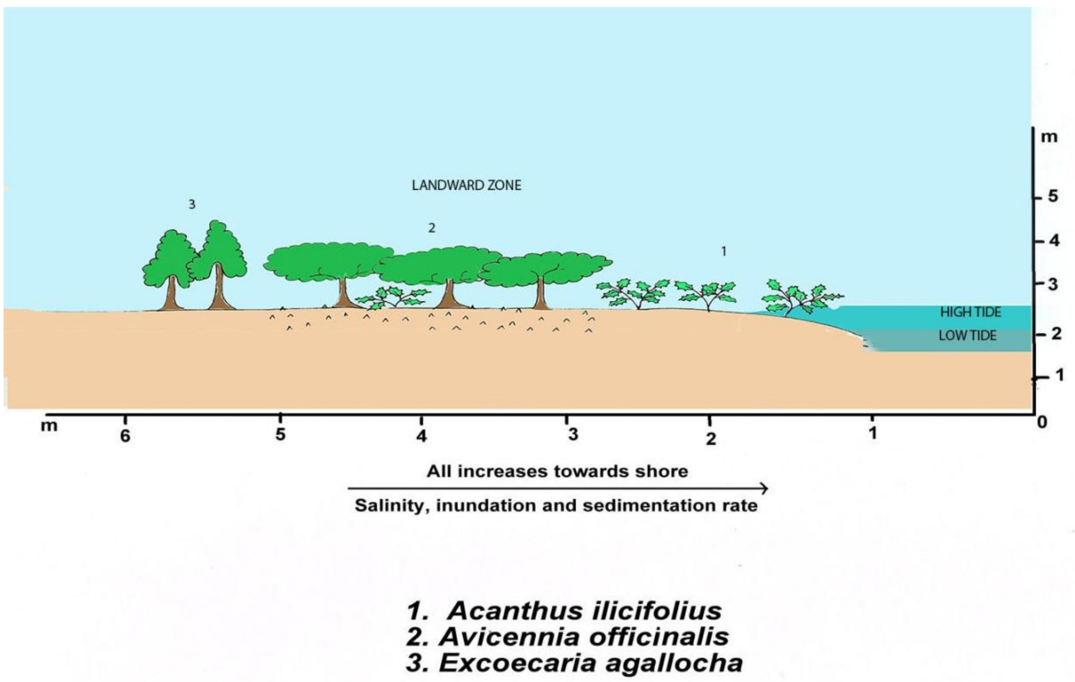


Figure 4.20 Zonation along the transect of mangrove vegetation of Edakkad, Kannur

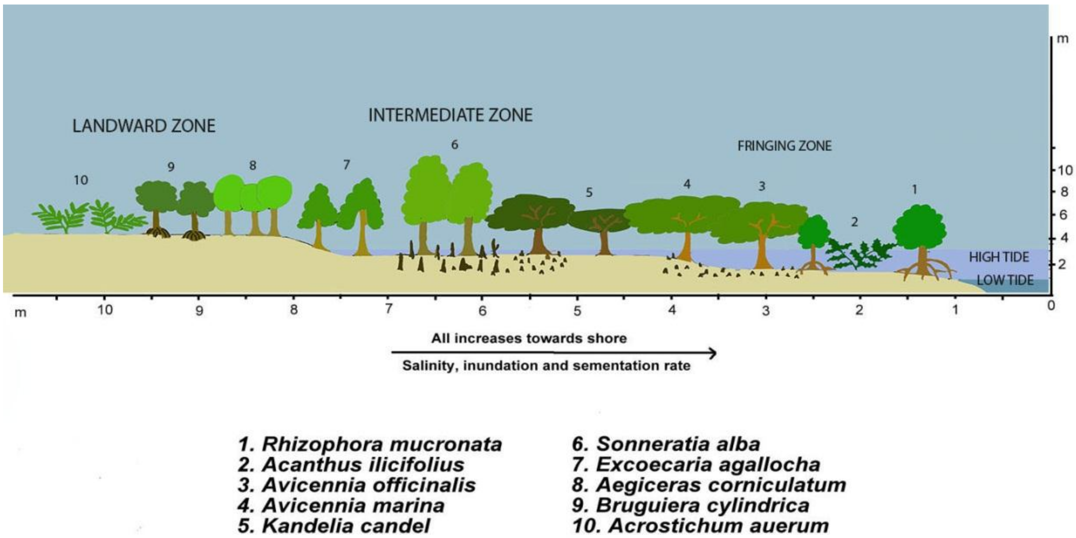


Figure 4.21 Zonation along the transect of mangrove vegetation of Thavam, Kannur

iii. Kozhikode

Kozhikode district had great extent of mangroves in the past which subsequently got degraded due to unscientific land use pattern and real estate activities. In the present floral survey mangroves were dotted along 8 transects extending from Chemancheri (11° 22' 42.20"N, 75° 44' 40.56""E) to Beypore (11° 11' 0.67"N, 75° 48' 59.04"E). Good patches of mangroves were observed along Beypore, Kallai, Koyilandi, Kolavipalam and Kadalundi regions where the tidal amplitude ranged between 0.59m to 1.27m. Estuarine type of vegetation was observed in Chemancheri, Atholi, Kallai, Koyilandi-Kanayamkodu, Koyilandi and Beypore while Kadalundi and Kolavipalam were coastal type of mangrove habitats.

Similar to Kannur district, *Acanthus ilicifolius*, *Acrostichum aureum* and *Avicennia officinalis* were found to be the proximal species while *Avicennia officinalis* and *Rhizophora mucronata* were the fringing species (Figures 4.22-4.25). However the species of *Avicennia officinalis* was replaced by *Sonneratia caseolaris* in the fringing zones of Kolavipalam along with *R. mucronata* (Figure 4.24). The *Sonneratia caseolaris* species was found gradually shifted to the intermediate zones in the transect of Koyilandi. Most of the transects exhibited an extended fringing zone (Kallai, Kadalundi, Koyilandi) with reduced intermediate and landward zones. The landward zones were mainly occupied by *Excoecaria agallocha*, *Bruguiera* *cylindrica* and *Aegiceras corniculatum* species and *Acanthus ilicifolius* along with *Kandelia candel* captured the intermediate zone. But *Acanthus ilicifolius* was completely absent in Kallai region. On the other hand the transect of Koyilandi marked broader landward zone than fringing zone. All the sites displayed a fringing type of mangrove forest.

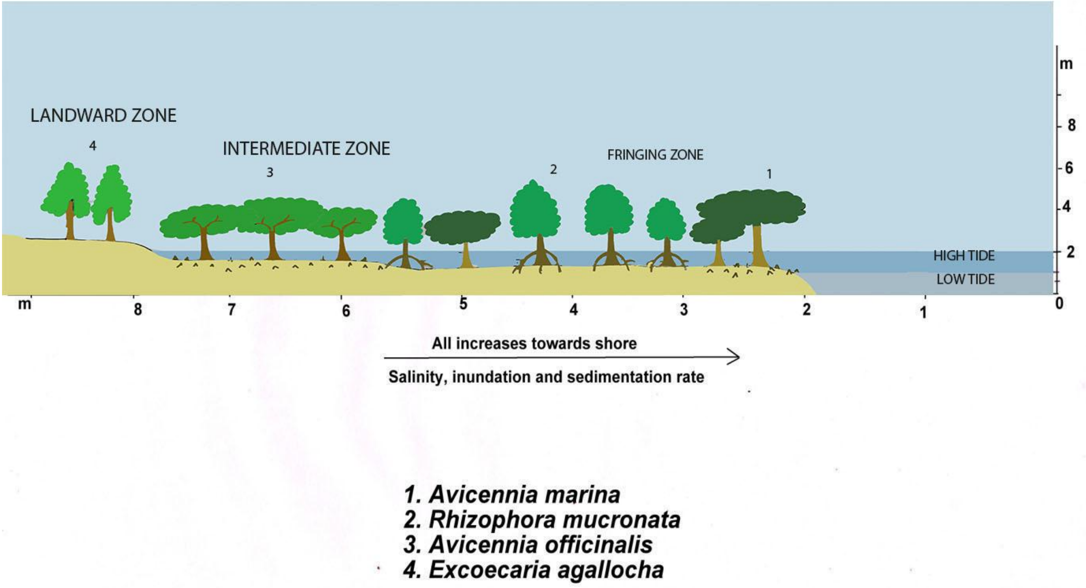


Figure 4.22 Zonation along the transect of mangrove vegetation of Kallai, Kozhikode

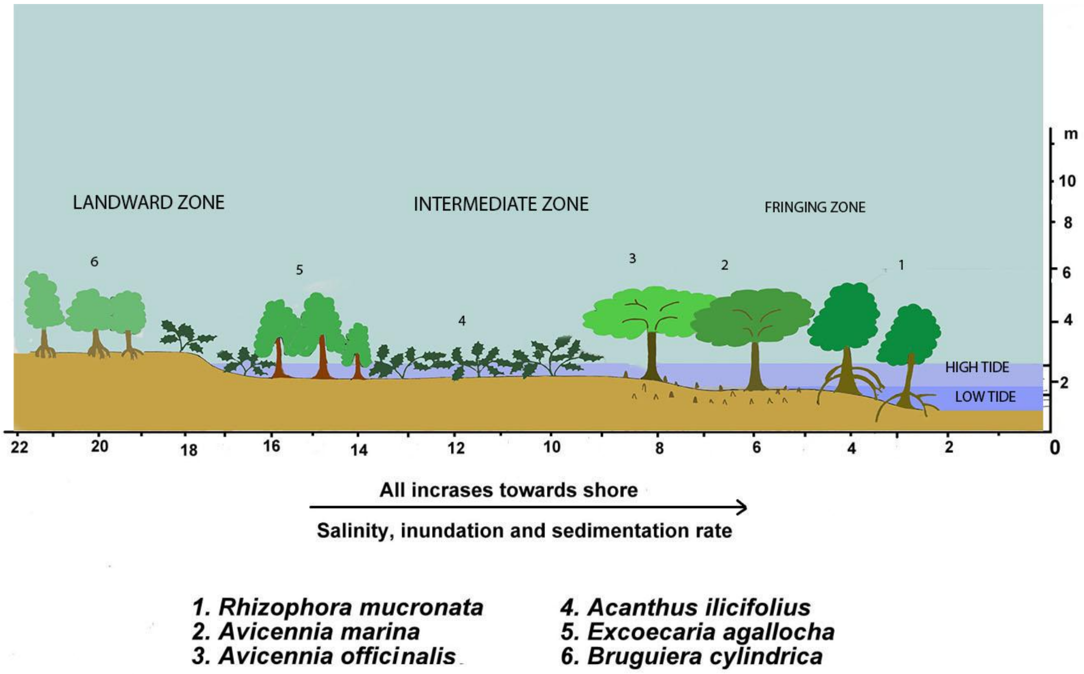


Figure 4.23 Zonation along the transect of mangrove vegetation of Kadalundi, Kozhikode

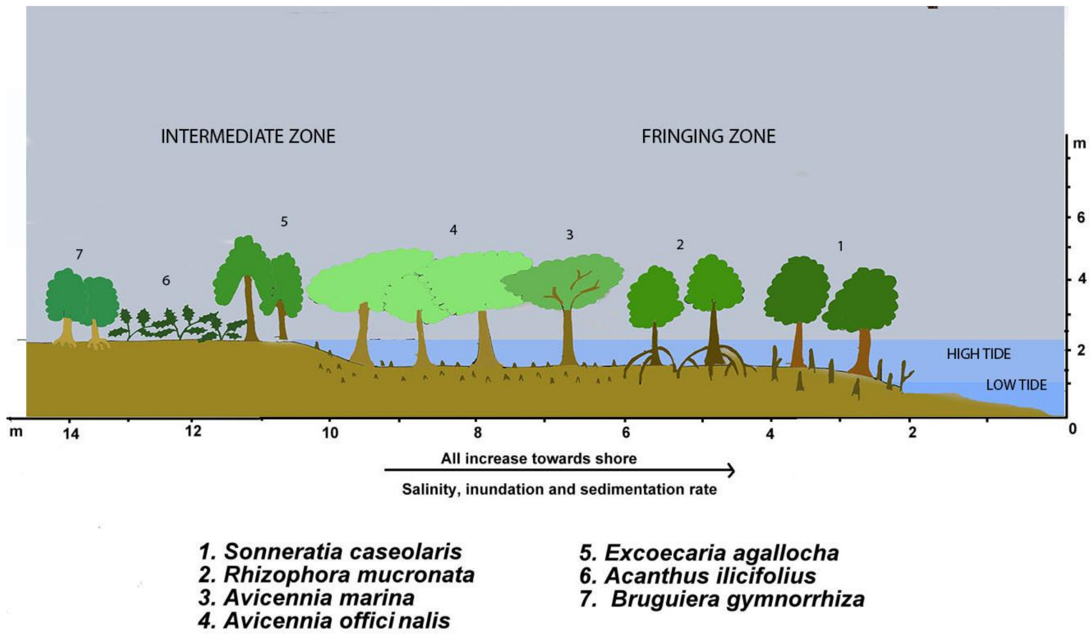


Figure 4.24 Zonation along the transect of mangrove vegetation of Kolavipalam, Kozhikode

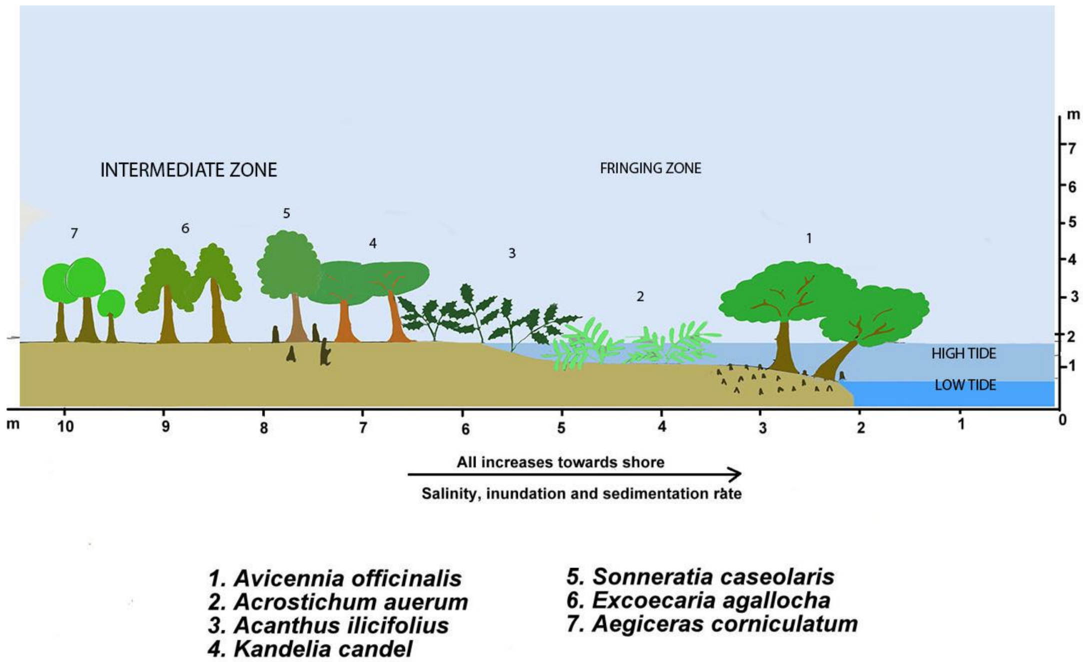
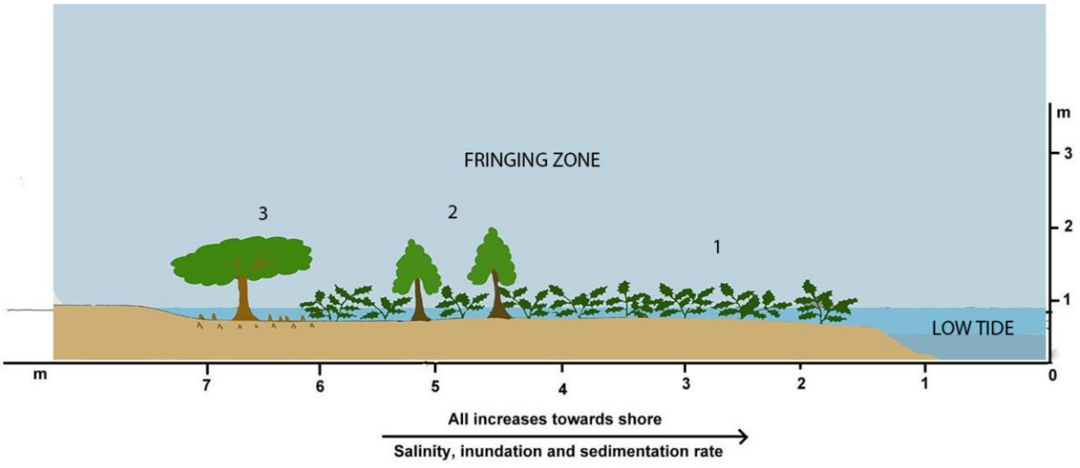


Figure 4.25 Zonation along the transect of mangrove vegetation of Koyilandi, Kozhikode

iv. Malappuram

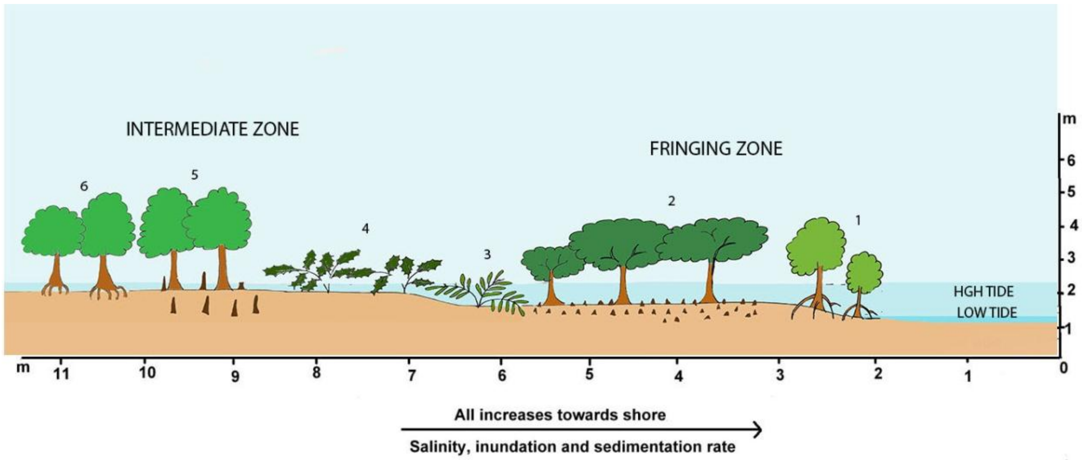
Mangrove cover in this district is less compared to other districts of northern zone. Better representation of mangroves can be seen in Kadalundi region (Kerala's first community reserve), a part of which is extended to Kozhikode district. Blotches of mangroves were found along 5 transects from Alathyur-Pullunni (10° 51' 34.27''N, 75° 55' 27''E) to Ponnani (10° 47' 01''N, 75° 55' 06''E), of which Pullunni of Tirur, Ponnani, Tanur and Thazhepalam had good mangrove cover. All the five transects portrayed an estuarine type of habitat with an average tidal range between 0.43m to 1.01m. Of the 7 species of true mangroves species identified from the district, *Acanthus ilicifolius* was the dominant species followed by *Avicennia officinalis*, *Acrostichum aureum* and *Sonneratia caseolaris.*

The species inhabiting the fringing zones were different in many of the transects (Figures 4.26-4.28). The fringing zones were occupied by *Acanthus ilicifolius* and *Excoecaria agallocha* in Ponnani, *Sonneratia caseolaris* in Mangateripalam while *Rhizophora mucronata* and *Avicennia officinalis* were seen in Pullunni. In Ponnani mangroves were present only in the fringing zone with *Acanthus ilicifolius* at the waterfront, gradually extending to a mixed vegetation of *Acanthus ilicifolius*, *Excoecaria agallocha* and *Avicennia marina*. On the other hand clear extension of fringing zone and intermediate zones were visible in Pullunni and Mangateripalam. The intermediate zone was inhabited by *Acrostichum aureum, Sonneratia caseolaris* and *Bruguiera gymnorrhiza* in Pullunni, whereas it was replaced by *Acrostichum aureum* and *Kandelia candel* in Mangateripalam. The landward expansion of mangrove species was not evident in the study sites and all were fringing type of mangroves.



1. *Acanthus ilicifolius*
2. *Excoecaria agallocha*
3. *Avicennia officinalis*

Figure 4.26 Zonation along the transect of mangrove vegetation of Ponnani, Malappuram



1. *Rhizophora mucronata*
2. *Avicennia officinalis*
3. *Acrostichum auerum*
4. *Acanthus ilicifolius*
5. *Sonneratia caseolaris*
6. *Bruguiera gymnorrhiza*

Figure 4.27 Zonation along the transect of mangrove vegetation of Pullunni, Malappuram

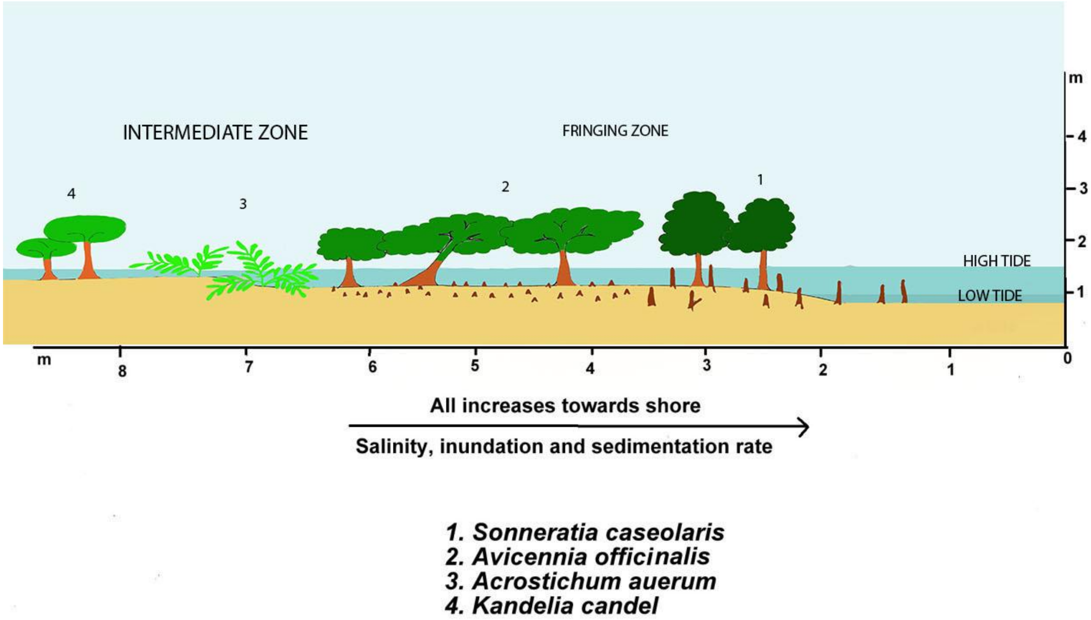


Figure 4.28 Zonation along the transect of mangrove vegetation of Mangateripalam, Malappuram

v. Thrissur

Chettuva, Kodungallur and Azhikode are the major estuaries supporting mangrove vegetation in Thrissur district. Majority of the mangrove vegetation had been degraded during the course of time and at present patchy distribution of mangroves can be seen near backwaters of Chettuva, Kodungallur, Poyya, Anapuzha and Mullassery. Nine species of true mangroves were identified along 8 transects extending from Chettuva (10° 32' 10"N, 76° 0' 19" E) to Anapuzha (10° 12' 38"N, 76° 12' 55"E). Chettuva, Mullassery-Idiyanchira, Koshavankunnu, Poyya and Anapuzha displayed estuarine type of vegetation while landward mangrove vegetation was visible in Chapara, Pezhungadu-Vallivatttom and Narayanamangalam. *Acanthus ilicifolius* was the most dominant species followed by *Avicennia officinalis* and *Rhizophora mucronata*.

In Poyya, mangroves were found only in fringing zone while intermediate and landward zones were absent (Figure 4.29). The fringing zone exhibited a mixed vegetation of *Acanthus ilicifolius* (at water front), *Sonneratia caseolaris, Avicennia officinalis, Kandelia candel, Aegiceras corniculatum* and *Acrostichum aureum* (towards land).The mangroves of Chettuva were much denser compared to other parts in the district. It exhibited an overwash type of mangrove forest dominated by

Rhizophora spp. (Figure 4.30). Species of *Bruguiera*, *Excoecaria* and *Avicennia* were also distributed within the system. Unlike the mangroves of Kasaragod and Kannur districts, *Aegiceras corniculatum* and *Acanthus ilicifolius* showed the preponderance in the fringing zone. However in Mullassery, *Aegiceras corniculatum* occupied the landward region and the fringing zone by *Rhizophora mucronata* and *Acanthus ilicifolius.* Fringing type of mangroves was evident in Poyya and Mullassery.

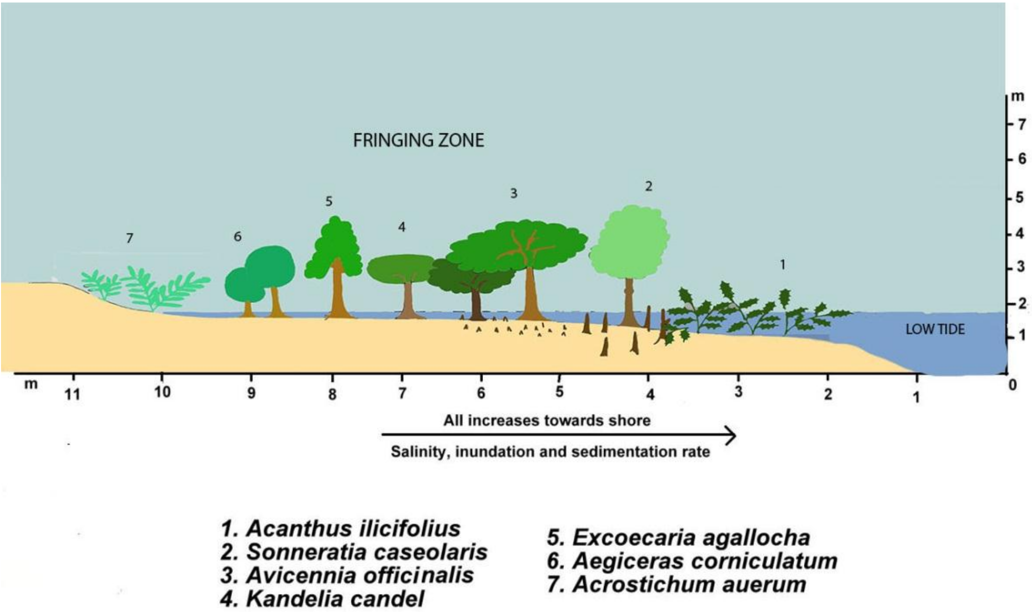


Figure 4.29 Zonation along the transect of mangrove vegetation of Poyya, Thrissur

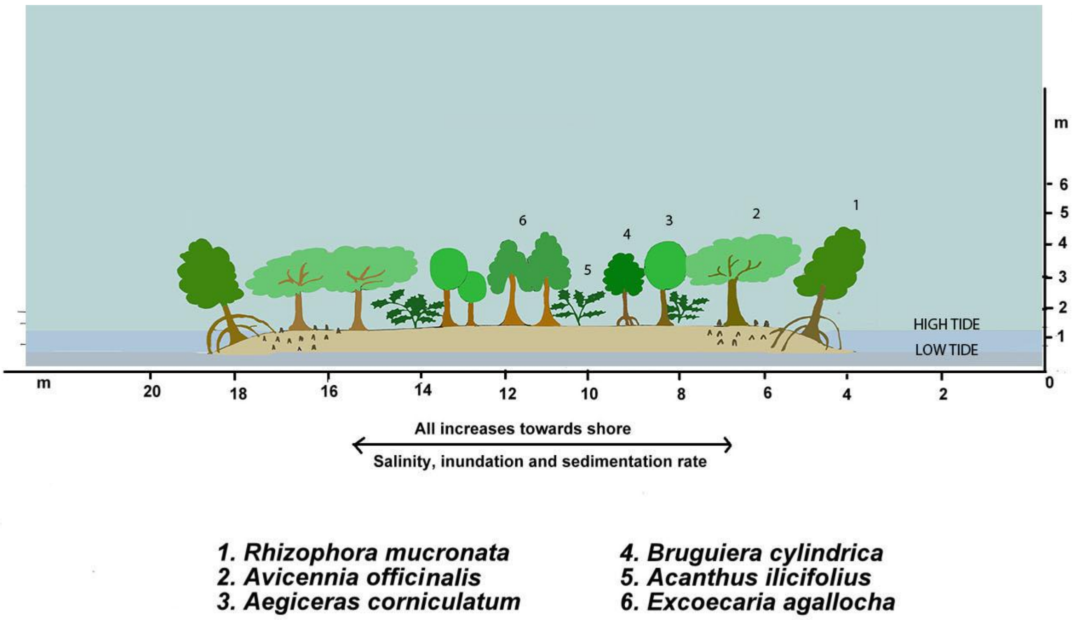


Figure 4.30 Zonation along the transect of mangrove vegetation of Chettuva, Thrissur

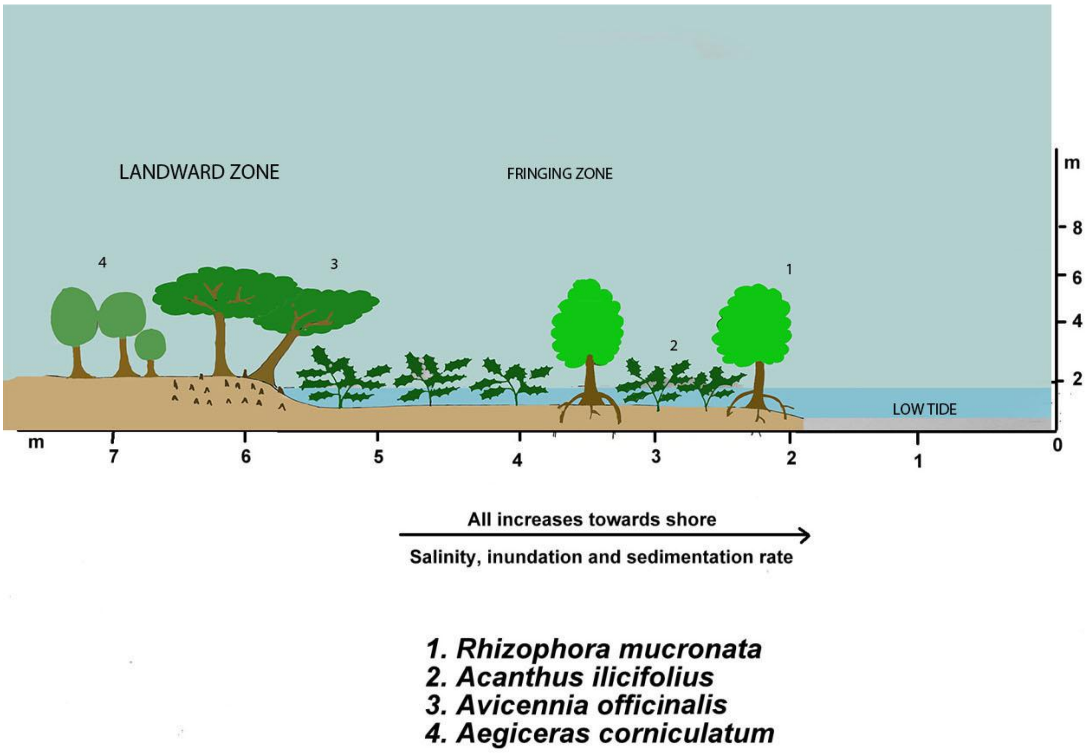


Figure 4.31 Zonation along the transect of mangrove vegetation of Mullassery, Thrissur

vi. Ernakulam

Ernakulam district occupy second highest extent of mangroves in the state after Kannur district. Mangroves were spotted along 21 transects extending from Kumbalangi (9° 51' 7"N, 76° 17' 36"E) to Panambukad (9° 59' 47"N, 76° 14' 51"E). Out of these 21 transects, 12 sites were estuarine (Kumbalangi, Panangad, Aroor south, Kumbalam, Thirunettur, Valanthakad, Sattar Island, Mulavukad, Vallarpadam, Edakochi, Mangalavanam and Panambukad); 7 sites were coastal type (Chellanam, Kannamali, Elankunnapuzha, Fisheries Research Station Puthuvypin, Cherai, Valappu and LNG Puthuvypin) and only Pallipuram exhibited landward vegetation type. The average tidal variation ranged from 0.49m during low tide to 0.82m during high tides.

Out of the 14 species of true mangroves identified *Avicennia officinalis*, *Excoecaria agallocha* and *Rhizophora mucronata* were the frequent species whereas *Rhizophora apiculata*, *Avicennia marina*, *Excoecaria indica*, *Sonneratia alba* and *Bruguiera sexangula* were found to be rare in the district. In general, the fringing zones were spotted with species of *Avicennia*, *Acanthus* and *Rhizophora* and landward zones with species of *Bruguiera* and *Excoecaria. B. gymnorrhiza*, *B. cylindrica* , *Excoecaria agallocha* and *Acrostichum aureum* were limited to the landward zone in all the sites while species like *Rhizophora mucronata*, *R. apiculata* and *Acanthus ilicifolius* were encountered only in the fringing zone and not found elsewhere (Figures 4.32-4.36). The intermediate zone was mainly occupied by *Avicennia officinalis, Sonneratia alba*, *S. caseolaris* and *Kandelia candel* which also marked their presence in the fringing zones in some sites. An exception to this general trend was noticed in Chellanam transect were *Excoecaria agallocha* were the dominant species in the fringing zone. Most of the habitat showed an extended fringing zone proceeding to landward zones with absence or reduced intermediate zones. Mainly three types of mangrove forest were identified in the district: Fringing mangrove forest (Chellanam, Puthuvypin, Kumbalanghi); Hammock forest type (Sattar Island, Thirunettur) and Overwash type (Valanthakad).

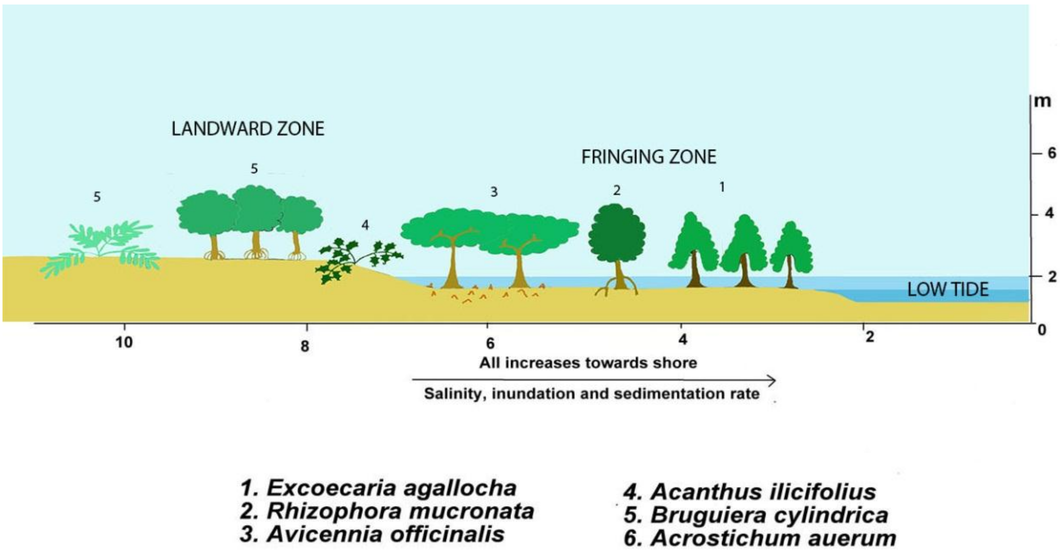
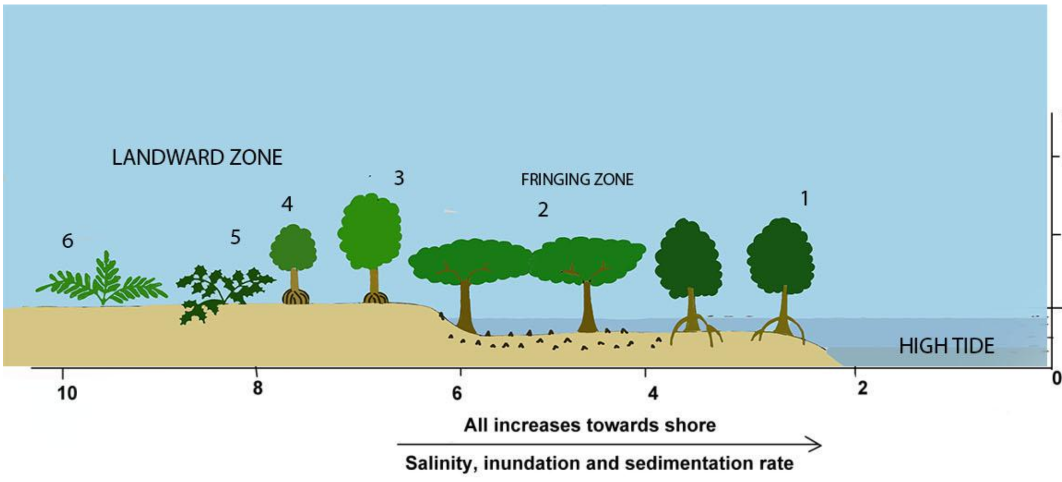
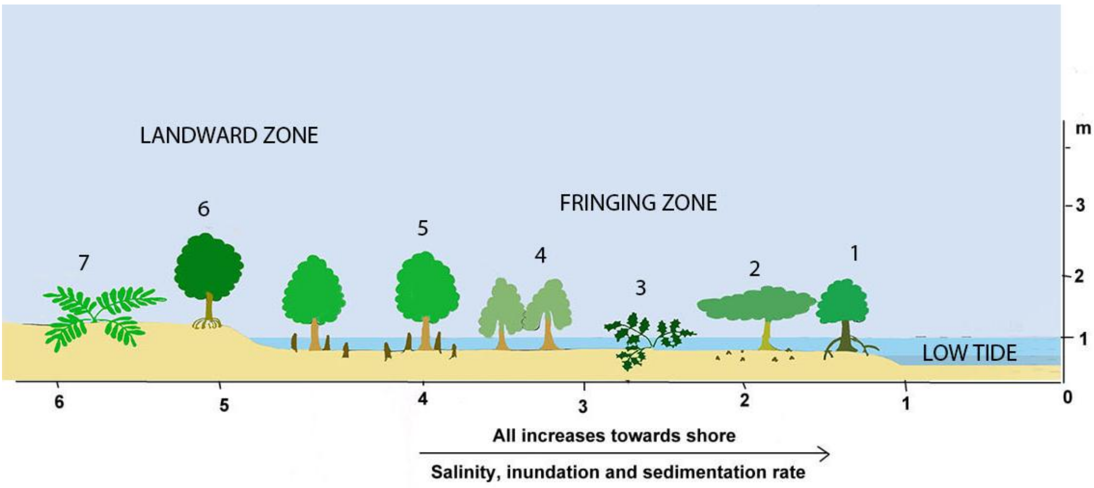


Figure 4.32 Zonation along the transect of mangrove vegetation of Chellanam, Ernakulam



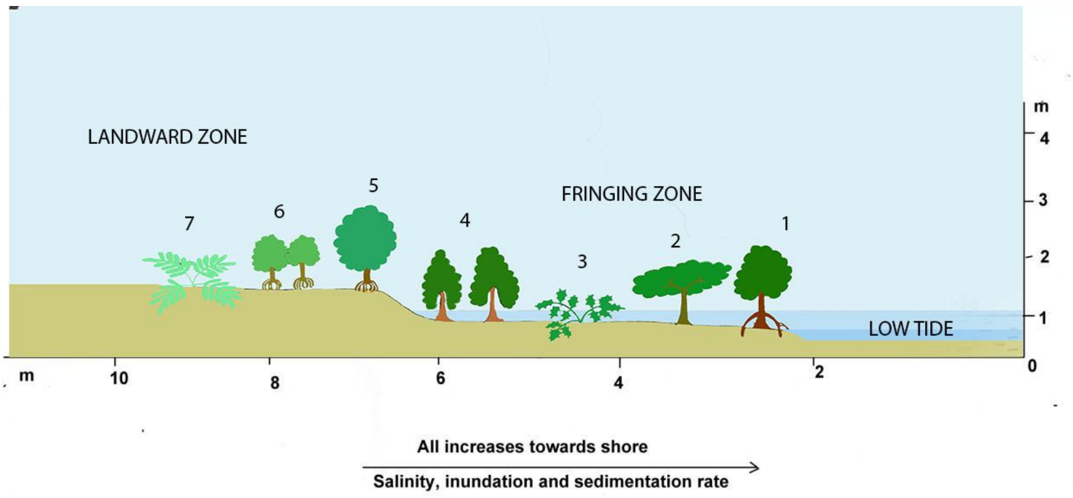
1. *Rhizophora mucronata*
2. *Avicennia officinalis*
3. *Bruguiera gymnorrhiza*
4. *Bruguiera cylindrica*
5. *Acanthus ilicifolius*
6. *Acrostichum auerum*

Figure 4.33 Zonation along the transect of mangrove vegetation of Mangalavanam, Ernakulam



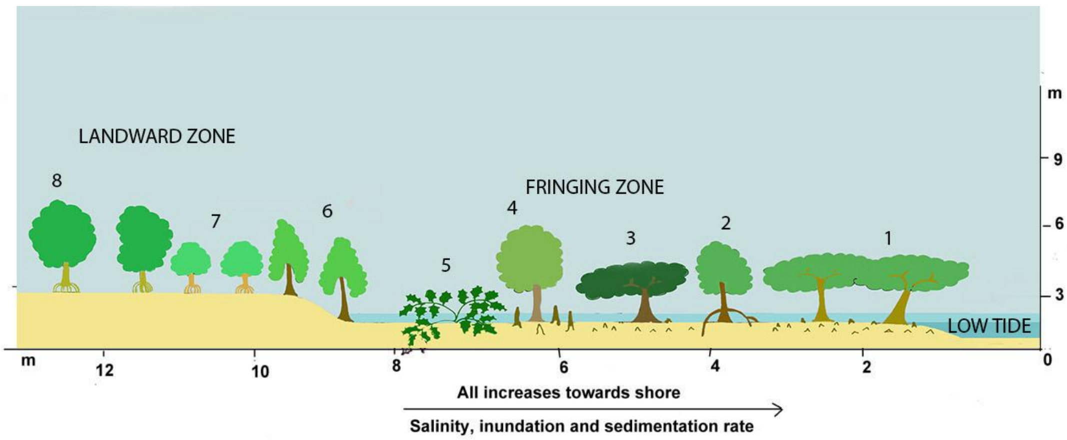
1. *Rhizophora mucronata*
2. *Avicennia officinalis*
3. *Acanthus ilicifolius*
4. *Excoecaria agallocha*
5. *Sonneratia caseolaris*
6. *Bruguiera gymnorrhiza*
7. *Acrostichum auerum*

Figure 4.34 Zonation along the transect of mangrove vegetation of Panambukad, Ernakulam



1. Rhizophora mucronata
2. Avicennia officinalis
3. Acanthus ilicifolius
4. Excoecaria agallocha
5. Bruguiera gymnorrhiza
6. Bruguiera cylindrica
7. Acrostichum auerum

Figure 4.35 Zonation along the transect of mangrove vegetation of Malippuram, Ernakulam.

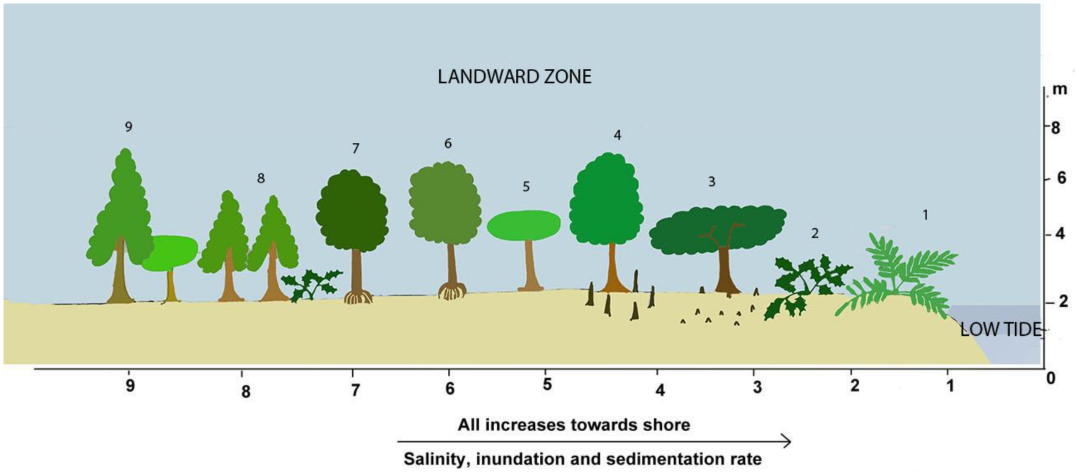


1. Avicennia officinalis
2. Rhizophora mucronata
3. Avicennia marina
4. Sonneratia alba
5. Acanthus ilicifolius
6. Excoecaria agallocha
7. Bruguiera cylindrica
8. Bruguiera gymnorrhiza

Figure 4.36 Zonation along the transect of mangrove vegetation of Puthuvypin, Ernakulam

vii. Kottayam

Mangroves of this district existed as fragmented assemblage of few species along the 3 transects studied from Pallichira (9° 36' 12''N, 76° 25' 54''E) to Thalayazham-Vaikom (9° 41' 55''N, 76° 24' 44''E). All the transects exhibited estuarine type. *Acrostichum aureum*, *Acanthus ilicifolius* and *Bruguiera sexangula* were the major species. In Vaikom transect, the fringing zone were inhabited by *Rhizophora mucronata* and *Acrostichum aureum* while *Excoecaria agallocha* and *Bruguiera* spp. were seen towards the landward zone (Figure 4.45). On the other hand the transects along Kumarakom Bird Sanctuary and Nerekadavu portrayed all the species in the landward zone (Figure 4.37 & 4.39). Kumarakom Bird Sanctuary exhibited low species diversity and had representations of only 4 mangrove species. *Acanthus ilicifolius* dominated the site and the rare species; *B. sexangula* was the proximal species occupying the water front region. The Nerekadavu transect displayed comparatively better representation of mangrove species (9sps). *Acrostichum aureum* and *Acanthus ilicifolius* were the dominant and proximal species inhabiting the water front, while *Excoecaria agallocha* and *E. indica* occupied the landward region. All the study sites displayed hammock type of mangrove forest.



1. Acrostichum auerum
2. Acanthus ilicifolius
3. Avicennia officinalis
4. Sonneratia caseolaris
5. Kandelia candel
6. Bruguiera gymnorrhiza
7. Bruguiera sexangula
8. Excoecaria agallocha
9. Excoecaria indica

Figure 4.37 Zonation along the transect of mangrove vegetation of Nerekadavu, Kottayam

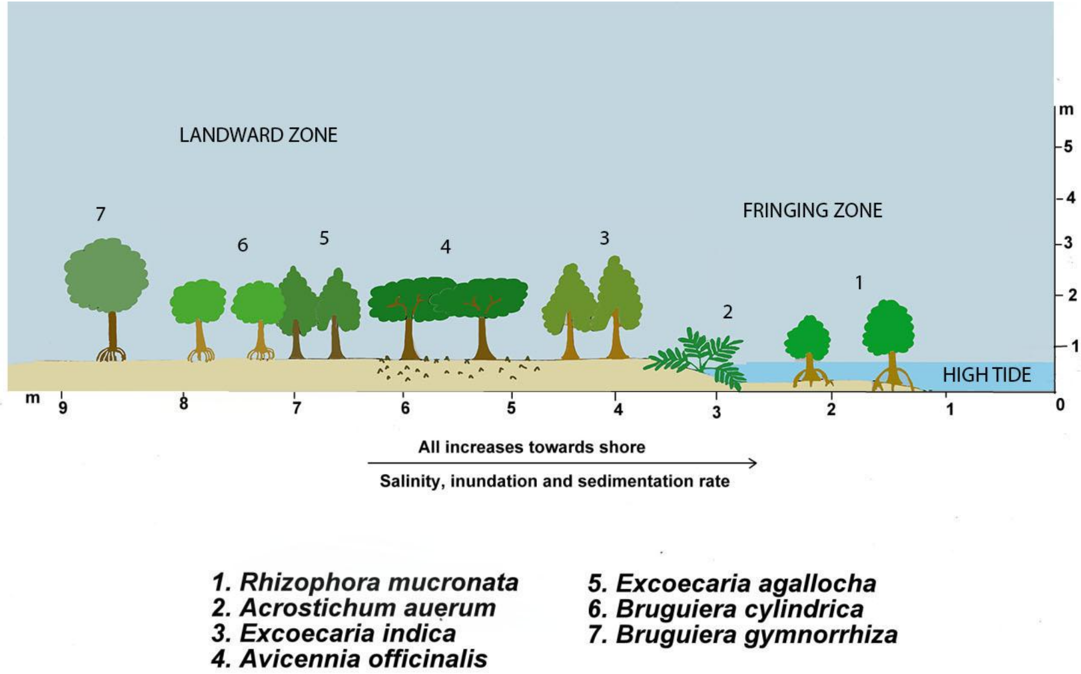


Figure 4.38 Zonation along the transect of mangrove vegetation of Vaikom, Kottayam

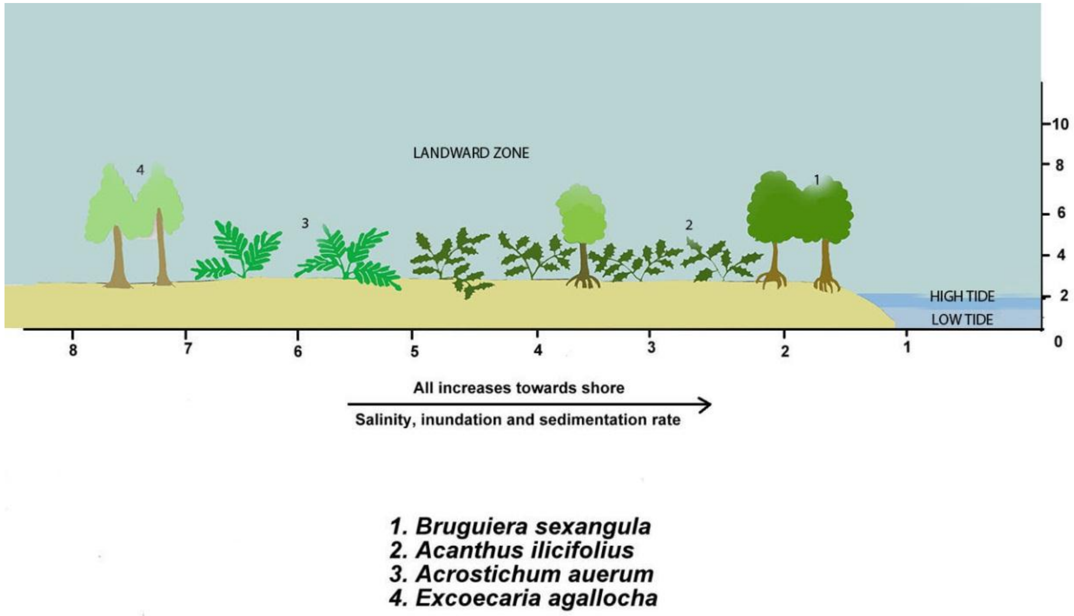
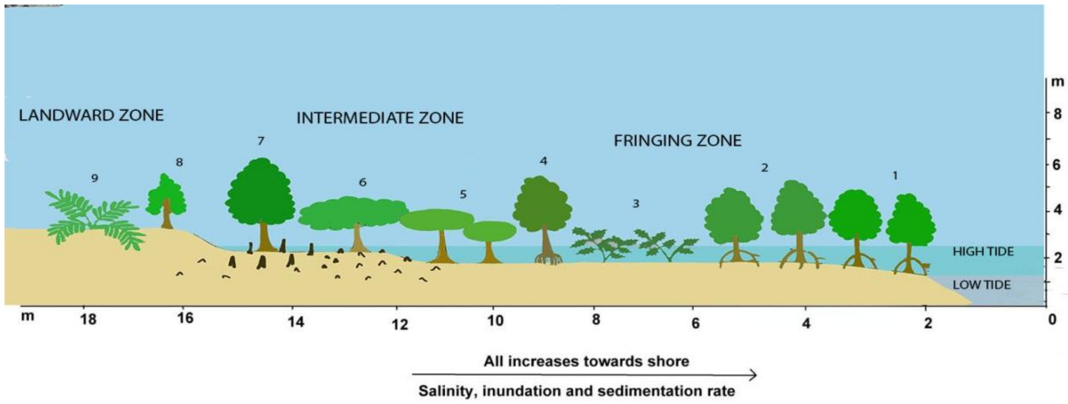


Figure 4.39 Zonation along the transect of mangrove vegetation of Kumarakom bird sanctuary, Kottayam

viii. Alappuzha

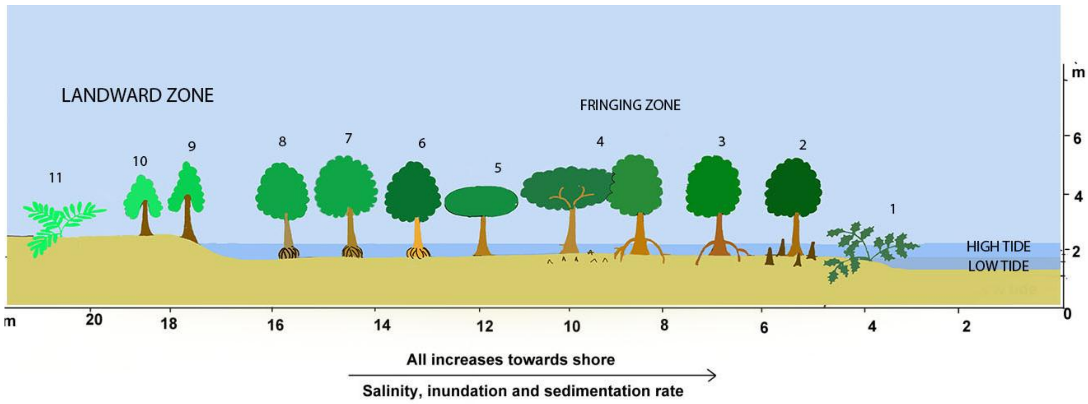
The district is well known for its network of backwaters and swamps. Even though these backwaters help in profuse growth of mangroves, most of the extensive patches have been degraded. Around 29 transects of mangroves were studied along the areas in and around Kayamkulam and Vembanad backwaters extending from Nerekadavu (9° 46' 38''N, 76° 22' 37''E) to Kochide jetty (9° 10' 14''N, 76° 27' 26''E). All the sites displayed estuarine type of habitat. Almost all the transects exhibited a similar zonation pattern, with species of *Rhizophora*, *Avicennia* and *Sonneratia* inhabiting the fringing zone; *Kandelia candel*, *Lumnitzera racemosa* occupying the intermediate zone; species of *Excoecaria*, *Bruguiera* and *Aegiceras corniculatum* in the landward zone.

Most of the transects displayed an extended fringing zone gradually leading landward zones (Arookutty, Poochakal, Aroor). While in many transects like Vaduthala, Chandiroor, Eramalloor, Kudapuram jetty and Thuravoor the intermediate zones were absent (Figure 4.40-4.47). Mainly two types of mangrove forest were identified in the district: Fringing mangroves in Arookutty, Vaduthala, Aroor, Poochakal, Chandiroor, Eramalloor, Kudapuram jetty, Thuravoor and Overwash mangrove forest seen in most of the small islands (Kizhake mattel, Anjuthuruth and Kakkathuruthu). The rare species of *Excoecaria indica* formed the major species in the transects of Kizhake mattel, Poochakal, Anjuthuruth, Pallipuram, Vayalar and Eramalloor. *Lumnitzera racemosa* was another rare species of the state, marked its dominance in few transects (Padinjare manakadom – Thuravoor, Pallithodu and Valiyazheekal).



1. *Rhizophora mucronata*
2. *Rhizophora apiculata*
3. *Acanthus ilicifolius*
4. *Bruguiera gymnorrhiza*
5. *Kandelia candel*
6. *Avicennia officinalis*
7. *Sonneratia caseolaris*
8. *Excoecaria agallocha*
9. *Acrostichum auerum*

Figure 4.40 Zonation along the transect of mangrove vegetation of Arookutty, Alappuzha



1. *Acanthus ilicifolius*
2. *Sonneratia caseolaris*
3. *Rhizophora mucronata*
4. *Rhizophora apiculata*
5. *Avicennia officinalis*
6. *Kandelia candel*
7. *Bruguiera gymnorrhiza*
8. *Bruguiera sexangula*
9. *Excoecaria agallocha*
10. *Excoecaria indica*
11. *Acrostichum auerum*

Figure 4.41 Zonation along the transect of mangrove vegetation of Vaduthala, Alappuzha

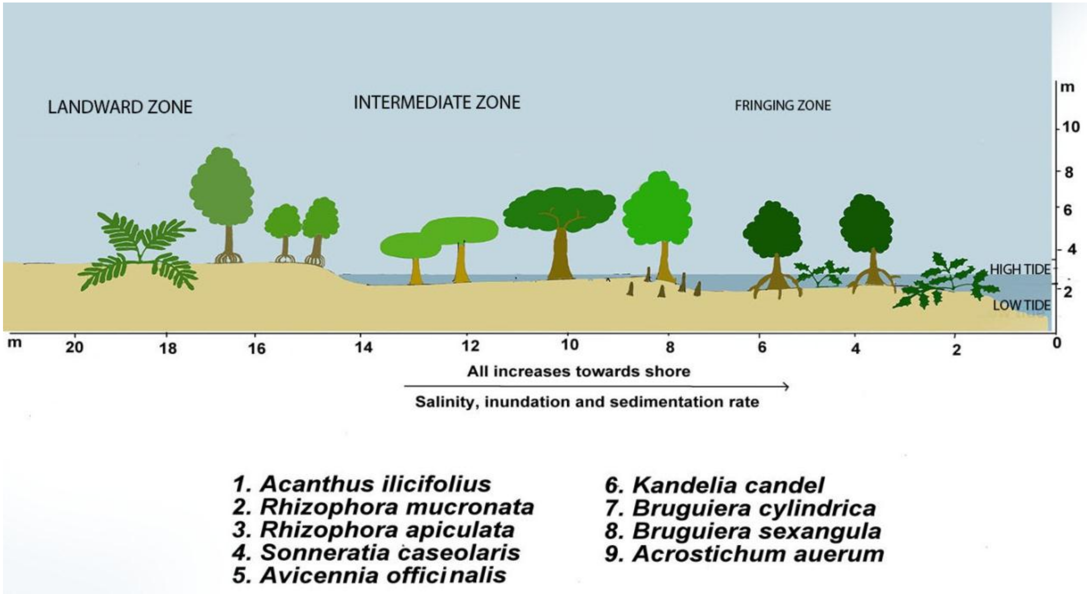


Figure 4.42 Zonation along the transect of mangrove vegetation of Aroor, Alappuzha

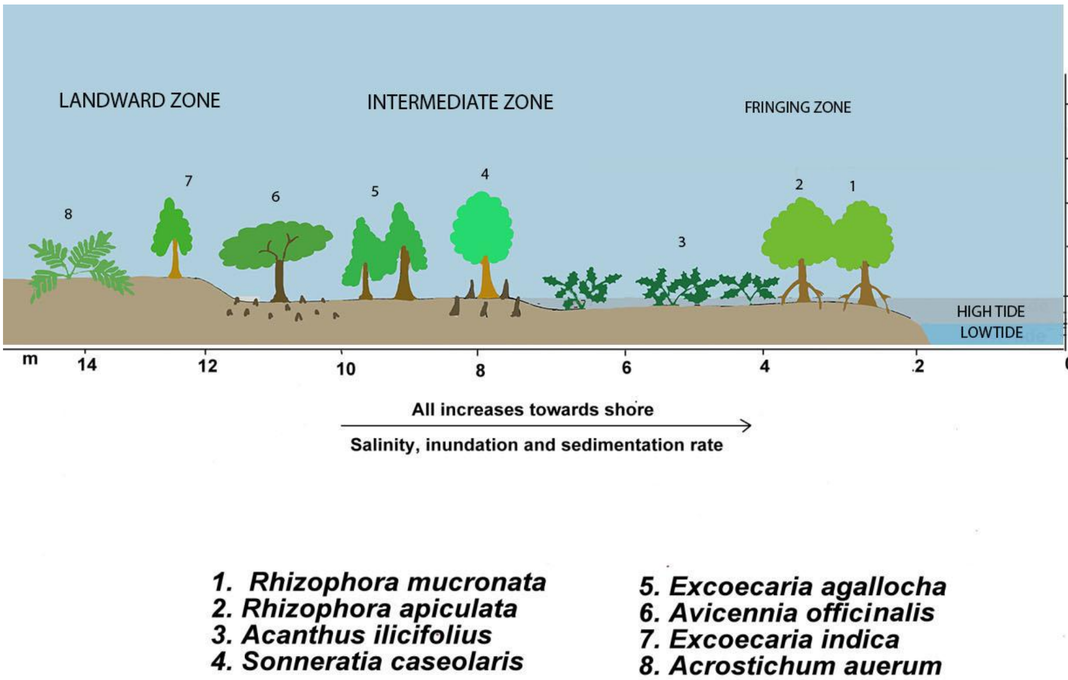
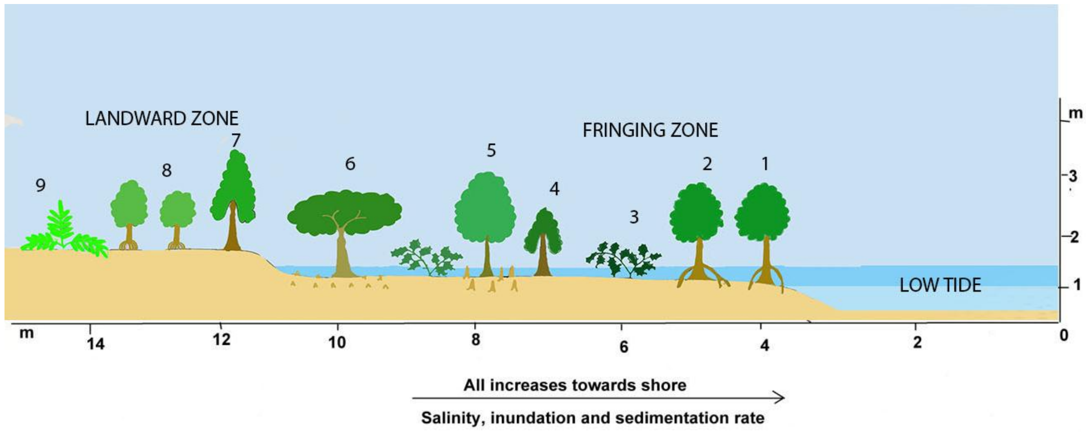
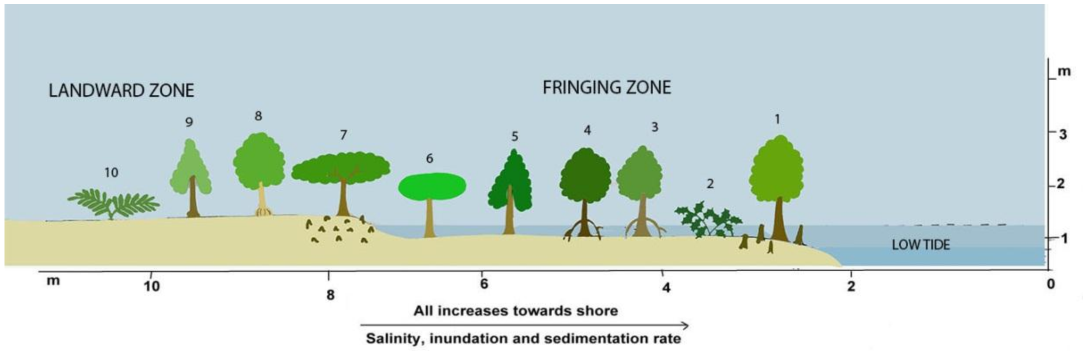


Figure 4.43 Zonation along the transect of mangrove vegetation of Poochakal, Alappuzha



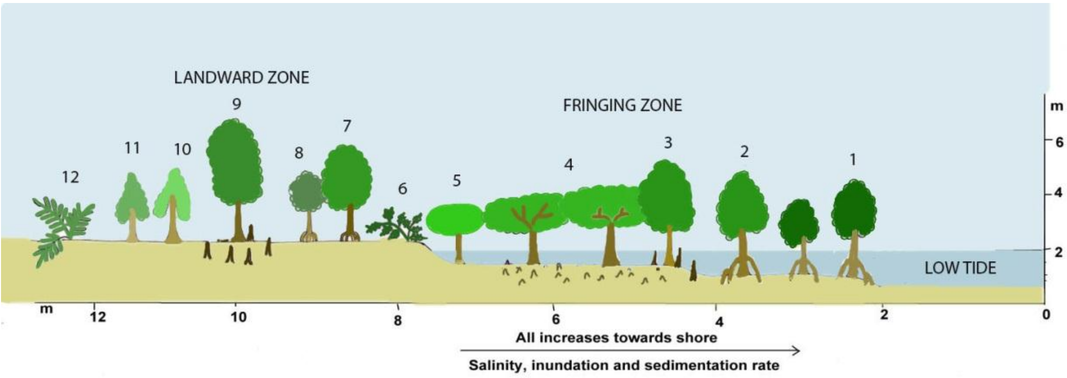
1. Rhizophora mucronata
2. Rhizophora apiculata
3. Acanthus ilicifolius
4. Excoecaria agallocha
5. Sonneratia caseolaris
6. Avicennia officinalis
7. Excoecaria indica
8. Bruguiera cylindrica
9. Acrostichum auerum

Figure 4.44 Zonation along the transect of mangrove vegetation of Chandiroor, Alappuzha



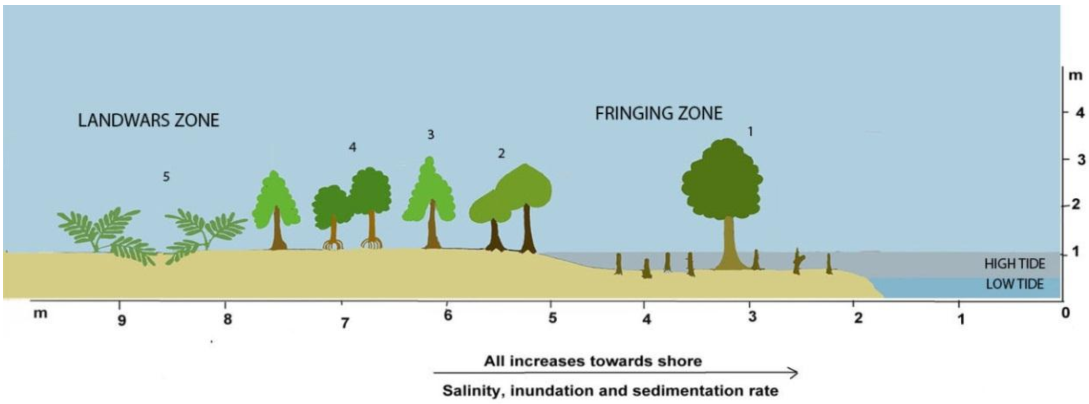
1. Sonneratia caseolaris
2. Acanthus ilicifolius
3. Rhizophora mucronata
4. Rhizophora apiculata
5. Excoecaria indica
6. Kandelia candel
7. Avicennia officinalis
8. Bruguiera gymnorrhiza
9. Excoecaria agallocha
10. Acrostichum auerum

Figure 4.45 Zonation along the transect of mangrove vegetation of Eramalloor, Alappuzha



1. *Rhizophora apiculata*
2. *Rhizophora mucronata*
3. *Sonneratia caseolaris*
4. *Avicennia officinalis*
5. *Kandelia candel*
6. *Acanthus ilicifolius*
7. *Bruguiera gymnorrhiza*
8. *Bruguiera cylindrica*
9. *Sonneratia alba*
10. *Excoecaria agallocha*
11. *Excoecaria indica*
12. *Acrostichum auerum*

Figure 4.46 Zonation along the transect of mangrove vegetation of Kudapuram jetty, Alappuzha



1. *Sonneratia caseolaris*
2. *Lumnitzera racemosa*
3. *Excoecaria agallocha*
4. *Bruguiera cylindrica*
5. *Acrostichum auerum*

Figure 4.47 Zonation along the transect of mangrove vegetation of Thuravoor, Alappuzha

ix. Kollam

Kollam district exhibited most species diversity in Kerala (15sp.). Even though the mangrove flora was now restricted to small isolated strands or narrow continuous belt along the banks of the estuary especially along the Ashtamudi and Kayamkulam wetlands, many rare species such as *Ceriops tagal* and *Avicennia alba* were encountered from here. Mangrove patches were located along 11 transects extending from Ayiramthengu (9° 6' 59"N, 76° 28' 50"E) to Asramam (8° 53' 45.74"N, 76° 35' 6.64’’ E). All the sites exhibited estuarine type of vegetation of which Ayiramthengu was the most species rich site inhabited by 11spp. of true mangroves. *Rhizophora mucronata, Avicennia officinalis* habited the fringing zone and was seen parallel to the estuarine banks whereas *Avicennia marina* was often found towards the seaward region. The intertidal zones were occupied by *Avicennia alba, Sonneratia caseolaris* and *Aegiceras corniculatum* gradually proceeding to the mixed vegetation of landward zone occupied by *Lumnitzera racemosa, Bruguiera cylindrica and Acrostichum auerum.*

Ayiramthengu region had the highest speies diversity and had an extended fringing zone occupied with *R. mucronata, Acanthus ilicifolius, Avicennia marina* and *A. officinalis*. Intermediate zone was inhabitated by mixed stands of *A. officinalis* and *Lumnitzera racemosa*. *Aegiceras corniculatum, B. cylindrica, E. agallocha* and *Acrostichum aureum* occupied the landward zones (Figure 4.48). Thekumbhagam also displayed a similar zonation pattern with *Acanthus ilicifolius* occuping the proximal end of fringing zone (Figure 4.51). Rare species of *Avicennia alba* was identified from this site. Eventhough the species diversity (5sps.) was less in Munrothuruthu, similar zonation pattern was evident in this site (Figure 4.56).The fringing zone was limited in Neendakara transect and was inhabited by *R.mucronata*. A graduall progression to the landward zone with rare species of *Ceriops tagal* and *Avicennia marina* was evident. The landward zone was captured by *B. cylindrica* and *Acrostichum aureum* (Figure 4.50). Fringing mangrove forest was prevalent in this district.

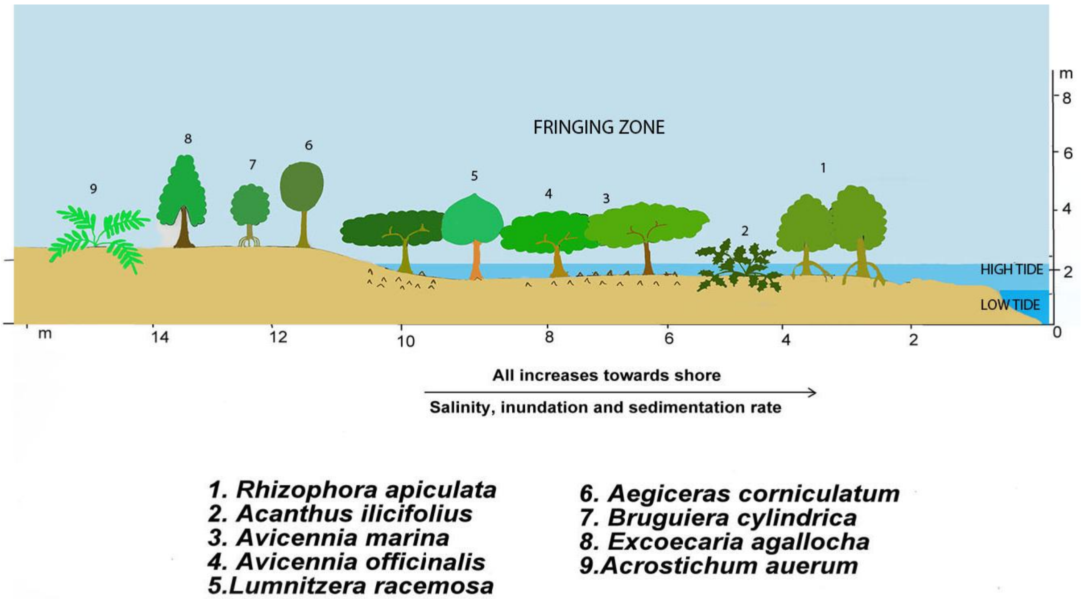


Figure 4.48 Zonation along the transect of mangrove vegetation of Ayiramthengu, Kollam

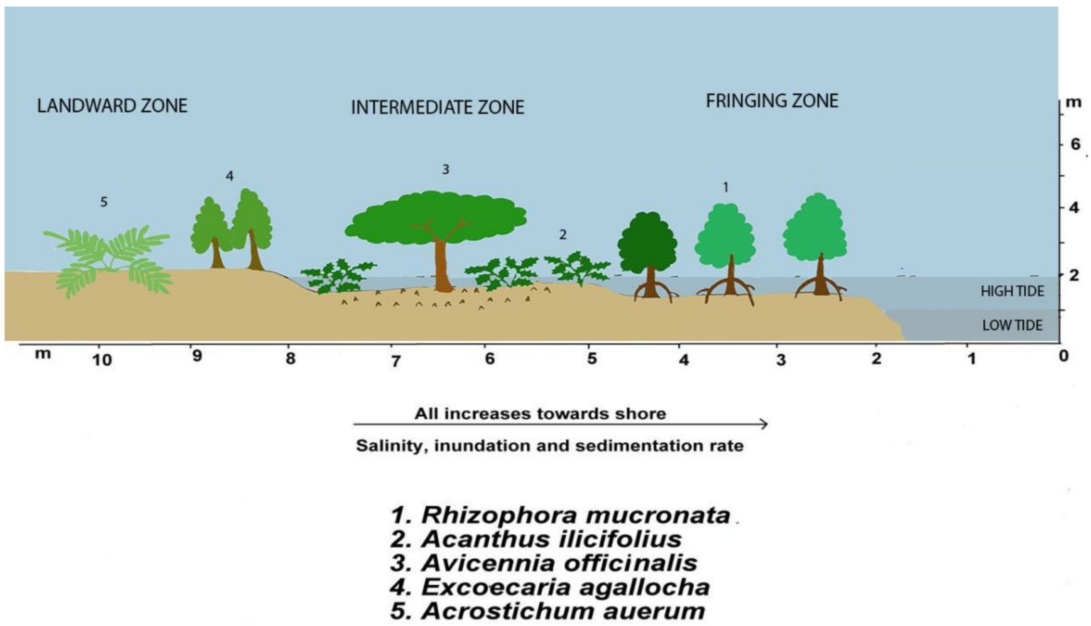


Figure 4.49 Zonation along the transect of mangrove vegetation of Munrothuruthu, Kollam

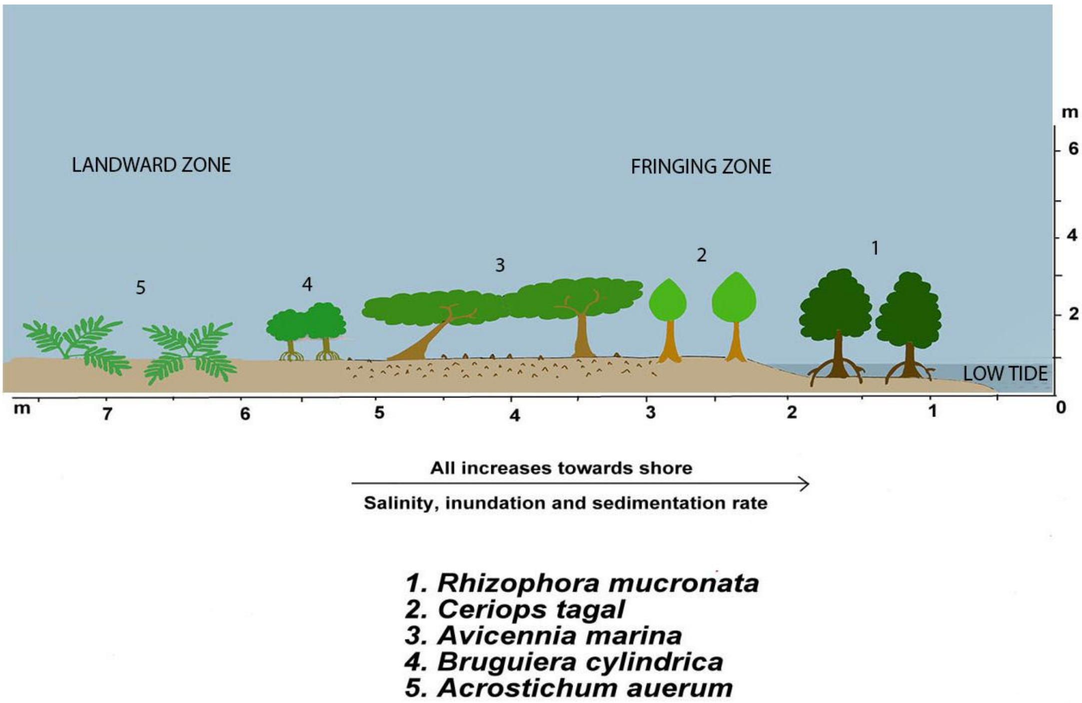


Figure 4.50 Zonation along the transect of mangrove vegetation of Neendakara, Kollam

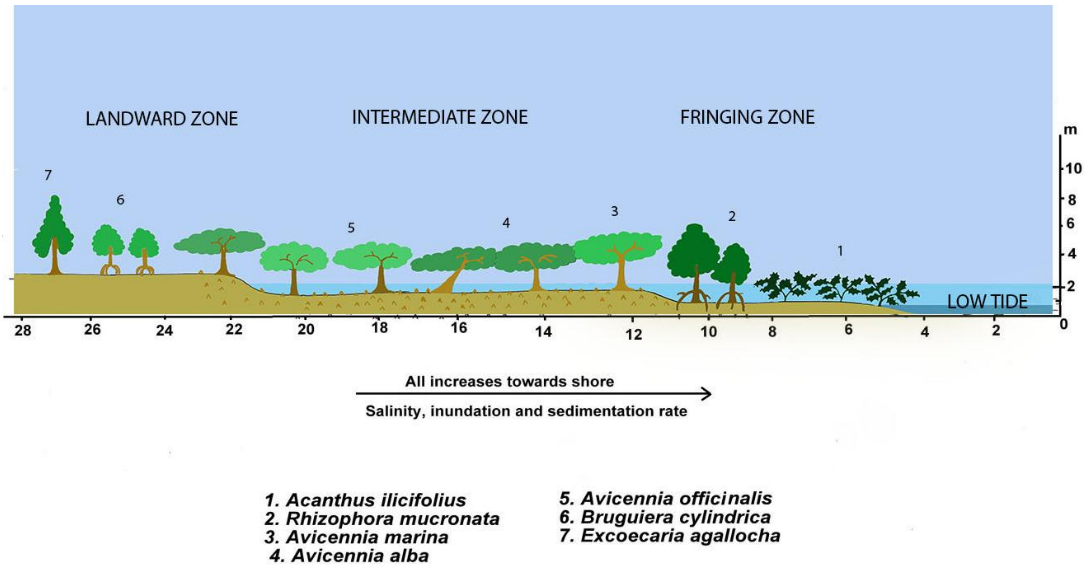


Figure 4.51 Zonation along the transect of mangrove vegetation of Thekkumbhagam, Kollam

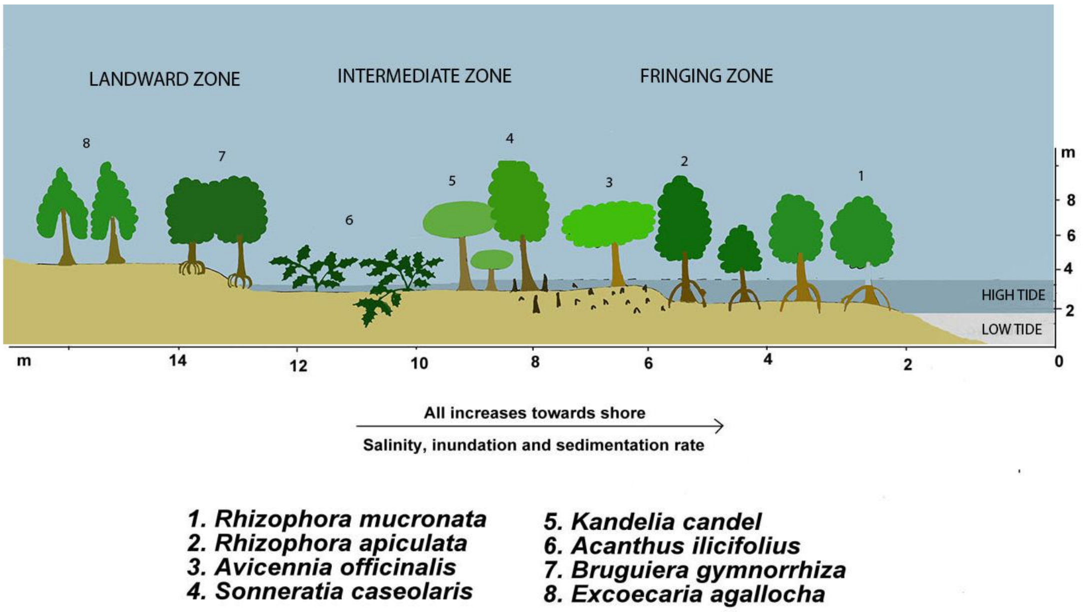


Figure 4.52 Zonation along the transect of mangrove vegetation of Asramam, Kollam

x. Thiruvananthapuram

Luxuriant mangrove vegetation was once evident in this district, but during the present study limited area of mangrove existence were identified. Mangroves were spotted along Akkulam- Veli estuarine region. Akkulam exhibited estuarine type and Veli exhibited coastal type of mangroves. Only three species of mangroves were identified (*Sonneratia caseolaris*, *Avicennia officinalis* and *Acrostichum aureum*) from the district. A clear zonation pattern was not identified in the district. The fringing and intermediate zones were much reduced and the mangroves mainly occupied a landward ward position (Figure 4.53). *Acrostichum aureum* was the dominant species prevailing in the mangrove habitats.

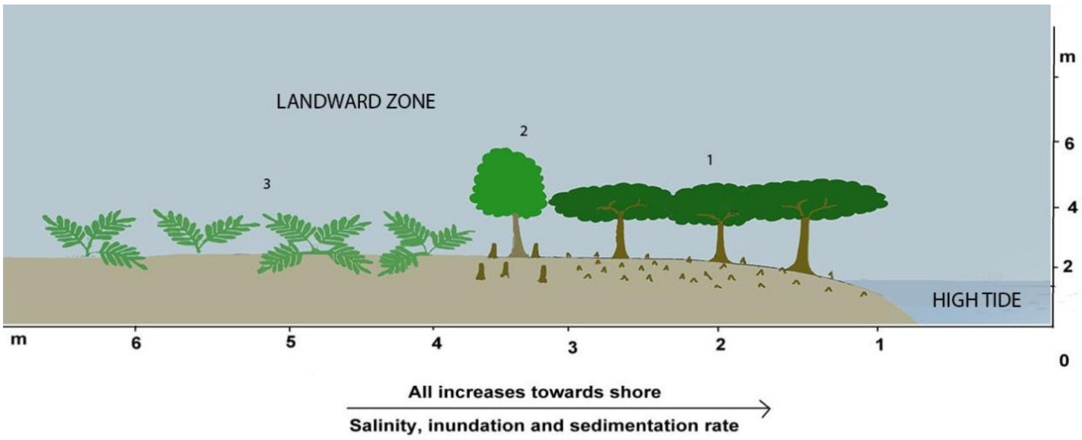


Figure 4.53 Zonation along the transect of mangrove vegetation of Veli, Thiruvananthapuram

4.4.4 Mangrove vegetation cover of Kerala

The present study mapped a total of 1782ha mangrove cover along various districts of Kerala (Table 4.4). The northern zone constituted greater mangrove cover (1191ha) followed by the central zone (440ha) and the southern zone (151ha). The district wise mangrove vegetation cover revealed the highest area in Kannur followed by Ernakulam and Alappuzha. The least mangrove cover was recorded in Thiruvananthapuram (5ha).

Table 4.4 District wise mangrove cover (ha) in Kerala

Sl.No.	District	Area (ha)	Zone	Area (ha)
1	Kasaragod	90		
2	Kannur	900		
3	Kozhikode	74	Northern	1191
4	Malappuram	38		
5	Thrissur	89		
6	Ernakulam	396	Central	440
7	Kottayam	44		
8	Alappuzha	110		
9	Kollam	36	Southern	151
10	Thiruvananthapuram	5		
	Total	1782	3	1782

i. Northern zone

The mangrove habitats along 51 sites extending from Manjeswaram (Kasaragod) to Anapuzha (Thrissur) represented the northern zone (Figure 4.54). Along the northern zone highest extent of mangrove cover was observed in Kannur (900ha) followed by Kasaragod (90ha). Even though patchy and fringing mangrove habitats were spotted along the Kasaragod district, mangroves were denser in Kumbala (N4), Neeleswaram (N7) and Kariyamkodu (N10). All the mangrove habitats were estuarine type and much denser patches were found fringing the upstream of Kumbala River. The Pallam backwaters also supported better mangrove vegetation.

The larger chunks of mangrove stands of Kerala was observed along the Kannur district and are better represented along Pazhayangadi, Pappinissery, Valapattanam, Ezhome and Kunjimangalam. Majority of the mangrove habitats were estuarine type and only Dharmadam represented coastal mangroves. The extent of mangroves in Kozhikode was 74ha while only 38ha of mangrove vegetation was mapped along Malappuram district. In Kozhikode, good patches of mangroves were witnessed along Beypore, Kallai, Koyilandi, Kolavipalam, Atholi and Chemancheri. In Malappuram district, good mangrove vegetation was evident in regions of Tirur, Ponnani, Tanur and Thazhepalam. Thrissur district represented better mangrove vegetation (89ha) than Kozhikode and Malappuram districts. Chettuva and Kodungallur-Azhikode estuaries supported mangrove vegetation of the district. Fringing mangrove vegetation was evident along the Poyya, Anapuzha and Mullassery.

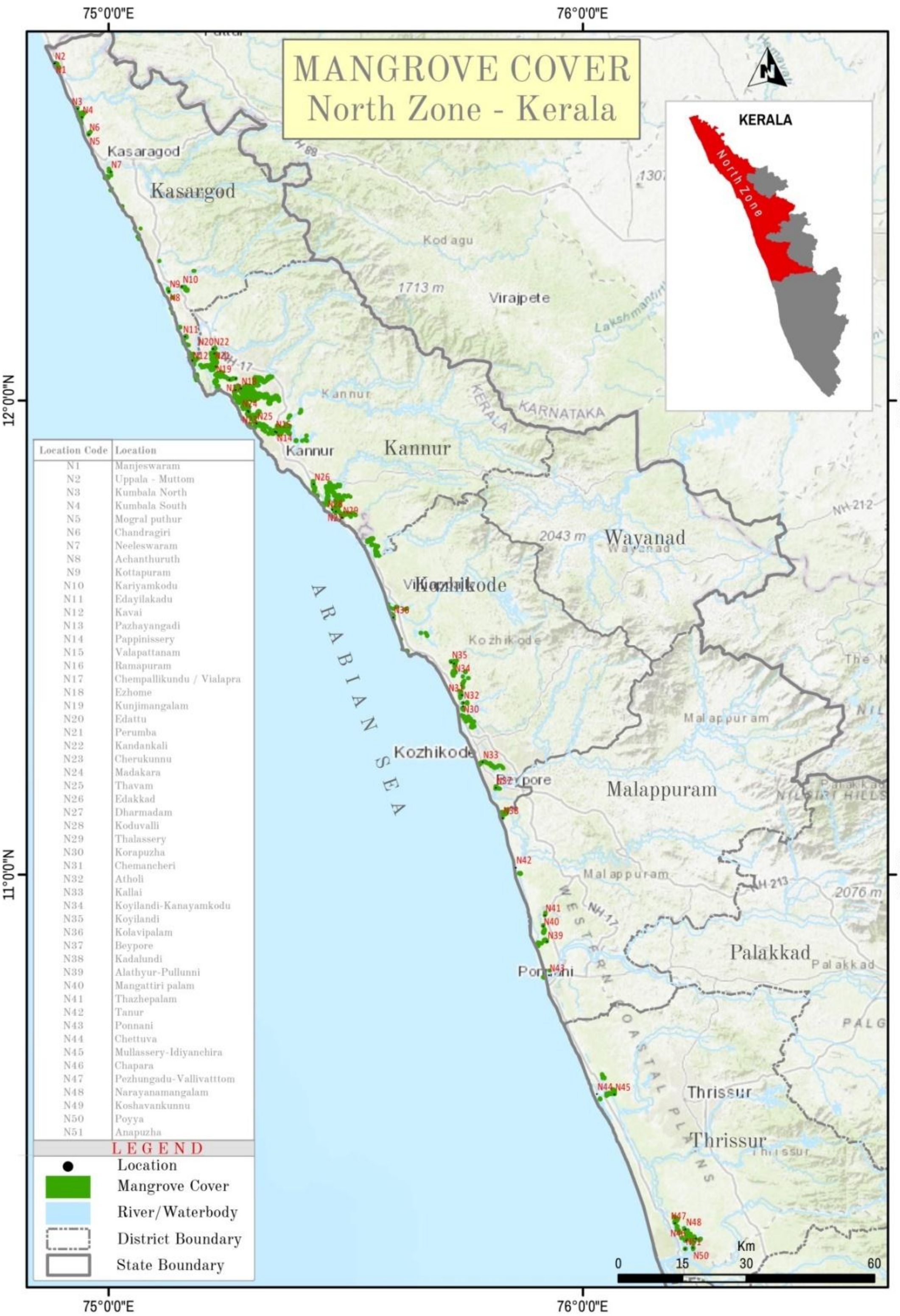


Figure 4.54 Mangrove cover of North zone of Kerala

ii. Central zone

The central zone of Kerala is represented by districts of Ernakulam and Kottayam. Various mangrove habitats along Ernakulam (C1-C19) recorded 396ha of mangrove cover, which was next to extent of mangroves in Kerala (Figure 4.55). The denser patches were observed along Puthuvypin, Vallarpadam, Mangalavanam and Valanthakad. Most of the mangrove habitats were estuarine type, while few sites like Chellanam, Kannamali, Elankunnapuzha, Fisheries Research Station Puthuvypin, Cherai, Valappu and Near LNG, Puthuvypin represented coastal type of mangroves. However the mangroves of Kottayam recorded only 44ha of mangrove area along Pallichira, Kumarakom Bird Sanctuary, Vaikom and Nerekadavu (C20-C23). All the mangrove habitats were estuarine type but exhibited reduced fringing zones and extended landward zones.

iii. Southern zone

The south zone of Kerala was represented by districts of Alappuzha, Kollam and Thiruvananthapuram. The Alappuzha district marked the highest area under mangrove vegetation (110ha) along the southern zone (S1-S30). Most of the mangrove vegetation were fringing along the shores of backwaters along the district. Even though the mangrove cover recorded in Kollam was lower (36ha), the district represented the highest species diversity during the present investigation. Ayiramthengu, Munrothuruthu, Poothuruthu, Bhavanithuruthu were the regions of Kollam district exhibiting better mangrove vegetation. The least mangrove cover was mapped along the district of Thiruvananthapuram (5ha). The district represented degraded mangrove habitats with lower species diversity

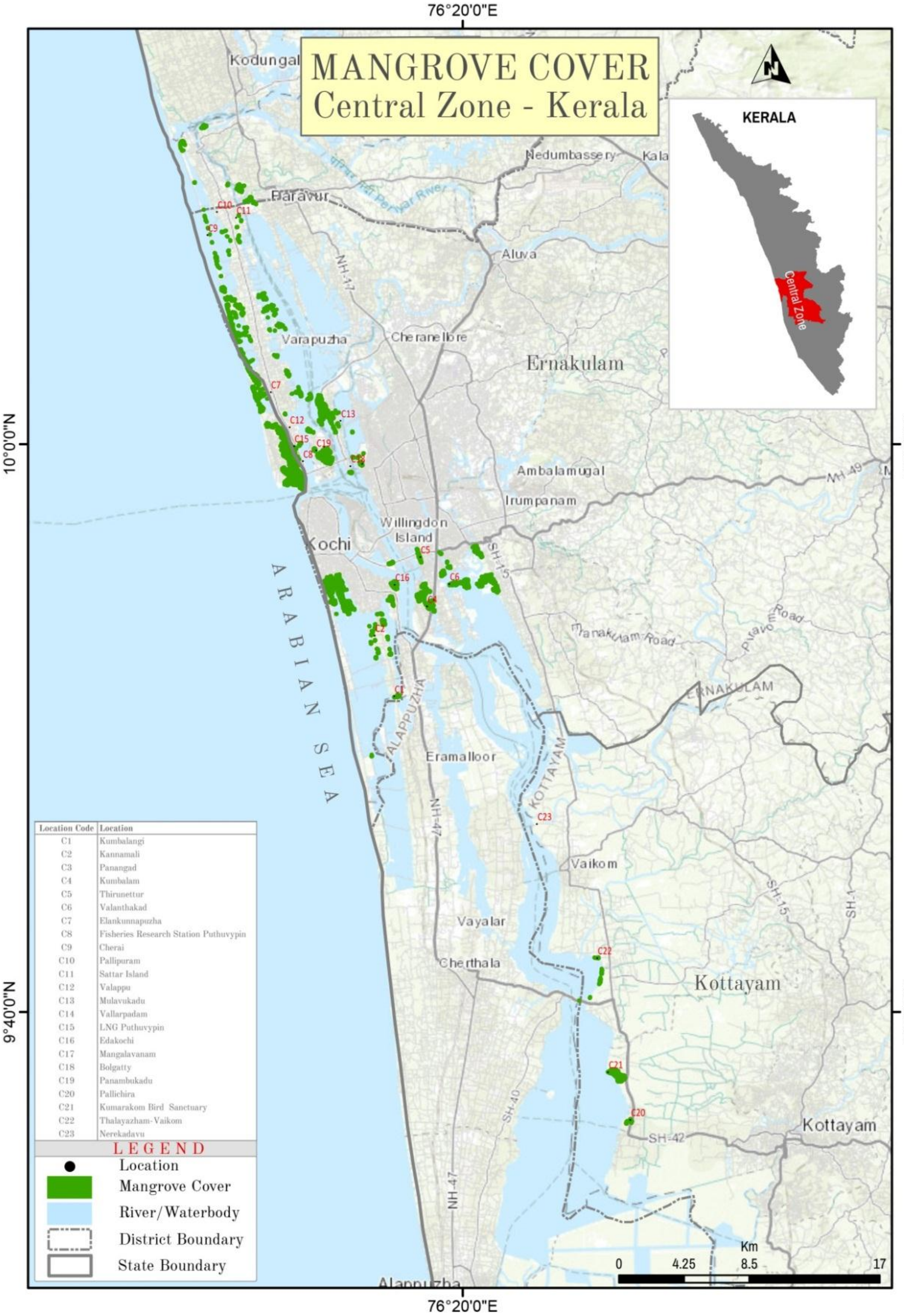


Figure 4.55 Mangrove cover of central zone of Kerala

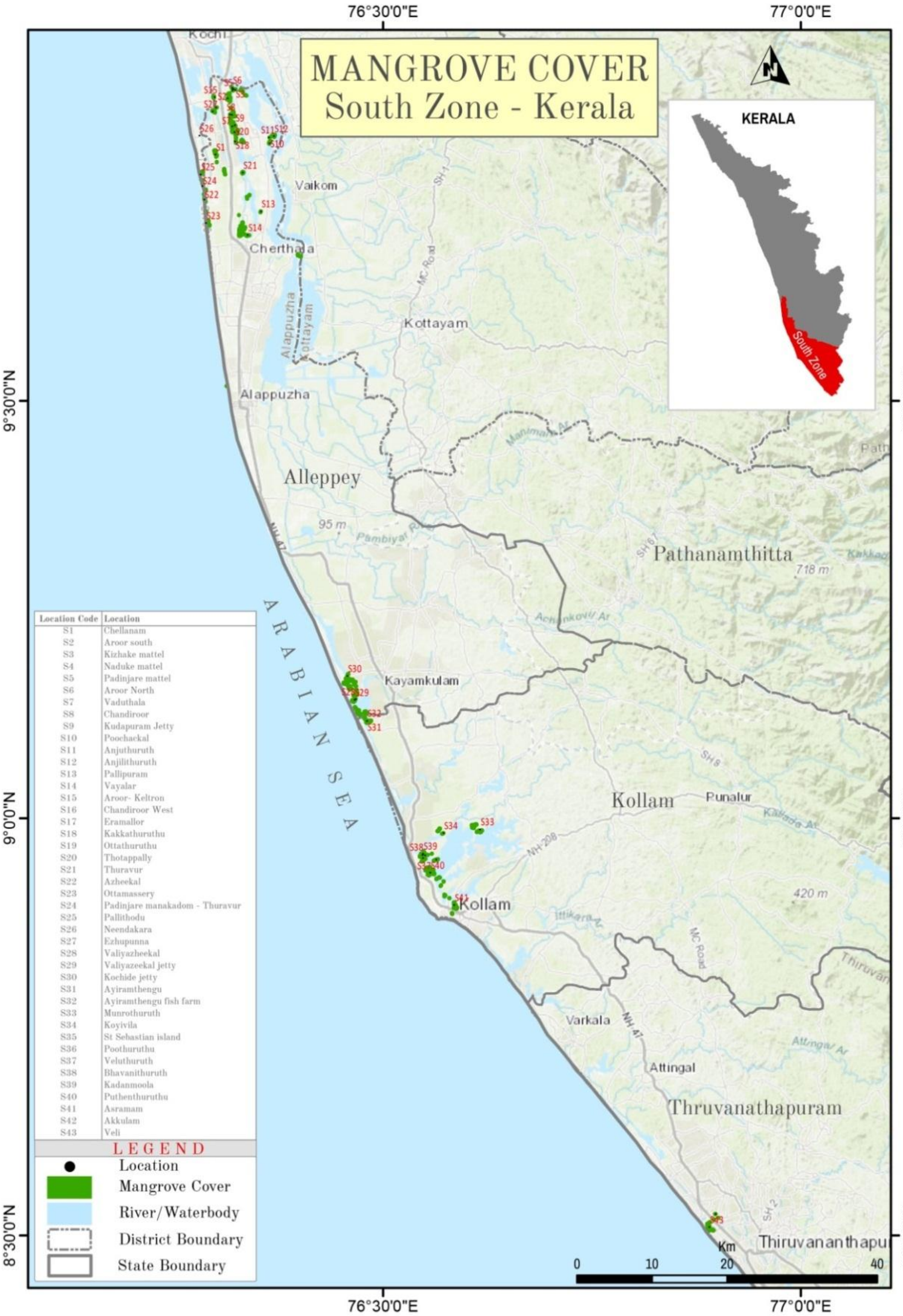


Figure 4.56 Mangrove cover of southern zone of Kerala

4.4.5 SWOT analysis

The SWOT analysis was carried out in various mangrove habitats of all ten districts of Kerala. The analysis was based on the visual infection of various mangroves study site and through secondary collection of information from local communities. The analysis revealed the following strengths, weaknesses, opportunities and threats in various districts (Table 4.5).

Table 4.5 SWOT analysis in mangrove habitats of Kerala

	KSD	KNR	KZH	MLP	TSR	EKM	KTM	ALP	KLM	TVM
Strengths										
Dense mangrove cover	2	5	2	2	2	4	2	3	3	1
Rich biodiversity	3	4	3	3	3	4	3	4	5	1
Conservation programmes	2	3	1	-	-	2	2	-	-	-
Weaknesses										
Lack of awareness	3	2	3	3	3	3	3	3	3	5
Low involvement of local people	2	3	3	2	2	2	2	2	2	5
Passive involvement of Government	2	3	3	2	2	3	3	2	2	2
Opportunities										
Sustainable tourism	3	5	3	3	3	5	2	5	5	1
Income generation for local people	3	4	3	3	3	4	2	4	4	1
Threats										
Urbanization	3	2	3	2	3	5	3	3	3	5
Conversion to aquaculture ponds	2	2	2	2	3	5	1	4	4	1
Land reclamation	3	3	3	3	4	5	3	4	4	5
Tourism	2	3	2	2	4	3	4	4	3	1
Wood extraction for local purposes	2	2	2	2	2	3	2	2	2	2
Prevention of salt water	2	2	2	2	2	3	5	2	2	5

Weightage: 5-Very high, 4-High, 3-Moderate, 2-Low, 1-Very low

i. Strengths

Dense mangrove vegetation, rich biodiversity and active conservation programme were the major strengths of various mangrove sites and showed varying levels of weightage in various districts. The dense mangrove vegetation was the strength of mangroves of Kannur district and moderately dense patches are found along the Puthuvypin, Valanthakad and Vallarpadam regions of Ernakulam district.

Even though the extent of mangrove cover was less in Kollam, the district exhibited rich species diversity (15spp. of true mangrove). Ayiramthengu (Kollam) had representatives of rare species of mangroves. The conservation programmes were yet another strength of Kannur, Ernakulam and Kottayam mangroves. The Wildlife trust of India in connection with Apollo Tyres launched the conservation programme "The Kannur Kandal Project" with the aim of saving the existing mangrove habitats and to increase the acreage of mangroves in Kannur. The project site is situated at the Kunhimangalam region of Kannur. A good stand of mangrove is protected along the Kerala's first community reserve in Kadalundi, Malappuram. Mangalavanam Bird Sanctuary is the only mangrove conservation site in the Ernakulam district. Mangalavanam with ~2.74ha of mangrove cover is situated at the heart of Kochi, inhabiting various mangrove species and migratory birds. Initiatives have also been undertaken by Kerala University of fisheries and Ocean Sciences, in conserving the mangrove vegetation. The project site is situated at Puthuvypin; aims at increasing the mangrove cover along the coastline and creating awareness among local people. Kumarakom Bird Sanctuary (Kottayam) supports diminutive mangrove vegetation. Even though the mangroves are mainly landward and have restricted inflow of saline water, the species are protected from further destruction.

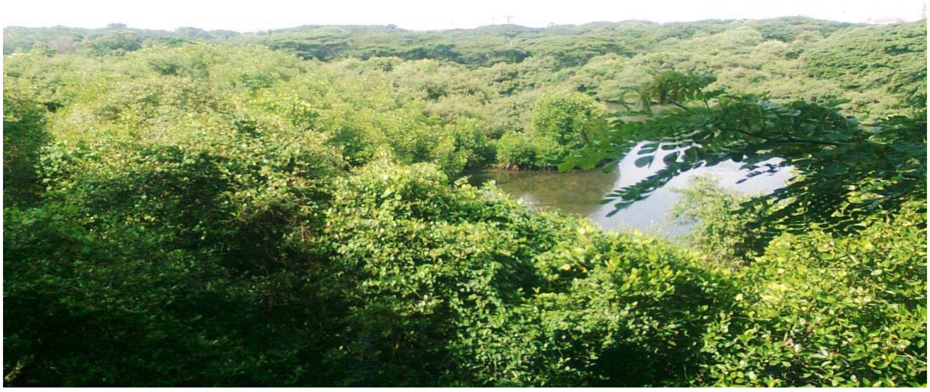


Plate 4.1 Mangroves of Mangalavanam Bird Sanctuary

ii. Weaknesses

Lack of awareness was found to be the weakness in many of the mangrove sites. Most of the local communities are unaware of the potentials of these ecosystems and consider these habitats as waste land and breeding grounds of mosquitos. Only few sites near coastal region, felt the importance of mangrove vegetation after the Tsunami of 2006. People of TVM were most ignorant on the importance of mangroves and that was clearly depicted in the area of mangrove cover identified in the present study. As the people are less aware of the mangroves, they displayed least participation in conservation programmes. Only the scientific communities like schools, colleges, universities and other government bodies were found involved in conservation activities. Government involvement in various conservation and reclamation issues were found to be passive in most of the areas.

iii. Opportunities

Most of the mangrove sites in Kannur, Alappuzha, Ernakulam and Kollam are most suitable sites for sustainable ecotourism development. This can also lead to a potential income generating source for local community. At present a small percentage of local people are found to be involved in tourism activities in mangrove sites. A small percentage of Kudumbashree people are found to be encouraging the tourism in mangrove sites of Puthuvypin and Malappuram regions by earning income through boating, fishing activities and refreshments.

iv. Threats

The SWOT analysis revealed most of the mangrove sites threatened by various human interferences such as urbanization, reclamation, conversion to aquaculture ponds etc. Ernakulam district displayed the maximum degradation by these activities. The LNG terminal site consumed a large portion of mangrove vegetation of Puthuvypin region. The construction of approach roads to Goshree Bridge has also taken away a good chunk of mangroves from Vallarpadam region. The conversion of mangrove habitats to aquaculture ponds is also evident in region of Puthuvypin, Chellanam and Kumbanghi. The extraction of mangrove woods by local communities were found to be low in most of the districts, however small scale reclamation of mangrove land for residential area were observed in most districts. Many of the mangrove sites also displayed reduction in saline water intrusion due to the construction of embankments and barrages thereby altering the ecological conditions in many mangrove sites. The most evident example is the construction of Thanneermukkom barrage in Kottayam district preventing the salt water intrusion which results in the ponding of mangrove sites.

4.5 Discussion

The mangroves of Kerala were studied from the past (Troup, 1921; Thomas, 1962; Blasco, 1975; Kurian, 1980) and the key objectives of these studies were to identify the major mangrove species and associates of Kerala. Most of these studies lacked the concept of distinct zonation patterns and possible explanations for such patterns. In the present study 18 species of true mangroves were identified along the Kerala coast, which marked the loss of many species which flourished in the past. Most of the mangroves along the Kerala coast are fast depleting and exist as small patches, thus many of the present studies are focused on the dense patches of mangroves in districts of Kannur, Kozhikode, Ernakulam and Kollam while small patches and open mangrove vegetation was neglected.

i. Distribution and diversity of mangrove species

In the present floral investigation variations in species composition was observed along the three zones of Kerala (northern, central and southern zone). Among the 18 spp. of true mangroves identified, *Acanthus ilicifolius* was the densest species, contributing more than 50% of the plant density in all the three zones except Thiruvananthapuram. Unlike earlier reports, *Acanthus ilicifolius* showed higher density throughout Kerala as most of the mangrove habitats were affected by anthropogenic interventions. Among the three species of *Avicennia, A. officinalis* was the dominant species and was recorded in all the districts while *A. marina* was observed only from Kasaragod, Kannur, Kozhikode, Ernakulam and Kollam. The species was more abundant in northern zone and in Ernakulam the species was found only in Puthuvypin region. On the other hand *A. alba* was encountered only from Ayiramthengu region of Kollam district and no other districted marked the representation of the species. *Ceriops tagal* is yet another rare species identified only from Kollam. Among the three species of *Bruguiera, B. cylindrical* was more common in all zones. *B. gymnorrhiza* was found to be abundant in central zone

(Ernakulam, Kottayam) and southern zone (Alappuzha, Kollam) and was more or less absent in northern part. The species was found only in Malappuram district with 1% tree density. *B sexangula* also marked its dominance along central part and in Alappuzha while was completely absent in north side. Occurrence of *Bruguiera parviflora* was also reported by Basha (1992) and Botanical Survey of India (2018) while the species was not spotted from any part of Kerala in the present investigation and possibly marked the loss/ extinction of the species.

Rhizophora species (*R. apiculata* and *R. mucronata*) were common in all zones and similar observation was reported by Mini et al. (2014); Vidyasagaran and Madhusoodanan (2014) and Neethu and Harilal (2018). Even though both the species were not spotted from Malappuram district during the present study, Vidyasagaran and Madhusoodanan (2014) spotted the rare occurrence of the species along the district. *Kandelia candel* was identified from all districts except Thiruvananthapuram. The species was better represented in northern zone with highest density along Kasaragod (7%) followed by Kannur, Kozhikode and Malappuram. Even though the central zone marked the presence of the species, they were rare in occurrence and were fast disappearing from the mangrove locations of most districts (except Kannur), as the stations are drastically affected by the land filling activities. *Excoecaria agallocha* was also identified from all other district except Thiruvananthapuram in southern zone. The species was more densely distributed in Ernakulam, Kannur and Kozhikode. The other species, *E. indica* was a rare and was identified only from Kottayam and Alappuzha. However apart from the two districts, Mini et al. (2014) reported the occurrence of the species also from Kollam. Basha, 1992 reported the rare species of *Excoecaria indica* in various districts of Kerala while it was not spotted by Vidyasagaran and Madhusoodanan (2014) from both Ernakulam and Kottayam districts. Among the two species of *Sonneratia, S. caseolaris* was identified from all districts with highest density along Malappuram.

On the other hand *S. alba* was rare in occurrence and was spotted only in Kannur, Ernakulam and Alappuzha. Vidyasagaran and Madhusoodanan (2014) also reported the profuse occurrence of the species along Kannur. With accordance to the earlier studies of Vidyasagaran and Madhusoodanan (2014); Sheela (2012); Basha (1992), *Aegiceras corniculatum* was encountered along northern zone and from Kollam in south, while was completely absent in central part. *Lumnitzera racemosa* was yet another rare species identified from few district (Kasaragod, Alappuzha and Kollam). *Acrostichum* was found in all other district except Kasaragod. Thiruvananthapuram (93%) recorded highest density for the species followed by Kottayam (41%). None of the mangrove associates were common to all study sites but many of the reclaimed lands were overgrown mainly by mangrove associates.

The diversity indices clearly portrayed highest species diversity for Kollam (15spp.) followed by Alappuzha (14spp.). However, Vidyasagaran and Madhusoodanan (2014) spotted only 13spp. from both the districts. Their study also marked the absence of *B. sexangula, E. indica* and *K. candel* along Kollam and species of *Acanthus* and *Acrostichum* were not included as true mangroves. Even though the present study could identify 15spp. along Ayiramthengu (Kollam), Vishal et al. (2015) reported only 9spp. from the same region. The least species diversity and species richness was displayed by Thiruvananthapuram district, representing only 3spp. namely *Avicennia officinalis, Sonneratia caseolaris* and *Acrostichum aureum.* In contrast to this, more number of species was reported by Vidyasagaran and Madhusoodanan, 2014 (4spp.) and Mini et al., 2014 (14spp.).

ii. Zonation pattern

a. Northern zone

The present study identified 10 true mangroves along Kasaragod district. *Acanthus ilicifolius* was identified as most dominant species. *B. cylindrica* constituted 13% of the plant population followed by *A. marina*, *Kandelia candel*, *R. mucronata* and *A. officinalis.* Kannur district displayed similarity in species density with that of Kasaragod. The least tree density was portrayed by species of *R. apiculata* and *S. caseolaris* in both districts. According to the reports of ENVIS center (BSI, 2018) the mangroves of Kasaragod range are found along the forest range office (13.4ha) and near NH-17 (56.6ha).The study highlighted the occurrence of *Avicennia officinalis*, *Avicennia marina*, *Kandelia candel*, *Excoecaria agallocha* and *Rhizophora apiculata* as the major mangrove species and was parallel to the present observations. Mangroves identified along Kanhangad range included *A. officinalis, A.marina, R. apiculata* and *A. ilicifolius* exhibiting 10-70 % density. The present study noted the dominance of *Lumnitzera racemosa*, *Rhizophora mucronata* and *Avicennia officinalis* with occasional patches of *Aegiceras corniculatum* along Kasaragod. The district exhibited small scale destruction of mangroves in Manjeswaram and Kumbala region, but were also far ahead in management and conservation programs. Mainly *Rhizophora apiculata* and *Kandelia candel* were the species planted during 2003 by ENVIS center (BSI, 2018).

Kannur district has the most luxuriant mangrove forest having around 12 mangroves species with a common occurrence of *Avicennia officinalis*, *A. marina*, *Rhizophora mucronata*, *R. apiculata*, *Sonneratia caseolaris*, *S. alba*, *Aegiceras corniculatum* and *Excoecaria agallocha* were marked from the region. The report of ENVIS center also marks the prominence of *A. corniculatum* along Kannur (BSI, 2018). Mixed patches of mangroves species of *Avicennia, Excoecaria, Kandelia, Rhizophora*, *Sonneratia* and *Acrostichum* were observed in most of the study sites. Better mangrove representation in visible along the Kavai estuary, Valapattanam, Pappinissery and Kunjimangalam region. BSI (2018) also reports the occurrence *Bruguiera parviflor*a in Taliparambu range along with the mixed vegetation of *Avicennia officinalis*, *Avicennia marina*, *Rhizophora apiculata*, *Acanthus ilicifolius* and *Excoecaria agallocha* extending up to 6km along Pazhayangadi River but the present study could not spot the species from Kannur district. Giant sized *Avicennia officinalis* trees were encountered in Kannur during the present study. Moderately dense mangroves of *Avicennia officinalis*, *Avicennia marina, Sonneratia alba* and *Rhizophora apiculata* (40- 70 % density) were reported along Kottiyur region (BSI, 2018). Limited human settlements and developmental activities were observed during the study period which thereby preserved the mangrove habitats intact compared to other districts. Extensive afforestation programmes by forest departments and private entrepreneurs such as Pappinissery mangrove parks have also been initiated in the district attributing to the rich mangrove vegetation. One of the major threat to the mangroves of Valapattanam estuary is the Irinav power project put forth by Kerala Industrial Infrastructure Development Corporation, which if carried out in near future would result in loss of 184 acres of land within the mangrove belt.

Unscientific land use pattern and real estate activities have resulted in the loss of mangrove habitats compared to the past. According to the ENVIS reports, Kadalundi area with dominance of *Avicennia officinalis* represented the mangroves of Kozhikode district (BIS, 2018) while in the present study extensive patches were also identified along Beypore, Kallai, Koyilandi and Kolavipalam. Predominance of *Avicennia officinalis* and *Rhizophora mucronata* in the fringing zone similar to Kannur mangroves were observed in Kozhikode. *Sonneratia caseolaris*, *Avicennia marina*, *Acrostichum aureum* and *Kandelia candel* where the other species of the region. Malappuram district occupy very less extent of mangroves at present and thus were not included in many of the recent studies. Kerala's first community reserve- Kadalundi along with Pullunni of Tirur, Ponnani, Tanur and Thazhepalam were recorded with good patches of mangroves in the present investigation. Developmental activities were evident in progressing phase which has resulted in establishment of more of landward species such as *Acanthus ilicifolius*, *Avicennia officinalis*, *Acrostichum aureum* and *Excoecaria agallocha.*

In the Thrissur district major mangrove distribution is noted along Chettuva with species of *Avicennia*, *Bruguiera*, *Rhizophora*, *Acanthus ilicifolius* etc. distributed mainly in two islands in the Chettuva backwaters which was also evident in reports of ENVIS center on floral diversity. Few patches of mangroves were also evident in Poyya, Anapuzha and Mullassery regions with dominance of *Acanthus ilicifolius* followed by *Avicennia officinalis* and *Rhizophora mucronata*. These fragile ecosystems are mainly disturbed by ecotourism activities in this district. The entire system was dominated by *Rhizophora* while the frequency of *Bruguiera* and *Excoecaria* were found to be increasing towards the landward side. The fringing zone was also characterized by the preponderance of *Aegiceras corniculatum.*

The zonation patter of northern zone (along the 5 districts) marked the dominance of *Rhizophora mucronata*, *R. apiculata*, *Acanthus ilicifolius*, *Kandelia candel*, *Sonneratia caseolaris*, *Aegiceras corniculatum* and *Avicennia marina* in the fringing zones gradually forming a mixed intermediate zone of *Sonneratia caseolaris, Excoecaria agallocha, Lumnitzera racemosa* and *Avicennia officinalis.* The landward zone is inhabited by the species of *Bruguiera* and *Acrostichum.*

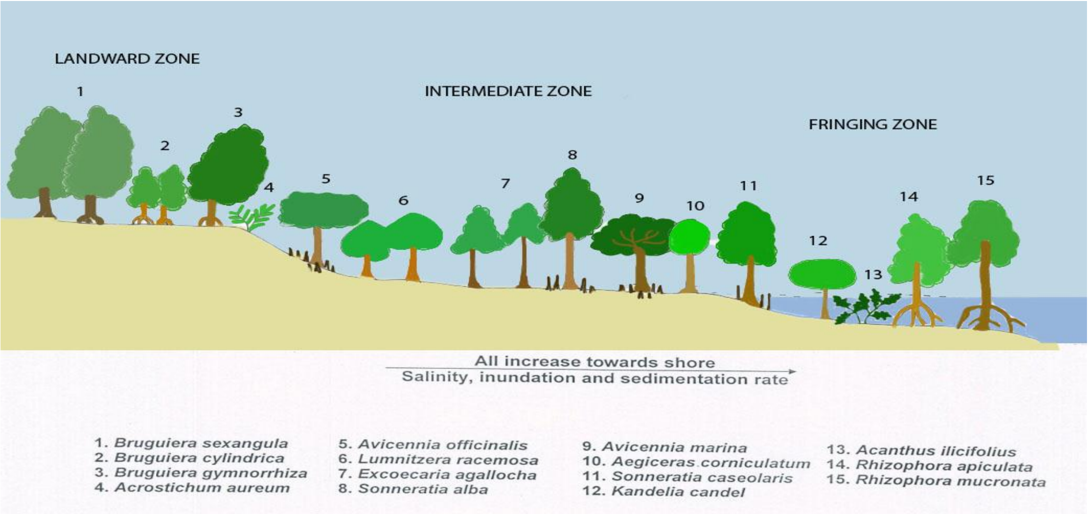


Figure 4.57 Zonation along the transect of mangrove vegetation of Northern Kerala

b. Central zone

Ernakulam district occupy second highest extent of mangroves in the state while ranks the first position in the scale of mangrove destruction. The studies by BIS (2018) reported only three sites of mangrove distribution in Ernakulam district (Puthuvypin, Mangalavanam Bird Sanctuary and Kundannur area) while the present study identified 21 mangrove sites. A large portion of mangroves of Puthuvypin are destroyed by the construction work by the BPCL and LNG Petronet Project. The salt water supply to the mangroves is cutoff by various construction activities in this area. *Avicennia marina* and *Avicennia officinalis* are the dominant species of Puthuvypin. In the present study *Avicennia officinalis* was found to be the early colonizer followed by *Rhizophora*, *Derris* and *Acanthus* species indicating fast changes in the mangrove vegetation in Cochin region. Around 2.24ha of mangroves are spotted in the Mangalavanam Bird Sanctuary. The species such as *Avicennia officinalis*, *Rhizophora mucronata*, *Acrostichum aureum*, *Acanthus ilicifolius* and *Bruguiera parviflora* were observed during earlier studies (Basha 1992) but the species of *Bruguiera parviflora* was not spotted in the present investigation. Very small patch of mixed mangroves of *Avicennia officinalis*, *Bruguiera sexangula* and

Acanthus ilicifolius were reported along the Kundannur region while species *Excoecaria agallocha* and *Rhizophora apiculata* along with *Acanthus ilicifolius* existed in a regenerating stage along Kumbalam region. In general, species of *Avicennia*, *Acanthus* and *Rhizophora* occupied seaward assemblage while species of *Bruguiera* and *Excoecaria* inhabited the landward zone. The adaptability of *Avicennia officinalis* to rarely inundated and low salinity areas were clearly evident in its distribution in the intermediate zone. *Rhizophora mucronata*, *R.apiculata* and *Acanthus ilicifolius* were encountered only in the fringing zone and not found elsewhere. Kurian (1980) reported patchy distribution of mangrove species in Cochin region with dominance of *Acanthus ilicifolius, Avicennia officinalis, Rhizophora* spp. and *Hibiscus* spp. Ramachandran et al., 1986 also reported the occurrence of *Acanthus*, *Excoecaria, Aegiceras***,** *Avicennia, Rhizophora* and *Clerodendron* species in reclaimed islands along Cochin backwaters. Muralidharan (1984) supported the dominance of *Acanthus* spp. in Cochin region and reported that tidal inundation, moderate soil salinity, fine gained soil with high silt and clay and low redox potential of Cochin area favoured the easy colonization of the species. The species *R. mucronata* and *B. cylindrica* were the dominant species reported along Panambukad region (Ramachandran and Mohanan, 1987) while the present study observed the dominance of *Bruguiera* species (*B. gymnorrhiza*, *B. cylindrica*) indicating more of a landward expansion of mangrove vegetation.

In the past Kottayam district exhibited luxuriant mangrove vegetation while in the present survey only fragmented patches of mangroves with very few representatives was encountered, possible due to the restriction of saltwater intrusion after the commissioning of Thanneermukkom barrier constructed in Vembanad estuary. The drastic changes in the physico-chemical conditions have resulted in severe regeneration problems in many of the mangrove habitats. In the present study mangroves were spotted only along Kumarakom Bird sanctuary, Pallichira and Vaikom. Mangroves of Kumarakom were facing serious threats due to tourism activities. The mangroves of Kumarakom were grouped under mangroves of Alappuzha district by Botanical survey of India (2018) and reported the common occurrence of *Avicennia marina* and degraded patches of *A. officinalis.* A mixed population of *R. mucronata* and *B. gymnorrhiza* bordering the Kumarakom estuary was reported by Ramachandran and Mohanan (1987). The present study spotted the occurrence of *Acrostichum aureum, Acanthus ilicifolius, Rhizophora mucronata, Excoecaria agallocha* and *Bruguiera sexangula* with *Rhizophora mucronata* and *Acrostichum aureum* inhabiting the fringing zone and all other species towards the landward margin.

In the central part of Kerala, the fringing zone is more or less reduced and occupied by few species such as; *Sonneratia alba, Avicennia marina, Rhizophora mucronata* and *R. apiculata.* The species such as *Acanthus ilicifolius, Kandelia candel, Sonneratia caseolaris, Excoecaria agallocha, E. indica* and *Avicennia officinalis* forms a broad mixed intermediate zone which gradually proceeds to landward zone of *Bruguiera* spp. and *Acrostichum aureum.*

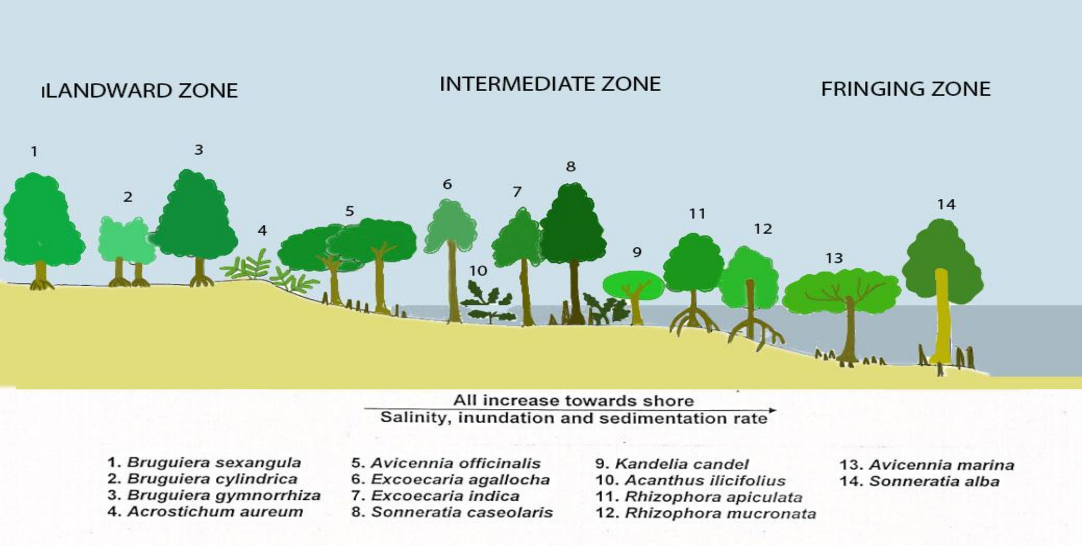


Figure 4.58 Zonation along the transect of mangrove vegetation of Central Kerala

c. Southern zone

Alappuzha being the land of backwaters and swamps has patches of mangrove vegetation confined in and around Kayamkulam and Vembanad backwater areas. *Acanthus ilicifolius, Excoecaria indica* and *Rhizophora mucronata* being the major species, followed the general zonation pattern with Rhizophora spp., *Avicennia* spp. and *Sonneratia* spp. towards the fringing zone. The intermediate zone was occupied by *Kandelia candel* and *Lumnitzera racemosa* while, *Excoecaria* spp., *Bruguiera* spp. and *Aegiceras corniculatum* were found in the landward zone. Remadevi and Binoj Kumar (2000) spotted the occurrence of *Acanthus ebracteatus* in Aroor region of Alappuzha however the present study could not identify the species from Aroor region but was spotted in Kannur district with low abundance. Obstruction of saline water intrusion also resulted in the invasion of mangrove associates like *Barringtonia racemosa*, *Annona glabra* and *Pandanus tectorius* in many sites.

Along the southern zone, Kollam district exhibited the highest species diversity but exist as small isolated strands or narrow continuous belt due to increasing human settlements and tourism activities. The present study encountered species of *Ceriops tagal* from Vincent Island, Kollam, which was considered to be extinct in Kerala coast. Wight (1796 – 1872) first reported this species from Kollam and was also described by Gamble (1915) in “Flora of the Presidency of Madras”. Until the recent reports by Vidyasagaran and Madhusoodanan (2014) the species was considered as extinct along Kerala coast. Similarly the present study spotted the occurrence of rare species of *Avicennia alba* along the Ayiramthengu and Thekkumbhagam islands even though no reports showed their presence after Kurian in1984. Blasco (1975) reported the predominance of *Acanthus ilicifolius* along the Kollam backwaters. Later on Bourdillon (1908) identified the occurrence of *Bruguiera gymnorrhiza* and two species of *Rhizophora* from the district. Studies by ENVIS center (BSI, 2018) also spotted mangroves along Adventure Park Asramam and Munrothuruthu islands but both the sites were included under Thiruvananthapuram district division. The report identified only two species: *Excoecaria agallocha* and *Acrostichum aureum* along the Munrothuruthu area (Munro islands) in contrast to the present study were highest species diversity was observed in Kollam (15sps.) and Munrothuruthu displayed 5sps. Mixed mangrove vegetation with matured trees was reported in Asramam region with species of *Sonneratia caseolaris*, *Bruguiera parviflora* and *Thespesia populnea* (BSI, 2018). Sekaran et al., 2015 reported 2.5ha of mangroves along Ayiramthengu and 1.5 ha area along Munrothuruthu respectively. Even though Thiruvananthapuram district, endowed luxuriant mangrove vegetation in the past, it was found to be severely degraded especially along the Akkulam-Veli estuarine region. The occurrence of *R. mucronata, Derris trifoliate, Acanthus ilicifolius* and *Avicennia officinalis* were reported by Thomas (1962) and Rao and Sastri (1972) from Veli region but the present study could identify only three species. The mangroves exhibited patchy occurrence with dominance of *Acrostichum aureum* clearly marking the degree of degradation.

The species diversity was high in southern zone (Kollam, Alappuzha) exhibiting a larger extended fringing zone, more or less overlapped by intermediate zone. *Avicennia marina, Sonneratia caseolaris, Kandelia candel, Acanthus ilicifolius, Ceriops tagal, Avicennia alba, Rhizophora mucronata* and *R. apiculata* dominated the fringing zone. The intermediate zone was occupied by species of *Aegiceras, Lumnitzera, Avicennia* and *Excoecaria*. Species of *Bruguiera, Excoecaria indica* and *Acrostichum* inhabited the landward margins.

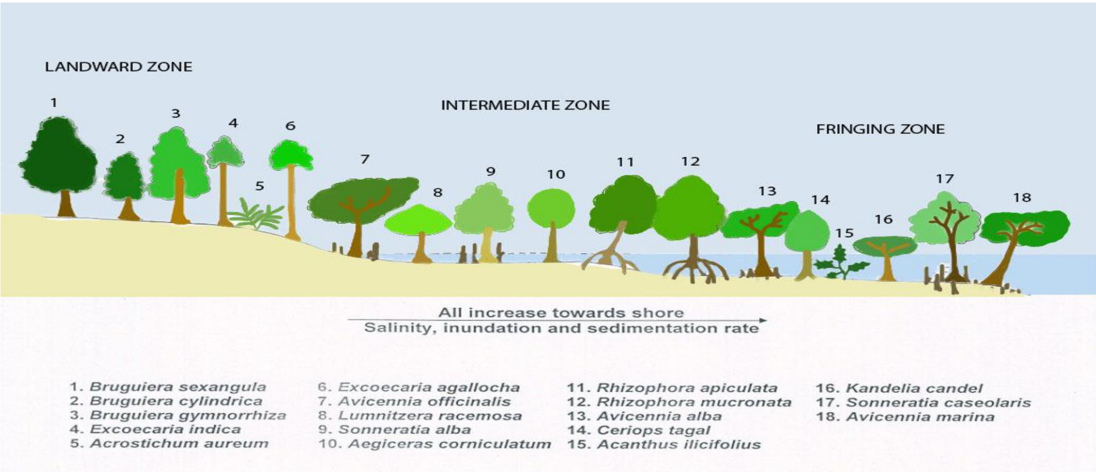


Figure 4.59 Zonation along the transect of mangrove vegetation of Southern Kerala

In the present study it was found that the mangrove ecosystem in Kerala have been degrading on large scale due to scale reclamation and constructional activities, natural calamities and climate change issues. Therefore many species are disappearing at a faster rate from the Kerala coast. *Bruguiera parviflora* reported in earlier studies has faced extinction and many species such as *Ceriops tagal, Avicennia alba* and *Sonneratia alba* has spares population. The vertical rise in water column has led to destruction of many mangroves and associated flora and also resulted in a gradual shift of mangroves to landward positions. The species of *Avicennia* shows a landward shifting as a result of sea level rise, at the same time many of sites exhibited a hindrance in landward expansion of mangroves due to human encroachments. Eventually most of the mangroves exist as narrow bands along the coast. Many of the study sites showed the dominance of associated flora, taking over major portion of the mangrove habitat. Singh et al., 1990 reports unsuccessful natural regeneration in highly disturbed mangrove habitats. In such conditions *Acrostichum aureum* and *Acanthus ilicifolius* are reported as invader species. During the present investigation, *A. officinalis* was found to be the fast invader of disturbed land followed by species of *Acanthus* and *Acrostichum* thus indicating more hardy and resistant nature of these species to stressed environment. It was observed that the environmental conditions and topography varied between the seaward belts, dense forest, mixed zones and clumps thus all the mangrove sites studied were so variable that the local zonation pattern cannot by validly extrapolated for the entire Kerala coast.

In general, the mangrove habitats of all the three zones of Kerala exhibited a wide-range similarity, even though exceptions were marked in many sites. The zzonation pattern showed that the species of *Avicennia*, *Sonneratia*, *Kandelia* and *Rhizophora* formed the seaward assemblage or fringing zone in most of the districts (Kasaragod, Kannur, Malappuram, Ernakulam, and Alappuzha). These species were replaced by *Acanthus ilicifolius*, *Acrostichum aureum* and *Avicennia officinalis* in Kozhikode and by *Aegiceras corniculatum* and *A. ilicifolius* in Thrissur. In Alappuzha, *Rhizophora* spp., Avicennia spp. and *Sonneratia* spp. occupied the fringing zone while *Kandelia candel* and *Lumnitzera racemosa* showed a shifting towards the intermediate zone. *Avicennia marina, R. mucronata, Avicennia officinalis* were seen parallel to the estuarine banks in Kollam. *R. mucronata* and *Acrostichum aureum* were the only species occupying the fringing zone in Kottayam, rest all the species were present in the landward region. However, intermediate zones were mainly inhabited by *A. officinalis* and *L. racemosa* while species of *Bruguiera* and *Excoecaria* occupied the landward regions. *Excoecaria agallocha* preferred both landward and intermediate zone. *Aegiceras corniculatum* occupied the landward region in Kasaragod and Kannur while in other districts it was seen in the fringing zone. Such a bimodaldistribution pattern was exhibited by *Avicennia marina,* which occupied a high tide level in Kannur while in Kollam they prefered the low tide level. In Kollam *Lumnitzera racemosa* was seen towards the landward region.

iii. Mangrove community and Forest type

In the present study based on percentage of tree density eight types of mangrove communities were identified from ten district of Kerala: (i) *Acanthus ilicifolius* dense, (ii) *R. mucronata* dense, (iii *Bruguiera* spp. dense, (iv) *Avicennia* spp. dense, (v) *Kandelia candel* moderately dense, (vi) *Excoecaria* spp. moderately dense, (vii) *Sonneratia caseolaris* moderately dense, (viii) Mixed vegetation. Most of the sites showed the abundance of *Acanthus ilicifolius,* but the most prominent Acanthus *ilicifolius* dense community was observed in Kumbala North (Kannur), Anapuzha (Thrissur) and Thirunettur (Ernakulam). *Rhizophora mucronata* dense communities were found in Manjeswaram, Pazhayangadi, Pappinissery, Ezhome, Perumba, Chettuva, Aroor South, Kumbalam, Asramam and Puthenthuruthu. Most of the islands of Alappuzha district exhibited this type of community.

Majority of the sites were *Avicennia* spp. dense community. Kumbala South, Mogral Puthur, Kottapuram, Valapattanam, Kunjimangalam, Thavam, Edakkad, Koduvalli, Beypore, Pullunni, Mangathiripalam, Tanur, Ponnani, Mullassery, Chapara, Poyya, Chellanam, Panangad, Valanthakad, Elankunnapuzha, Cherai, Pallipuram, Sattar Island, Puthuvypin, Bolgatty showed the dominance of *Avicennia officinalis* species whereas Edayilakadu, Kavai, Dharmadam showed dominance of *A. marina* species. *Bruguiera* spp. dense community was observed in many sites where the mangroves occupied more towards landward zone and the fringing and intermediate zones were reduced. Kumbalanghi, Valappu, Vallarpadam, Edakochi, Panambukad showed the dominance of *Bruguiera gymnorrhiza.* Pallichira, Kumarakom were the only two sites marked with the rare species *Bruguiera sexangula. Sonneratia caseolaris* community was found in Chandragiri, Chandiroor, Eramalloor and Thotappally region while the other species of *Sonneratia* (*S. alba*) was rare in occurrence. *Kandelia candel* dense community was observed along the northern zone mainly in the sites of Neeleswaram, Achanthuruthu, Kariyamkodu and Thazhepalam.

Chempallikundu, Edattu Kandankali, Narayanamangalam, Ottamassery, Azheekal were dominated by *Excoecaria agallocha* community. However five types of mangrove communities were identified along the Kerala coast by ENVIS center (BSI, 2018). The '*Rhizophora apiculata* - Moderately Dense' community was most common type and was reported along Kasaragod, Kottiyur, Valapattanam areas and Pazhayangadi river. '*Kandelia candel* - *Rhizophora apiculata* - Moderately Dense' was observed along Kasaragod range where more of plantation activities were taking place. The community of *'Excoecaria agallocha – Acrostichum aureum* – Sparse' reported mainly along the Munrothuruthu and Ashtamudi region. 'Mixed mangroves' areas like Pazhayangadi, Kunjimangalam, Valapattanam, Mangalavanam Bird Sanctuary and Puthuvypin area, exhibiting an aggregation of *Avicennia officinalis*, *A. marina*, *Rhizophora mucronata*, *R. apiculata*, *Sonneratia caseolaris*, *S. alba*, *Aegiceras corniculatum* and *Excoecaria agallocha.* Mixed mangrove vegetation was evident in most of the study sites. Mainly the species of *Avicennia, Sonneratia, Acanthus* and *Rhizophora* mixed, fringing zones prevailed in the study sites. In specific sites, species of *Aegiceras, Kandelia* and *Lumnitzera* were also evident in the fringing zones. Similarly the intermediate and landward zones were occupied by mixed vegetation of mangrove species indicating a more disturbed mangrove habitat throughout Kerala. Very few sites like Chettuva exhibited larger extend of single species zonation.

The present study figured four types of mangrove forests throughout Kerala: Fringing mangrove forest (Kozhikode, Malappuram and Ernakulam), Overwash mangrove forest (Thrissur, Ernakulam Alappuzha), Hammock mangrove forest and Dwarf forest type (Thiruvananthapuram). The fringe mangroves are most common in Kerala and almost all the larger and the rich stands of mangroves that exist today in Kerala, are of this type. In a few cases, the mangrove stands on mudflats are found associated with small islands or islets in the coastal zone remain flushed by tides daily during high tide, forming over-wash type of mangroves.

iv. Mangrove cover of Kerala

Mangroves are one among the most productive ecosystem of the world, providing a wide variety of goods and services to the adjacent coastal communities, but at present these are the most vulnerable ecosystem facing immense threats due to anthropogenic activities. Even though mangrove loss is taking place in many of the mangrove habitats of Kerala, the loss of mangrove area is unknown as most of these ecosystems are unmapped and lack authentic scientific knowledge on the current status. Only few reports are available (Table 4.1) and most of these reports are based only on major dense vegetation of Kerala while patchy as well as open vegetation are neglected. Net mangrove cover of Kerala was reported as 900ha (FSI, 2017), but the study was focused only on three major districts Kannur, Kasaragod and Ernakulam. However much greater area under mangrove vegetation (1782ha) was observed in the present study similar to the reports of Neethu and Harilal, 2018 (1953ha). The mangrove area in Kannur was reported as 3500ha by Mohanan (1997), however the area was found to be decreasing in the after years. Kerala forest Department (2006) reported 1671ha of mangrove area while the value further reduced to 1100ha as per Vidyasagaran and Madhusoodanan (2014).

Ernakulam district displayed the second largest mangrove cover in Kerala (396ha) while much higher area was reported by Vidyasagaran and Madhusoodanan, 2014 (600ha) and Neethu and Harilal (615ha). The present study identified 110ha of mangrove cover along Alappuzha district, while comparatively lower area were reported by Mohanan, 1997 (25ha). Neethu and Harilal (2018) reported 103ha of mangrove area along Alappuzha, however the mangrove stands of the district was completely neglected in reports of Kurien et al. (1994) and Forest Survey of India. The area mapped under Thiruvananthapuram district during the present study was found to be much lower (5ha) compared to earlier reports of Basha, 1991 (23ha); Mohanan, 1997 (15ha); Vidyasagaran and Madhusoodanan, 2014 (28ha). The districts of Kollam (36ha) and Kozhikode (74ha) also showed decline in mangrove cover compared to earlier reports.

The present study identified greater extend of mangrove loss along Ernakulam district. Even though Ernakulam district has better representation of mangrove (396ha) in the central zone of Kerala, a large portion of mangroves were lost from the Puthuvypin region during the last five years. The construction of LNG terminal and Goshree bridges have consumed a larger portion of mangroves from Puthuvypin thereby greatly reducing a net mangrove loss from 314acres to 185 acres. Nearly 70 acres of mangrove area were lost due to the reclamation activities by Kerala University of Fisheries and Ocean Sciences (G. Krishnakumar, 3rd Feb 2013; *The Hindu*). The dredging activities carried out by Cochin Port Trust has resulted in the loss of 25acres of mangrove land while almost 23 acres where lost due to construction of link roads of Goshree bridges. Similarly 11acres of mangrove area was reclaimed by Centre for Marine Living Resources and Ecology for infrastructural developments. An unaccounted loss of mangroves have taken place in the Puthuvypin region due to clear felling and by the discharge of large amount of waste and byproducts from the construction sites of LNG terminal. Since most of these losses were unnoticed as authentic information were not released by the officials and most of the information cited were based on the newspaper reports. Valanthakad region represents a good patch of mangroves vegetation with relatively few human settlements in Ernakulam district, but various types of human interference are posing threats to these habitats. A large extend of mangrove were lost in fire in the region as per the reports of *The Hindu* (14th Oct. 2007) and neither the cause nor the extent of mangrove loss were evaluated as no scientific information is available on the current extent of mangroves in these areas. Edakochi had a good bio-shield of mangroves adjoining the barren paddy fields, was proposed for the construction of International cricket stadium by Kerala Cricket Association. Even though the proposal was abandoned due to the violation of Kerala Conservation of Paddy land and Wetland Act, 2008, nearly 4.10acres of mangroves were cleared by the time. Even though Mangalavanam Bird Sanctuary represent the only protected mangrove patch in Ernakulam district, the ecosystem is also facing serious threats due to greater load of pollution and interruption in saline water intrusion.

Comparatively less degradation was noticed in other districts. Small scale destruction of mangrove patches was noticed in areas of Manjeswaram and Kumbala

(Kasaragod). However the district also exhibit initiation of conservation programmes. In Kannur, nearly 184acres of land in Valapattanam has been acquired by Kerala Industrial Infrastructure Development Corporation for the implementation of Irinav power project. If the project is put into action nearly one million tonnes of coal will have to be burnt per year and the ashes would be dumped to the adjoining mangrove habits causing pollution problems in near future. The mangroves of Kottayam are also subjected to tourism activities and only a few patches under Kerala Tourism and Development Corporation is found to be intact.

Plate 4.2 The proposed site for the international cricket stadium at Edakochi. (Source: *The Hindu.*)

Plate 4.3 Construction of roads and bridges through mangrove habitats of Puthuvypin

Plate 4.4 Acid burned mangrove patches of Puthuvypin

Plate 4.5 Waste disposal and mangrove trees felling by local community in Ernakulam

Plate 4.6 Land filling in mangroves of Kasaragod

Plate 4.7 Construction of embankments in mangrove site of Kollam

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Chapter 5

Anatomy of selected True Mangroves and Associates

Contents

5.1 Introduction

Mangroves are highly salt tolerant plants of intertidal zone, with well-developed morphological, anatomical and physiological adaptions to survive in such harsh environments. The mangrove soils are highly anoxic and the most striking adaptation of the mangroves to survive such condition is the development of aerial roots. *Rhizophora*, the fringing species of mangrove habitats produces stilt roots which are several meters above ground providing sufficient aeration and support in water logged conditions. However the stilt roots of *Bruguiera* and *Ceriops* are much reduced to buttresses as these species are found more landward positions in the mangrove habitats. Pneumatophores are the characteristic root adaptations of *Avicennia* spp. and *Sonneratia* spp. These are negatively geotrophic roots which enable them to breath in submerged conditions. The pneumatophores of *Avicennia* are small, pencil like attaining a height of 15-30cm, while the pneumatophores of Sonneratia are large, woody and grow up to 3m. The knee roots (*Bruguiera* and *Ceriops*) and plank roots (*Heritiera, Excoecaria*) are also root modifications of respective species.

The most efficient filtering mechanism is salt excretion and exclusion exhibited by various mangrove species. Many of the species take off salt along with water and excess salt are expelled out through special structure called salt glands present on the leaf surface. While many others store the salt in older leaves and are shed at the earliest. The other category of mangrove excludes salt at root level itself.

Thus most of the mangrove species have developed a set of morphological and anatomical adaptations to withstand these harsh environments. The basic anatomical structures of roots, leaves and stems of both dicot and monot plants show variation, which are further modified in mangrove species.

5.1.1 Leaf Anatomy

Two types of leaves can be identified based on orientation of leaves on the main axis: dorsiventral and isobilateral. The dorsiventral leaves are attached to the main trunk in such a manner that it is perpendicular to the direction of sunlight. Most dicot plants exhibit dorsiventral leaves. While the other category, the leaf orientation is parallel to main axis. Such type of leaves is characteristics of monocot plants. The anatomy of leaves reveals an upper and lower epidermis. The upper epidermis possess cuticle which helps in excess loss of water through transpiration. Followed by upper epidermis is the parenchymatous hypodermis. The mesophyll cells fill the portion between both epidermises. The vascular bundles are embedded in the mesophyll cells and possess xylem, phloem and cambium. The thickness of cuticle, number of epidermal and hypodermal layers, nature of xylem and phloem exhibit variations with species. Similarly the anatomy of leaves in both monocots and dicots exhibit certain variations (Table 5.1).

Table 5.1 Difference in leaf anatomy of dicots and monocots

	Dicots	Monocots
Leaves	Dorsiventral	Isobilateral
Stomata	Hypostomatic- stomata present only on lower epidermis.	Amphistomatic-both upper and lower epidermis have stomata.
Guard cells	Kidney shaped	Dump bell shaped
Mesophyll cell	Differentiated into palisade and spongy tissues	undifferentiated
Vascular bundle	Single at mid rib	numerous
Bundle sheath	parenchymatous	sclerenchymatous

5.1.2 Stem Anatomy

The anatomy of typical monot stems is circular in outline with a well-defined epidermis. The epidermal layer has an outer cuticle interrupted by stomata and hairs. The epidermal layer is followed by hypodermis, ground tissues with numerous scattered vascular bundles. The hypodermis is formed by 2-3 layers of sclerenchyma cells. The ground tissue is usually made of parenchyma cells and there is no clear demarcation of cortex, endodermis, pericycle and pith. The vascular bundles are small, numerous and scattered in ground tissue. They are usually conjoint, collateral, closed and endarch. The bundle sheath is usually made of sclerenchyma cells. The xylem consists of vessels, tracheids and xylem parenchyma and the phloem with sieve tubes and companion cells. Both phloem fibers and phloem parenchyma are absent in monocots. Secondary thickening is usually absent in monocots, but at times certain species like Dracaena exhibit anomalous secondary thickening.

The dicot stems possess barrel shaped epidermal layer, with thick cuticle and multicellular hairs. The hypodermis is usually formed of multi layered collenchyma cells. The chlorenchymatous cortex is limited by a will developed endodermis. The multilayered pericycle has definite number of vascular bundles arranged in a circular fashion. The vascular bundles are conjoint, bicollateral, open and endarch. The xylem and phloem cells are separated by thin walled rectangular cells of cambium. The dicots exhibit secondary thickening, developing phellogen cells interrupted by lenticels.

Table 5.2 Difference in stem anatomy of dicots and monocots

	Dicots	Monocots
Epidermis	Single layered Parenchyma cells	Single layered Parenchyma cells
Hypodermis	Few layered Collenchyma cells	Few layered Sclerenchyma cells
Ground tissue	Differentiated into cortex, Endodermis, pericycle, pith	Undifferentiated
Vascular bundle	Wedge shaped	Oval shaped
Bundle sheath	Conjoint, bicollateral, open, endarch Lysigenous cavity absent	Conjoint, collateral, closed, endarch present

5.1.3 Root Anatomy

The root anatomy exhibits further variations from that of stem. The root anatomy divulges an outer epiblema, followed by cortex. The cortex is limited by endodermis. Lining the endodermal layer is the pericycle, which gradually leads to the vascular bundles. The pith is parenchymatous as in that of stems. The monocot roots exhibits much variations from that of dicots. The number of each layer as well as the cell types varies among species and ecological conditions. The basic difference between the stem and root anatomy of the dicots are listed in Table 5.3.

Table 5.3 Anatomical differences in dicot roots and stems

	Stem	Root
Epidermis	Cutinised	Not cutinised
Stomata	Present in young stem	Absent
Stem airs	Unicellular to multicellular	unicellular
Cortex	Narrow Differentiated to outer, middle, inner layer	Broad, Undifferentiated
Hypodermis	present	absent
Endodermis	Not distinct	distinct
Pericycle	multi-layered	Single layered
Vascular tissue	Conjoint, collateral	Radial
Xylem	Endarch	Exarch

Even though most of the mangrove species are dicots, the leaf, stem and root anatomy displays variation from the above mentioned characters due to the ecological conditions prevailing in the respective sites.

5.2 Review of literature

Mangroves are ecological grouping of unrelated plant species, sharing a set of uniform morphological, anatomical and physiological adaptations. Various studies by Dolph and Dilcher 1980; Givnish, 1984 reported that the leaf size, shape and anatomical features are greatly influenced by various environmental factors. The habitat related variation in leaf structure was elaborated by Taurner and Tan (1991). Stace (1966) studied four genera of Rhizophoraceae family to identify the intergeneric anatomic differences while Rao and Hugh (1984) studied the leaf structure of sixteen species of mangroves of Singapore. Rao (1977) also studied the leaf characters of *Aegiceras* and *Scaevola* species. However the study on leaf variation in other coastal plant species was studied by Waisel (1972) and Rao (1972). Ika (1996) studied the effect of nutrient enrichment on leaf anatomy of *Rhizophora mangal*. (Lin et al. (1987) and Wang and Lin (2000) studied the physiological adaptations of seven mangrove species in Fujian, China. Das et al., 1995 studied the deeply sunken stomatal structures of *Heritiera fomes.* Hannes (2011) studied the stomatal structure of *Rhizophora* species. The ontogeny of stomata and glandular hairs of Indian mangrove were elaborately discussed by

Sauren Das (2002). Similar studies on stomatal ontogeny were reported by many researchers; Stebbins and Khush (1961), Fryns-Claessens and Van Cotthen (1973), Nyawuame and Gill (1990), Terhune et al. (1991), Das and Paria (1992), Karatela and Sangal (1993).

Paramita et al., 2005 provided an elaborate discussion on the leaf micromorphology and water effluxes in Indian mangroves. The studies on the leaf thickness and stomatal structure of *Avicennia* and *Sonneratia* were given by Yuanyue et al., 2009. The leaf anatomical structure of selected mangroves was elaborated by Poompozhil and Kumarasamy (2014). The leaf anatomy of Rhizophoracean members in Port Blair was studied by Abhinay and Jayakumar (2015). Morphological and anatomical aspects of leaves of *Rhizophora mangal* under different lighting conditions were reported by Camilla et al., 2015.

Most of anatomical studies were based on the leaf anatomy however root and stem anatomy were also reported from various parts of the world. Horizontal structures of pneumatophores of *Avicennia* were given by Hovenden and Allaway (1993). Allaway et al. (2001) studied the root anatomy of *Rhizophora* and reported the presence of more arenchymatous cortex. The xylem anatomy of *Rhizophora* spp. was studied in depth by Stern and Brizicky, (1957). Lawton et al. (1981) studied the root of *Avicennia* of Japan and identified the various gas spaces and reported the lysigenous origin of such air chambers. Many studies were conducted on the root anatomy of *Avicennia marina* (Chapman, 1939; Baker 1915; Curran, 1985).

Many anatomical studies have been reported on the root anatomy of mangroves (Steinke et al., 1993; Frusher et al., 1994; Lee, 1998; Lee, 1999; Cannicci et al., 2008).William et al., 2001 provided a detailed study on the gas space and oxygen exchange in the roots of *Avicennia marina.* Hery Purnobasuki (2011) studied the lenticel structures of *Avicennia marina.* The wood and root anatomy of many mangrove species are well documented by Walsh (1974) and Lin et al. (2000). The wood anatomy and the concentric xylem rings were investigated by Gill (1971). Comparative morphology and anatomy of few mangrove species in Sundarbans, West Bengal, were reported by Humberto et al., 2012.

Krishnamurthy et al (2014) studied the physiological adaptation of mangrove roots in highly saline soil and opined that the suberin deposit in the epidermal cells of the roots is responsible for the filtration of salt. Subrin is the polyphenol compounds deposited in the cell walls of roots which acts as a plasma membrane allowing the water movement while highly restrict the salt uptake (Kolattukudy, 1984). Nandy et al. (2007) studied the specific leaf area, stomatal conductance, chlorophyll content and photosynthetic rates in mangrove species of *Bruguiera, Excoecaria, Heritiera, Phoenix* and *Xylocarpus*. Sobrado (2007) studied the leaf xylem anatomy of *Laguncularia racemosa* and reflected various structural changes based on variation in salinity concentration. A comparative leaf anatomy of 4 mangrove species of Mangalavanam mangroves were given by Vidyasagaran and Madusoodanan (2014). Vidyasagaran et al. (2014) also provided an elaborate study on wood anatomy of mangroves in the west coast. However very few studies were reported on anatomical aspect of mangroves of Kerala coast.

5.3 Methodology

The specimens of both mangrove and associated plants were collected from Station1 Aroor, Ernakulam (detailed description of study area in Chapter 2). The fresh leaf samples of mangroves (*Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Avicennia officinalis*, *Acanthus ilicifolius* and *Acrostichum aureum*) and associated plants (*Derris trifoliata, Thespesia populnea*) were collected from the study site. The pneumatophores of *Avicennia officinalis* and the aerial roots of *Acanthus ilicifolius* were collected from the same sites for anatomical study.

Free hand sectioning method as per Berlyn and Miksche (1976) was adopted for the anatomical studies. The specimens were cut into thin section using thin razor blades and placed in water to prevent formation of air bubbles. The sections were stained with safranin and excess stain was washed off with water. Temporary slides were prepared by mounting the sections in glycerol. The specimens were observed under microscope and photographed.

5.4 Results

5.4.1 Leaf Anatomy

i. *Rhizophora mucronata*

The leaves of *R. mucronata* were large, green, succulent and dorsiventral. The leaf anatomy of *R. mucronata* displayed an upper epidermis (2-3lyers) with thick cuticle. The lower epidermis was formed by 1-2 layers of cells. The upper epidermis was followed by three layers of parenchymatous hypodermis. The hypodermal cells contained numerous tannin cells. The mesophyll cells were composed of single layer of large palisade cells and 10-12 layers of spongy tissue. Mucilage cells or oil globules were seen in-between palisade cells. Both palisade and spongy cells were large and succulent. The vascular bundle was closed, collateral type with endarch xylem.

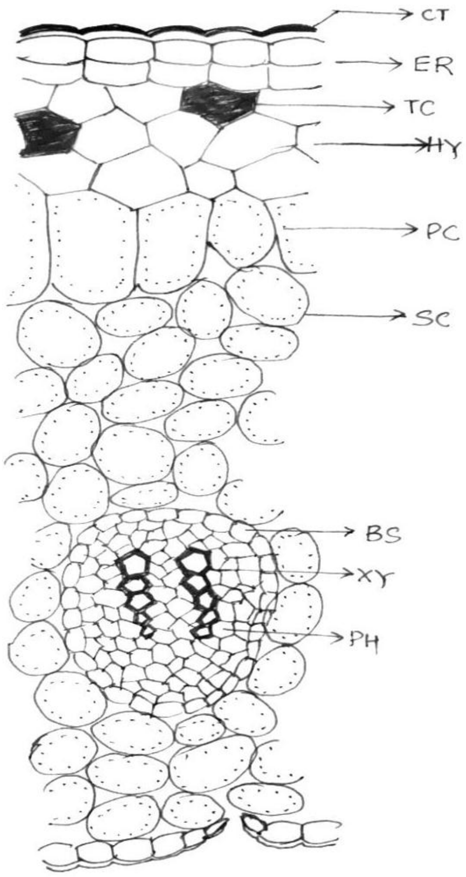


Figure 5.1 L.S of leaf of *R. mucronata*; CT- cuticle, ER-Endodermis, TC-tannin cell, HY- hypodermis, PC-palisade cell, SC- spongy cell, BS-bundle sheath, XY- xylem, PH-phloem.

ii. *Bruguiera gymnorrhiza*

The leaves are entire, thick, dorsiventral with prominent mid rib. The longitudinal section of leaf revealed single upper and lower epidermal layer of parenchymatous cells. The upper layer had thick cuticle coating. The upper hypodermis consisted of single layer of parenchyma cells. Lower hypodermis was absent. The mesophyll cells consist of four layers of palisade cells and 10-12 layers of spongy cells. The bundle sheath was formed of parenchymatous cells. The vascular bundle exhibited closed collateral bundles similar to *R. mucronata* but the xylem was exarch type.

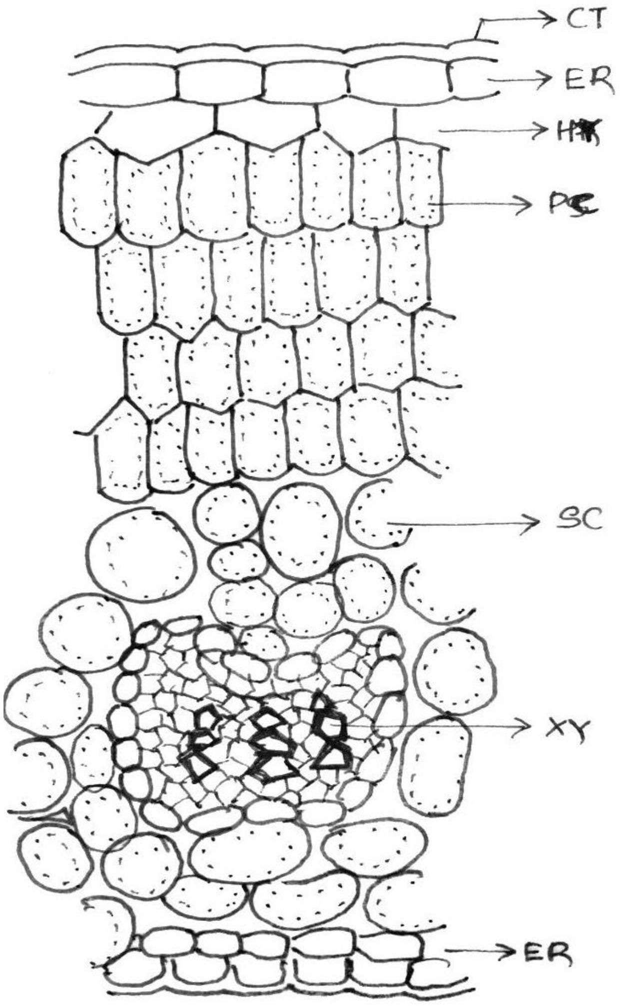


Figure 5.2 L.S of leaf of *B. gymnorrhiza* CT- cuticle, ER-Endodermis, HY-hypodermis, PC-palisade cell, SC- spongy cell, BS-bundle sheath, XY- xylem.

iii. *Avicennia officinalis*

The leaves of *A. officinalis* are smaller, thin and less succulent compared to the leaves of *Rhizophora* and *Bruguiera.* The L.S of leaf displayed single layered upper and lower epidermis. The cuticle was thin and the lower epidermis marked the presence of hairs. The hypodermis comprised of 4 layers of compressed parenchymatous cells. The vascular bundle was closed collateral type with mesarch xylem.

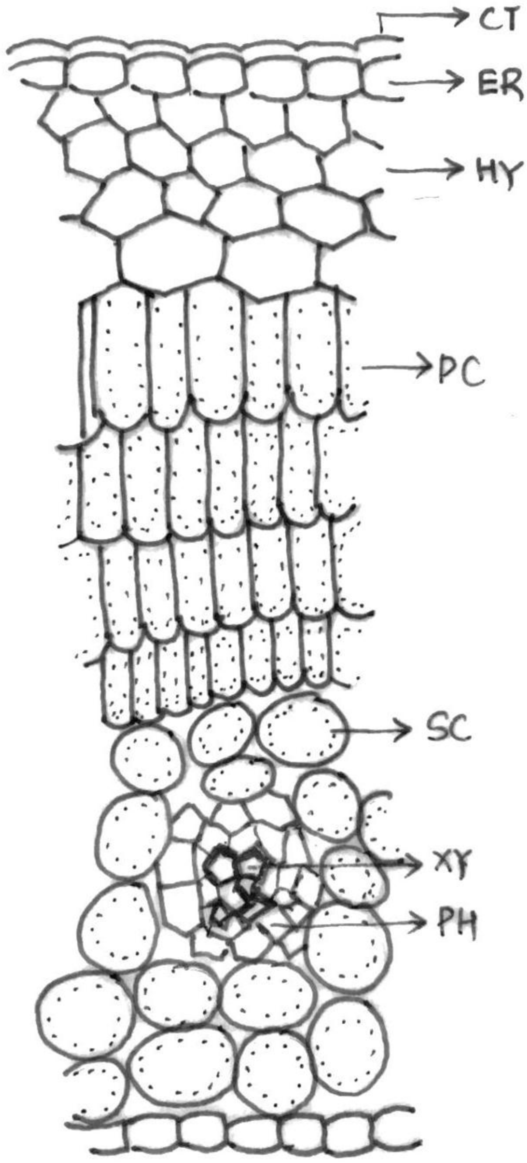


Figure 5.3 L.S of leaf of *A. officinalis* CT- cuticle, ER-Endodermis, TC-tannin cell, HY- hypodermis, PC-palisade cell, SC- spongy cell, BS-bundle sheath, XY- xylem, PH-phloem.

iv. *Acanthus ilicifolius*

The leaves are thick, leathery, dark green with spiny margin. The leaf anatomy exhibited thick cuticular deposition on both upper and lower epidermis. Both upper and lower epidermis compressed of single layer of cells. The upper epidermis was followed by 2 layers of hypodermal cells. The mesophyll call composed of 2 layers of palisade cells followed by 5 layers of loosely arranged spongy tissues. The vascular bundle exhibited closed collateral type with mesarch xylem.

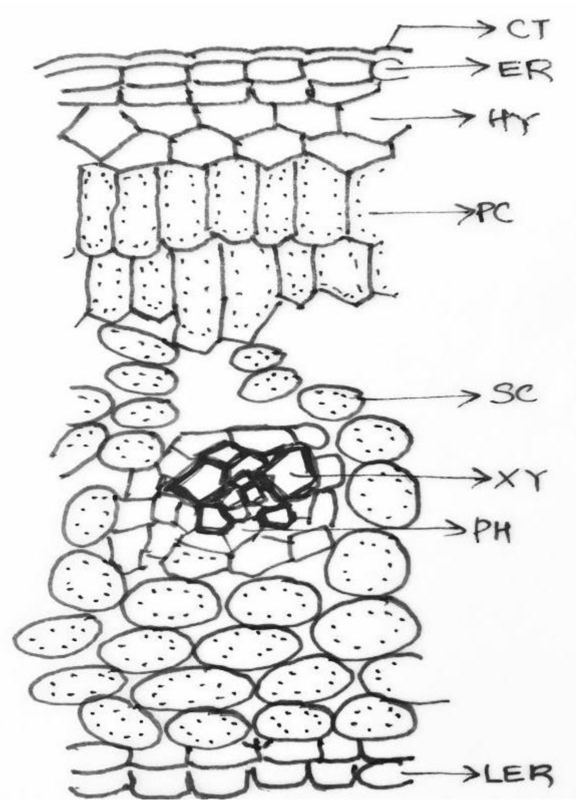


Figure 5.4 L.S of leaf of *A. ilicifolius* CT- cuticle, ER-Endodermis, HY-hypodermis, PC-palisade cell, SC- spongy cell, BS-bundle sheath, XY- xylem, PH-phloem, LER- lower epidermis.

v. *Acrostichum aureum*

The species is the only pteridophyte mangrove species. The fronts are large green with prominent mid rib. The anatomy revealed absence of cuticle and single layered upper and lower epidermal cells. The hypodermis composed of single layered sclerenchymatous cells. The palisade and spongy tissues were multi-layered.

The vascular tissues were loosely arranged without formation of a definite bundle. The xylem was exarch in nature.

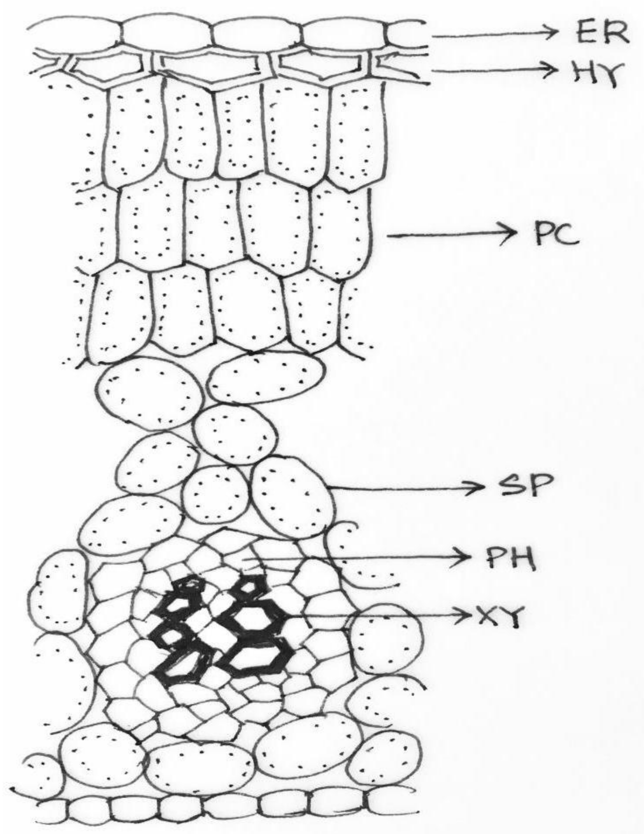


Figure 5.5 L.S of leaf of *A. aureum* ER-Endodermis, HY- hypodermis, PC-palisade cell, SC- spongy cell, XY- xylem, PH-phloem

vi. *Derris trifoliate*

The species is one of the major mangrove associate identified from the mangroves zones of Ernakulam. The leaves are simple, entire, thin and dark green in colour. The L.S. of leaf displayed a thin cuticle above the upper epidermis. The upper and lower epidermis was composed of single layers of parenchyma. Single layered parenchymatous hypodermis was evident beneath both upper and lower epidermis. The palisade tissues were composed of single layered compact cells and several layers of spongy cells were found in compartments. The vascular tissue exhibited open, bicollateral bundles with mesarch xylem.

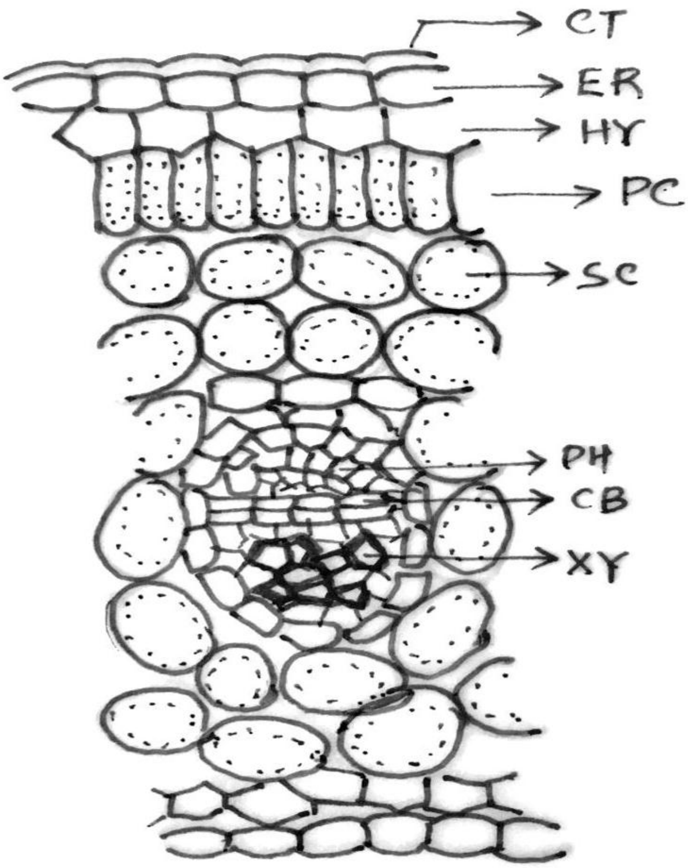


Figure 5.6 **L.S of leaf of *D. trifoliata*** CT- cuticle, ER-Endodermis, HY-hypodermis, PC-palisade cell, SC- spongy cell, CB- cambium, XY- xylem, PH-phloem.

viii. *Thespesia populnea*

The species represents the mangrove associate belonging to the family Malvaceae. The leaves are thin, green and characterized by hairy ventral surface of Malvaceae family. The leaf anatomy revealed thin cuticle in the upper epidermis and peltate hairs on the lower surface. Single layered parenchymatous epidermis bordered the both surface, followed by single layered hypodermis layer. The mesophyll tissue composed of single layered palisade tissue and multi layered spongy tissue. The vascular tissue composed of closed, collateral bundles with mesarch xylem.

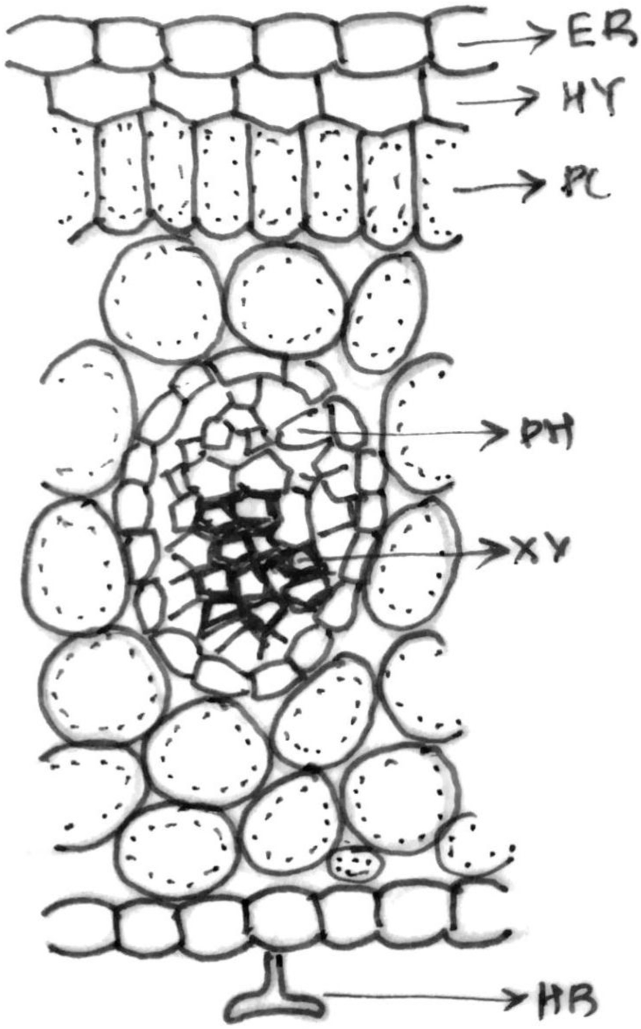
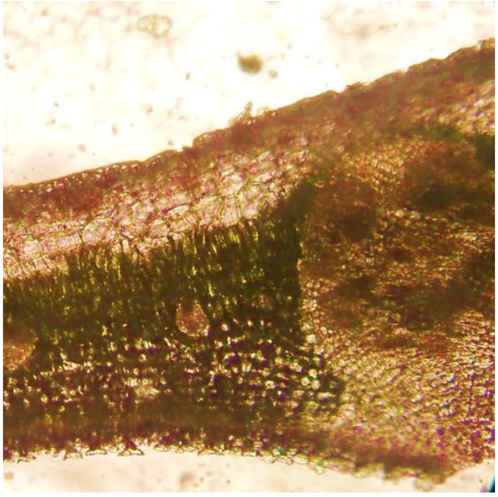


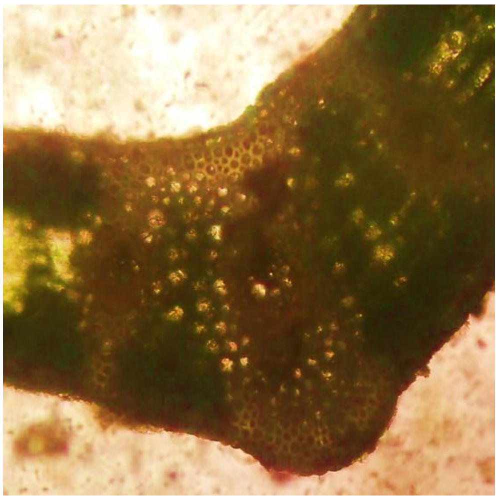
Figure 5.7 L.S of leaf of *T. populnea*; ER-Endodermis, HY- hypodermis, PC-palisade cell, SC- spongy cell, BS-bundle sheath, XY- xylem, PH-phloem, HR- hair

Table 5.4 Leaf anatomical features of selected mangroves and associates

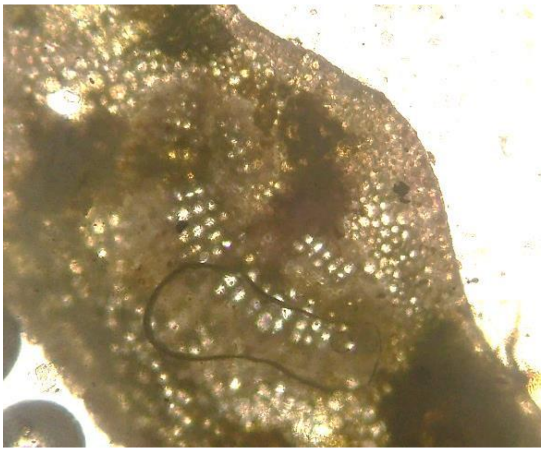
Species	Cuticle	Epidermis	Hypodermis	Palisade	Spongy cell	Vas. bun.	Xylem
R. mucronata	Waxy, thick	3(U), 1-2(L)	3(U)	1	10-12	Closed, collateral	Endarch
B. gymnorrhiza	Waxy, thick	1(B)	1(U), 2(L)	4	10-12	Closed, collateral	Exarch
A. officinalis	Waxy, hairy	1(B)	4	3	3-4	Closed, collateral	Mesarch
A. ilicifolius	Thick, both	1, glands	2	2	5	Closed, collateral	Mesarch
A. aureum	-	1(B)	1(B)	multi	multi	-	Exarch
D. trifoliata	thin	1(B)	1(B)	1	compartmented	open, collateral	Endarch
T. populnea	Peltate hairs (L)	1(B)	1(B)	1	Multi- space	Closed, collateral	Mesarch

U-upper, L- lower, B-both.





a. Avicennia officinalis *b. Acrostichum aureum*



c. Acanthus ilicifolius *d, Thespesia populnea*

Plate 5.1 (a-d) Leaf anatomy of selected mangrove and associated plant species

5.4.2 Anatomy of Pneumatophore

i. *Avicennia officinalis*

The small peg like, negatively geotropic roots are called pneumatophores and are characteristic feature of Avicennia species. The C.S of pneumatophore revealed a thick layer of periderm with numerous lenticular openings. The multilayered cork cells was followed the single layered phellogen. The cortex was composed of loosely arranged network of parenchymatous cells, producing large air cavity chambers for gaseous storage. The cortex is limited by single layered endodermis. The pericycle was composed of s2-3 layers of sclerenchymatous cells. The xylem was exarch in nature, with large parenchymatous central pith.

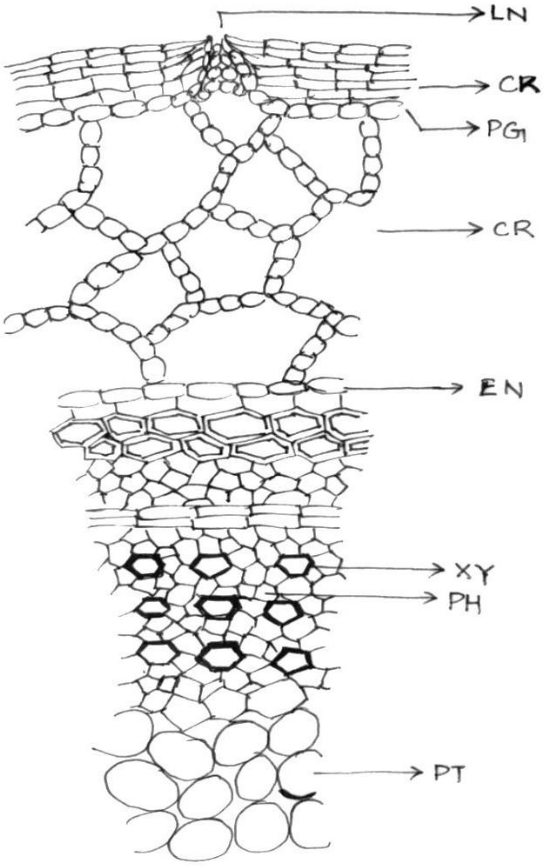
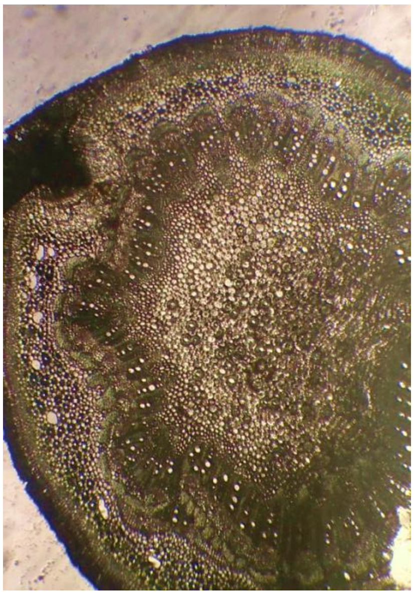
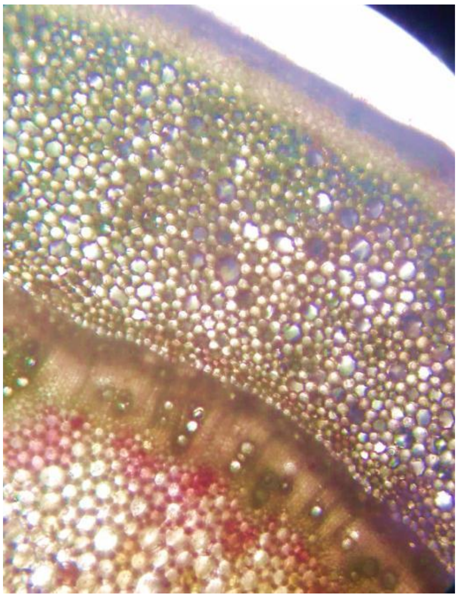


Figure 5.8 CS of Pneumatophore of *Avicennia officinalis;* LN-lenticel, CK-Cork, PG-phellogen, CR- cortex, EN-endodermis, XY- xylem, PH-phloem, PT- pith.



a. C.S of Pneumatophore



b. A portion enlarged

Plate 5.2 Anatomy of pneumatophore of *Avicennia officinalis*

5.5 Discussion

The mangroves are well adapted to saline water logged conditions and the exhibits more or less the anatomical features of the halophytes. Even the mangrove plants in the same habitat exhibit variation in leaf anatomy based on their physiological adaptations. For example the plants species which exclude salt at root level exhibit high suberin content in the epidermal layers of root to prevent salt intrusion into the cell. The suberin act as a plasma membrane permitting only the water movement while the solutes are prevented from entering the root cells. *Rhizophora* spp. are excellent salt excluders and such suberin deposits are reported in their roots. On the other hand species of Avicennia and acanthus are excellent salt excreters. Thus there is not such root modifications instead the excess salts are excreted through the salt glands in leaves.

The present study enumerated the leaf anatomy of five mangrove species; *R. mucronata, B. gymnorrhiza, A.officinalis, A. ilicifolius, Acrostichum aureum* and two mangrove associates; *Derris trifoliate* and *Thespesia populnea* from the mangrove habitats of Aroor. Most of the species excluding *Acrostichum aureum* all were dicots and thus the general leaf anatomy of the dicot leaves were evident with very few deviations. The leaves were dorsiventral. Most of the mangrove leaves were fleshy, flattened and shiny with coriaceous dorsal surface. Thick cuticle or wax deposition were evident on the upper epidermal layers. While most of the mangrove associates lacked thick cuticle and represented thin layer. The presence of thick cuticle in the upper epidermis is also reported by Naskar and Mandal (1999). The only exception was exhibited by the mangrove species of *Acrostichum,* which lacked the cuticle layer. The presence of sunken stomata, aqueous hypodermal layer, swollen cortical tissues, presence of sclerids, stone cells, tannin cells are some the characteristic features of mangroves. The salt glands in the leaves help in secreting excess salt to the dorsal surface of the leaf. These salt glands are also identified in some halophytes and hence were not considered as a key characteristic of mangroves. The present study identified the following anatomical features of halophytes (Table 5.5)

Table 5.5 Characteristic features of Halophytes

Veg. part	Morphology	Anatomy	Function
Leaf	Fleshy, flattened, shiny, large sized, dark green	-Thick cuticle, hairy - Salt glands -sunken stomata	-Reduce transpiration rate -Excrete excess salt -conserve water
Root	Pneumatophores, stilt roots, buttress	Lenticels, air cavity	Gaseous exchange

All these characters were exhibited by all the five mangroves selected for the study. However the associated flora; *Derris trifoliata* and *Thespesia populnea* showed deviations in leaf anatomy. The leaves of these species were thin and did not exhibit succulence. The cuticle layer was thin or absent. The palisade and spongy cells were reduced in numbers and compactly arranged in associates without air spaces. Special structures like sclerids (for mechanical strength), salt glands, non-glandular hairs, lenticels with air spaces etc. are most common among mangroves and rarely seen among associates. Thus the anatomical feature clearly indicate that the true mangrove species can grow in anaerobic soil, inundated twice a day, can tolerate high salinity and are found only in halophytic environment on the other hand mangrove associates grow in fringes of mangrove habitat, get inundated rarely and are also found in mesophytic environment.

The present study enumerated the modified morphological and anatomical characters of leaves and pneumatophore and found that to be in relation to halophytic adaptation. The leaf lamina is fleshy, flattened, shiny, coriaceous in dorsal surface, so that it can easily reflect bright sunlight and check the high transpiration rate.

The anatomy revealed thick cuticle and waxy epidermis with dense hair, unicellular /multicellular glands, sunken stomata, aqueous tissue in hypodermis and central pith, presence of sclerids and stone cells, salt glands and cork wart on lenticels, each helps in reducing the transpiration rate thereby storing of water, by maintenance of succulence. The stone cells and sclerids provide mechanical support while the salt glands help in excretion of excess salt.

Various stem characteristic such as swollen trunk base, gall, provide mechanical support and facilitate aeration. The greater number of vessels with and multiseriate fiber, secondary anomalous growth, helps in the uplift of a huge amount of water. The typical aerial roots, pneumatophores, cable roots, pseudo taproots, provide mechanical support and facilitate breathing. The anatomical features such as lenticels, number of air cavities and circular rings of sclerids aids in breathing and provide mechanical support.

Various reproductive adaptations like vivipary, cryptovivipary, facilitate seed germination while attached with mother plant are marked features of mangrove species. These reproductive organs also have numerous air cavities, conspicuous vacuum between seed and pericarp to support breathing and salt excretion as well as buoyancy to the propagules. Most of these characters are exhibited by members of families Rhizophoraceae, Avicenniaceae, Sonnertiaceae. While the mangrove members of the families Combretaceae, Arecaceae, Sterculiaceae, Meliaceae, Euphorbiaceae, Rubiaceae, Aegialitidaceae, Poaceae, and Acanthaceae possess characters only certain features leaf, stem and root modifications. Acrostichum spp. the member of Pteridaceae exhibit certain leaf modifications such as salt secretion through salt glands, stilt roots etc. but none of the mangrove associates families of Fabaceae, Solanaceae, and Rutaceae exhibit any of characters.

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Chapter 6

Physico-Chemical characteristics of Mangrove habitats of Ernakulam

Contents

6.1 Introduction

Mangroves being the buffer zone between the land and water are always subjected to frequently changing physico- chemical parameters. The ecology of mangrove waters depends on two major factors: the short term changes like tidal inundation and the seasonal changes based on monsoonal cycles (Saraya, 1984). This continuous mixing of water masses causes changes in hydrography and nutrient cycling. Various hydrological processes like weather impacts, climate variability, rainfall and runoff characteristics, groundwater flow and storage, frequency and extent of tidal inundation, water and soil salinity, wave exposure and inundation due to river flooding etc. also have a fundamental role in determining the mangrove ecosystem function (Blasco, 1984; Twilley, 1985; Ong et al., 1991). The tidal movements (ebb and flood flows) causes the fluxes in dissolved inorganic nutrients and the outgoing ebb tides leach nutrients from the mangrove swamp soils to adjacent coastal ecosystems.

The physical and chemical properties of the water determine the welfare of organisms in the ecosystem. The mangroves and the biological components of these ecosystems are always under the influence of both saline and fresh water conditions. To overcome problems of anoxia, salinity and frequent tidal inundations, the mangroves have developed a set of physiological adaptations. Although a small area of the world's coastal ecosystem is occupied by mangroves, they have immense ecological and economic importance. The carbon fixed in mangroves play an important role in coastal food web. The detritus formed from the litter degradation and the various nutrients generated in these ecosystems feed a large number of organisms and also support adjacent ecosystems. As a result of various nutrient cycles operating in this system, the water quality is greatly influenced by a large number of physical and chemical processes which makes the mangrove areas more complex and dynamic aquatic environment. Besides numerous natural processes like precipitation inputs, erosion, weathering etc., the quality of water resources of mangroves is greatly exploited by anthropogenic influences.

During the last few decades most of the estuaries, lakes and wetlands are degrading as a result of unsustainable anthropogenic activities. This has immense effect on the flora and fauna residing in these ecosystems. Mangroves are no exception in facing similar faith. The rampant urbanisation, costal expansion, aquaculture and industrial expansions have greatly affected the water quality of mangrove ecosystems to greater extend. The mangroves, which play a critical role in carbon, nitrogen and sulphur cycling, are in fact considered as a reservoir of waste at present. This situation has depleted the water quality which is vital for the growth and functioning of both flora and fauna. Mangroves being rich in biodiversity, supporting a wide range of organisms are critically stressed due to the depleting water quality and habitat loss. Therefore it is necessary to prevent and control the pollution of these aquatic ecosystems and require regular monitoring of the physico-chemical characteristics of these habitats.

Cochin estuary is one of the largest eutrophic estuary located along the southwest coast of India. Until five decades ago, the estuary was reported as highly autotrophic (Qasim et al., 1968) but due to the aftermaths of vast urbanisation, there is a radical shift to a heterotrophic condition (Gupta et al., 2009). The coastal areas are severely impacted by the addition of large quantity of organic and inorganic matter, due to the increased anthropogenic activities such as navigation, construction of ports, increase in human settlements, industries, aquaculture and so on. During the last 50 years, the discharge from the Ernakulam industrial city has increased to several million tons per year. Mangroves being the only adjacent intertidal ecosystem are subjected to these hap hazardous human activities. The indiscriminate input of effluents and wastes especially into the mangrove areas harbouring the coast has considerably altered the physico-chemical characters of the water body. In this context, the study is particularly relevant as knowledge of numerous physicochemical parameters, their magnitude, pollution load etc. helps in determining the quality of water resources and aids in better utilisation of these resources for other sustainable activities.

6.2 Review of Literature

6.2.1 International and National studies

It was found that the scientific interest on mangrove ecosystems began with botanists, later in collaboration with botanists, it was extended to ecologists. Being a unique coastal habitat with frequently changing physical and chemical parameters, these ecosystems were of great interest for several workers all over the world. Many ecological studies were conducted as there were several unanswered questions in front of ecologists. Numerous studies highlighted various hydrological processes together with micro variations in topography in mangrove ecosystems of the world and during the last ten years considerable literature were added by many ecologists.

Various hydrographic and edaphic factors play a critical role in shaping a mangrove environment. The magnitude of fresh water as well as the salt water reaching the mangrove environment from the river discharge and offshore tides respectively determines the hydrography of the same. The role of tides, river discharges, sea waves and other chemical as well as biological processes in mangrove habitats are well documented by Lugo and Snedakar (1974); Cintron and Novelli (1984); Wolanski and Ridd (1986); Ridd and Stieglitz (2002) and so on. Since innumerable literature are available on the ecological attributes of mangrove environment, the present review focuses on the international and national studies of past ten years. Jayakody et al. (2008) studied the vegetative structure and gross primary productivity of mangrove habitats of Meegamuwa, Sri Lanka. Wu et al. (2008), Yang et al. (2008) and Zhang et al. (2010) studied the role of mangroves in treatment of municipal waste waters. Hydrological controls on salinity in mangroves and lagoons of the north Hutchinson Island was studied by Christina (2010). Wang et al. (2010) studied the role of mangroves in maintaining the estuarine water quality. Lawson (2011) studied the mangroves of Nigeria, with respect to various physico- chemical parameters and heavy metal content of water. Orathai et al. (2012) monitored the water quality from mangrove forest of Thailand. Physical and chemical parameters of Luubara Creek, Ogoni Land, Niger Delta, Nigeria were studied by Deekae et al. (2010). Toriman et al., 2013 carried out multivariate statistical analysis of water quality of mangroves of Suppa coast, Indonesia. Abiotic water quality control on mangrove distribution in estuarine river channels was assessed by a novel boat-mounted electromagnetic- induction technique by Melissa et al., 2016. Seca et al. (2016) conducted a comparative study of water quality status of both disturbed and undisturbed mangrove forest along the Awat-Awat mangrove forest of Malaysia.

In India, during last four decades considerable work has been carried out on mangrove ecosystems. Mangroves have been ecologically well-studied along the mangrove habitats of Sundarbans, Andaman- Nicobar Islands, Bhitarkanika, Mahanadi delta, Krishna estuary, the Cauvery delta, Pichavaram, Mumbai coasts and so on. Water quality assessment of aquaculture ponds located in Bhitarkanika mangroves were carried out by Rashmi et al., 2008. A study was attempted on the physico-chemical variability along Parangipettai, Cuddalore coastal and estuarine waters of Bay of Bengal by Sundaramanickam et al. (2008) while an in-depth ecological study of Pichavaram mangrove was reported by Prabu et al. (2008). Seasonal and tidal dynamics of dissolved nutrients, Chlorophyll a, and primary production of Pichavaram mangroves were studied by Senthilkumar et al., 2008 and Prasad and Ramanathan (2008). Rita and Ramanathan (2008) examined the nutrients and dissolved metal concentration in Bhitarkanika mangrove system, Orissa. Physico-chemical parameters along various estuarine and riverine mangrove regions were studied by: Saravanakumar et al., 2008 (mangroves of Kachchh-Gujarat); Soundarapandian et al., 2009 and Nedumaran and Perumal, 2009 (Uppanar estuary); Satpathy et al., 2009(Kalpakkam coast); Pradhan et al., 2009 (Odisha coast); Muduli and Panda, 2010 (Dhamara estuary); Varunprasath and Daniel, 2010 (Bhavani River, Tamilnadu); Prabhahar et al., 2011 (Vellar Estuary, Porto Novo Coastal Waters); Srilatha et al., 2012 (Muthupet mangrove).

Dynamics of Sundarban estuarine ecosystem with special emphasis on eutrophication induced threat to mangroves was investigated by Suman et al. (2010). Martin et al. (2010) examined the formation of anoxia and identification in the bottom waters of a tropical estuary of south west coast of India. A multivariate statistical analysis of various water quality parameters of lake waters of Mysore, Karnataka was done by Mahadev et al. (2010). Ashok Kumar et al., 2011 investigated various hydrographical parameters, nutrients, total coliforms and total heterotrophic bacteria populations in water and sediment samples of Mullipallam Creek in Muthupet mangroves. Palpandi (2011) studied the distribution of biotic components of Vellar river estuary in relations to the seasonal variation in physico-chemical parameters such as nitrate, phosphate, silicate and DO. Identification of mangrove water quality by multivariate statistical analysis methods in Pondicherry coast, India was done by Satheeshkumar and Khan (2012), in which different multivariate statistical analysis such as, cluster analysis, principal component analysis, and multidimensional scale plot were employed to evaluate the trophic status of water quality. A detailed review on the physico- chemical parameters of river water were given by Kumar and Prabhabar (2012) while Habeau (2013) investigated various plant water relations of mangrove species with special emphasis on *Rhizophora stylosa*. Water quality analysis of Bhavanapadu mangrove swamps and Ennore Creek were studied by Krishna Mohan and Gopala Krishna (2013) and Rajkumar (2013) respectively. Rahman et al., 2013 monitored the water quality of the world's largest mangrove forest, Sundarbans.

The seasonal variation in water and sediment characteristics of Kolavoi Lake, Chengalpet was monitored by Ramesh and Selvanayagam (2013). Sakineh et al. (2013) also assessed the water quality of Alibaug mangrove forest using multivariate statistical techniques. Mohan et al. (2013) compared the water quality parameters of Muttukadu estuary with that of coastal water of Muttukadu. Fakir et al. (2014) studied the water quality of Bhitarkanika mangrove systems and observed a seasonal variation in various physico chemical parameters such as temperature, pH, DO, BOD, conductivity, potassium, magnesium etc. Evaluation of physico-chemical parameters and nutrients in the mangrove ecosystem of Manakudy estuary was carried out by Arumugam and Sugirtha, 2015 while that of Thengaithittu estuary, Puducherry and Thane Creek, Mumbai were studied by Vijayakumar et al. (2014) and Vijay et al. (2015) respectively. The ecology of mangrove waters of Mahanadi delta, Odisha was evaluated by Beheral et al. (2014).

6.2.2 Regional studies

The ecological studies in the Cochin estuary were pioneered by Sankaranarayanan and Qasim (1969). During last few decades various studies highlights unfavorable changes in the hydrodynamics (Joseph and Kurup, 1990; Balachandran, 2001) thereby affecting hydrobiological conditions of the ecosystem (Menon et al., 2000). Joseph et al. in 2008 reviewed the available literature and suggested that the sources of nutrients and its association with other physico-chemical variables of highly threatened mangrove ecosystems are poorly studied along the Kerala coast.

The literature review of the past ten years revealed numerous reports on physico-chemical characteristics, nutrient concentrations and productivity patterns of various mangrove and estuarine habitats of Kerala. Anila Kumary et al., 2007 carried out water quality study of Adimalathura estuary in Kochi, Kerala exposed to pollution from the domestic wastes and coconut husk retting. Their results revealed the deleterious effects of waste disposal on the water quality and marked increase in the concentration level of nutrients and a decrease in dissolved oxygen. Several studies were carried out to document the concentration of dissolved, particulate and sedimentary metals (Balachandran et al., 2005; Joseph et al., 2008).

Distribution and chemistry of major inorganic forms of nutrients along with physico-chemical parameters were investigated for surface sediments and overlying waters of the Ashtamudi and Vembanad lakes by Sujatha et al., 2009. Assessment of nutrients using multivariate statistical techniques in estuarine systems and its management implications of Cochin Estuary was done by Shijo et al., (2010).

Meera and Bijoy Nandan (2010) studied the water quality status and primary productivity of Valanthakad Backwater in Kerala. Madhu et al., 2010 evaluated the short-term variability of water quality and its implications on phytoplankton production in Cochin backwaters. Jayachandran and Bijoy Nandan (2011) carried out an assessment of trophic change and its probable impact on tropical estuarine environment of Kodungallur-Azhikode estuary. Seasonal variability of dissolved nutrients in the mangrove ecosystems of south west coast of Kerala was monitored by Geetha et al. (2009) and Manju et al. (2012). A statistical approach to assess the water quality parameters in mangrove ecosystems of Kerala coast was initiated by Manju et al., 2012. Assessment of spatial variation in hydrogeochemical characteristics was carried out in a tropical estuary of Cochin by Robin et al., 2012. Navami and Jaya (2013) carried out an assessment of pollution stress on the physico-biochemical characteristics of mangrove species in Akkulam-Veli Lake, South India. The phytosociological and edaphic attributes of Chettuva backwaters, Thrissur was reported by Sindhumathi et al. (2014).

6.3 Methodology

The water samples were collected from the selected stations of the Ernakulam mangroves as elaborated in chapter 2, on monthly basis for two years (September 2010 to August 2012). Sampling was carried out in early morning hours. The rainfall data for the respective study period was collected from Department of Atmospheric sciences, Cochin University of Science and Technology, Cochin. The satellite data TRMM (Tropical rainfall measuring mission) was used for the study. The ambient and water temperature, pH, dissolved oxygen (DO) and carbon dioxide (CO_2) were measured in the respective study sites. The water samples for analysis were collected in 500ml sterile plastic bottles. Water samples were also collected in BOD glass bottles of 125ml capacity for the analysis of dissolved oxygen, biological oxygen demand and hydrogen sulphide. The samples were fixed at the study site with manganese sulphate and alkali iodide- azide reagent for the analysis of dissolved oxygen and zinc- acetate solution for hydrogen sulphide samples. The water samples for chlorophyll estimation were collected in 2.5L dark containers and freezed immediately. All the hydrographic parameters studied were grouped into two categories: physical parameters and chemical parameters.

6.3.1 Physical parameters

The **depth** of the mangrove sites were measured using a graduated weighted rope. The rope was immersed in water until it reached the bottom and the measurements were recorded in meters (m). The **ambient** and **water temperature** was measured in the field using a 0-50^{0}C precision thermometer (accuracy ± 0.01^{o}C). **Salinity** was measured using Mohr-Knudsen method (Strickland and Parsons, 1972). The samples were titrated with standard silver- nitrate solution and potassium chromate indicator. The formation of red- brown precipitate of silver chromate marks the end point of the titration. The values were recorded in parts per thousand (ppt). **Conductivity** and **Total Dissolved Solids (TDS)** were measured immediately in the laboratory using Systronics water analyser (Model no. 371) and were expressed in milli Siemens (mS) and parts per million (ppm) respectively. **Turbidity** was measured by using Nephelo–Turbidity meter– Systronics model no: 132 (APHA, 2005). The Nephlometeric method is based on the intensity of light scattered by the sample and was expressed in Nephlometeric Turbidity Unit (NTU).

Alkalinity is the measure of total OH^- ions present in water. It was measured by titrimetric method (Larson and Henley, 1955) using standard sulphuric acid and methyl orange indicator and was expressed in mg/L. **Total hardness** of a solution is defined as the sum of calcium and magnesium concentration and was measured using the EDTA titrimetric method (APHA, 2005). The sample with metal cations (calcium and magnesium) forms chelated soluble complexes with Ethylene-diaminetetra acetic acid (EDTA). The **calcium hardness** was measured by titrating EDTA with Eriochrome black T as the indicator. In presence of the dye the sample turns wine red, which on titration changes to blue indicating the end point. On the other hand, **magnesium hardness** was measured by using Murexide as the indicator. On titration with EDTA, the sample changes from pink to purple. This indicates the end point and the results were expressed in milligram calcium carbonate per litre (mg $CaCO_3L^{-1}$).

6.3.2 Chemical parameters

The **pH** of the water column was measured using portable pH meter (Systronics model no. 371; accuracy±0.01). The **redox potential** was measured using Digital Eh meter No.318; accuracy±0.01. **Free carbon dioxide** was analysed by the titrimetric method (APHA, 2005) and was expressed in milligram per litre (mgL^{-1}). **Dissolved oxygen (DO)** was estimated using modified Winkler method (Strickland and Parsons, 1972). The manganese sulphate and alkali iodide- azide fixed samples liberate iodine on acidification which is equivalent to the dissolved oxygen present. The quantity of iodine liberated was determined by titration with sodium thiosulphate and was expressed in milligram per litre (mgL^{-1}). The oxygen consumed in three day incubation period was measured as the **Biological oxygen demand (BOD_3)** as per standard methods (APHA, 2005). The oxygen utilized for the degradation of organic material as well as ionization of inorganic materials during the incubation period was measured and was expressed in milligrams per litre ($mg\ L^{-1}$). Dissolved **hydrogen sulphide** was measured by Cline's method (Grasshoff et al., 1969). The zinc-acetate fixed samples were treated with N, N-dimethyl-p-phenylene diamine dihydrochloride and ferric chloride reagent. The blue colour developed was measured at 630nm.

Phenate method as per Grasshoff et al. (1983) was used for the analysis of **ammonia-nitrogen**. The ammonia present in the sample forms monochloramine developing indophenol blue in presence of phenol, sodium nitroprusside and excess hypochlorite, which was measured at 640nm and expressed in $\mu molL^{-1}$. **Nitrite-nitrogen** was measured using diazotised method (Strickland and Parsons, 1968; Grasshoff et al., 1983). The nitrite present in the sample is determined by the azo-dye produced on reaction with sulphanilamide and N-(1-Naphthyl) ethylenediamine dihydrochloride (NED dihydrochloride). The spectrophotometric reading was taken at 543nm. Resorcinol method was used for the analysis of **nitrate-nitrogen** (Zhang and Fischer, 2006). The nitrate in the sample on addition of resorcinol (Benzene-1, 3-diol) forms a pink coloured product nitrosophenol. The absorbance was measured at 505nm. Dissolved inorganic **phosphate- phosphorus** was measured using the ascorbic acid method (Grasshoff et al., 1983; APHA, 2005). Ammonium molybdate, potassium antimonyl tartrate and ascorbic acid react with the phosphate present in the sample to form phosphomolybdenum complex. This complex is blue in colour and its intensity was measured using spectrophotometer at 882nm and was expressed in micromoles per litre ($\mu molL^{-1}$). Molybdosilicate method was used for the estimation of **silicate- silicon** in the water (Strickland and Parsons, 1972; Grasshoff et al., 1983). The sample on reaction with molybdate solution forms silicomolybdic acid, which is yellow in colour. This on further reaction with ascorbic acid and oxalic acid forms a blue coloured complex (molybdenum blue). The molybdenum blue was measured at 810 nm. All the spectrophotometric readings were taken at UV-VIS spectrophotometer (Systronics, Model No.117).

6.3.3 Data Analysis

Statistical Programme for Social Sciences (SPSS) version 16 was employed for analysing ANOVA, standard deviation and correlation of various water quality parameters, to test the presence of significant difference between stations and seasons. The PRIMER version 6 (Plymouth Routines in Multivariate Ecological Research) was used for univariate and multivariate analyses of data (Clarke and Gorley, 2006).

i) Cluster analysis and MDS

Cluster analysis was done to find out the similarity between groups. The most commonly used clustering technique is the hierarchical agglomerative method. It can be represented in the form of dendrogram where x-axis represents the samples and y-axis shows the similarity level between the samples. Commonly used cluster is Bray- Curtis cluster (Bray and Curtis, 1957) to produce dendrogram. Non-metric Multi-dimensional Scaling **(MDS)** was proposed by Shepard (1962) and Kruskal (1964). MDS plot is usually two dimensional or three dimensional, represents similarity of biological communities. In MDS plot goodness of fit is measured by the stress value; an ideal representation having zero stress. Relative stress value increases with increasing number of entities and decreasing dimensions.

ii) Principal Component Analysis (PCA)

The water quality data obtained from the laboratory analysis were used as input variables for PCA. The method helps to transform the observed variables to new set of variables of principal component with decreasing order of importance. It provides an ordination in which the variables are projected on to a best fitting plane. The purpose of the new axis is to as much of the variability in the original space as possible and the extent to which is a good reflection of the relationship between the samples is summarized by the % variation explained (a ratio of Eigen values) coefficients are termed and the coefficient are termed eigen vectors.

iii) BIO-ENV (BEST)

BIO-ENV was done to ascertain the relationship between biological and environmental variables using the BIO-ENV procedure (Clarke and Ainsworth, 1993). The basic principle behind this is to measure the agreement between the rank correlations of the biological (Bray- Curtis similarity) and environmental (Euclidean distance) matrices. A weighted Spearman rank correlation coefficient was used to determine the harmonic rank correlation between the biological matrix and all possible combinations of the environmental variables. Here the mangrove species data were related to the environmental variables so as to determine the factor responsible for the abundance of the biotic components.

6.4 Results

6.4.1 Rainfall

Kerala being a tropical area is characterised by a unique climate, receiving two peak rainfalls; southwest monsoon and northeast monsoon. Apparently three distinct seasons can be observed; monsoon (June-September), post monsoon (October - January) and pre-monsoon (February-May).The rainfall data showed that the first year (2010-11) received higher rainfall (2761mm) compared to second year (2069.88mm). The highest mean monthly rainfall was marked in October 2010 (457.5mm) from northeast monsoon and June 2011 (435.51mm) from the southwest monsoon respectively. Comparatively low rainfall was recorded in the month of

January during both years (10.68mm in 2010-11 and 5.16mm 2011-12). A clear seasonal variation can be observed in the rain fall data. The monsoon seasons marked higher rainfall 1132.93mm and 1189.89mm during first and second year respectively.

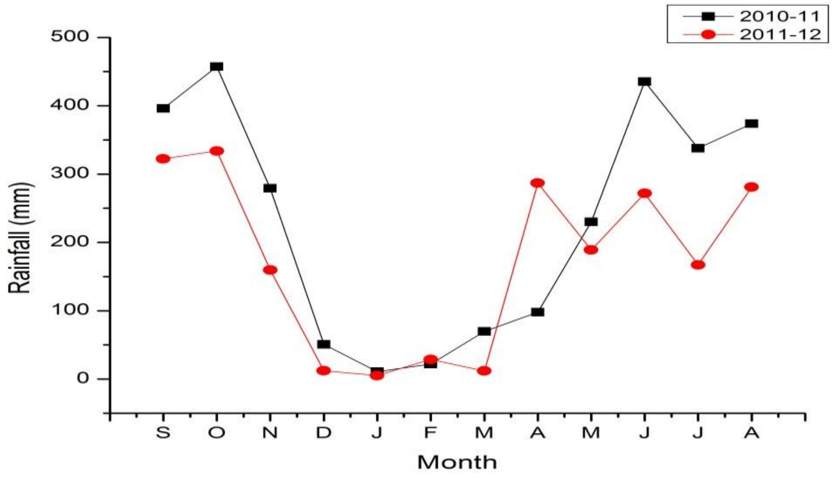

Figure 6.1 Mean monthly variation of rainfall in Ernakulam district during 2010-12

6.4.2 Physical parameters

i. Depth

All the stations were shallow in nature having a depth less than 1m and there were no significant difference between surface and bottom waters.

ii. Atmospheric temperature

The mean monthly variation in temperature ranged from 23.6 ±1.49 ^{0}C during December 2011 to 31.1±1.06 ^{0}C during April 2012. April 2012 was the hottest month recorded during the study period with all the stations exhibiting temperature values above 30^{0}C. The mean station wise values for two years showed that St.5 (Valanthakad-Magranazhi) had higher values (28±2.07 ^{0}C) followed by St.3 and St.4 (26.8 ± 2.07 ^{0}C). The atmospheric temperature was almost uniform during both years. The ANOVA results shows that the atmospheric temperature had significant variation between months (F=2.394, p=0.016).

The station wise annual mean temperature ranged from 26.1± 2.76^{0}C (St.4) to 28.29 ± 1.79^{0}C (St.5) and 27.08± 3.55 (St.3) to 27.75± 2.38 (St.2, 5) during the first year (2010-11) and second year (2011-12) respectively (Figure 6.2). The spatial annual temperature did not exhibit much variation during second year. Station 2 (Aroor North) and St.5 showed higher temperature values during both years. The highest temperature recorded was 33^{0}C at St.6 (Valanthakad –Arkathadam) in the month of September 2011 followed by 32^{0}C at St.2 in February 2011. The atmospheric temperature showed slight variation among seasons. The seasonal atmospheric temperature ranged from 25.3± 0.57^{0}C- 29.6± 1.7^{0}C during the study period. The temperature was low in monsoon season compared to pre and post monsoon seasons. Slightly higher temperature was observed in the post monsoon season of the first year (2010-11). The ANOVA showed an overall significance at 1% level with a R^2 value of 0.684.

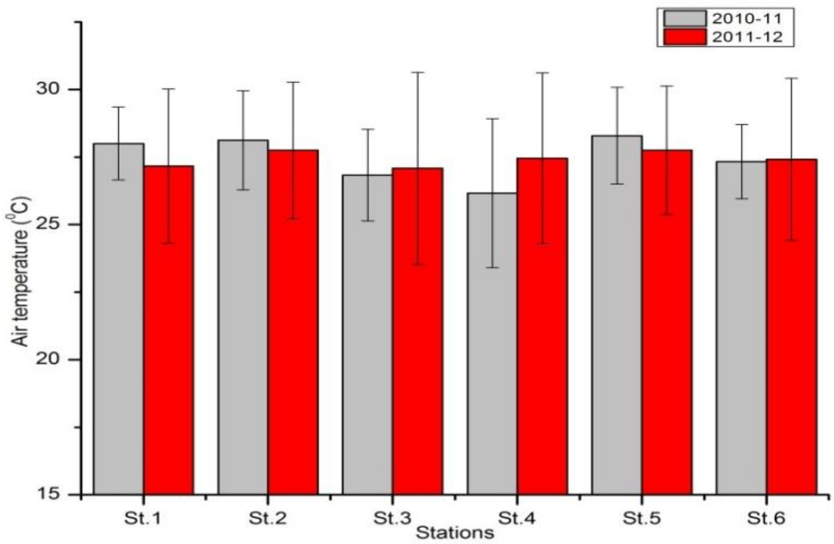

Figure 6.2 Annual variations in air temperature in selected mangrove habitats of Ernakulam during 2010-12

iii. Water temperature

The water temperature was higher compared to atmospheric temperature during the study period. The mean monthly water temperature ranged from 26.8± 0.98^{0}C (January 2012) to 33±2^{0}C (May 2012). The highest temperature recorded was 35^{0}C at St.4 during May 2012. The annual mean values did not exhibit significant variation between two years. Similar to atmospheric temperature, water temperature also displayed not much variation between years (Figure 6.3). During the first year (2010-11), April 2011 was the hottest month while in the second year all the stations exhibited higher temperature during the month of May.

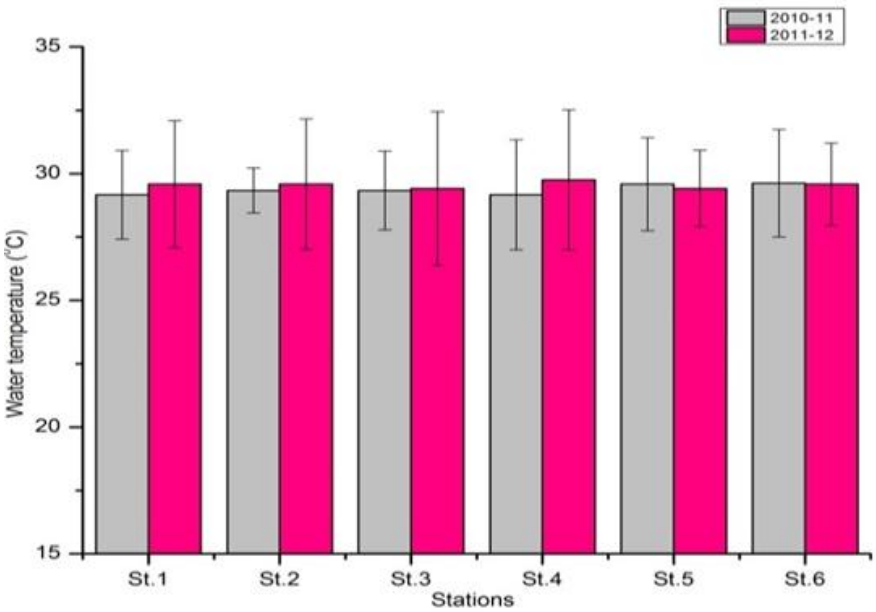

Figure 6.3 Annual variations in water temperature in selected mangrove habitats of Ernakulam during 2010-12

The seasonal water temperature ranged from 27.3± 1.15^{0}C at St.6 to 31.4 ±2.6^{0}C at St.4. There was no much variation in water temperature in pre-monsoon, monsoon and post monsoon seasons during the year 2010-11 however during second year (2011-12) the temperature was higher in the pre-monsoon. The post monsoon period of the year 2010-11 showed higher temperature (30.6^{0}C at St. 6) while the monsoon season of both years showed lower water temperature. The ANOVA results of water temperature showed 1% level of significance (R^2=0.766, p<0.001).

iv. Salinity

The salinity of the mangrove ecosystem is mixo-mesohaline in nature. The mean monthly salinity values ranged from 0.71± 0.52ppt (September 2010) to 19.73± 9.01ppt (February 2012). Higher mean values were also observed in the months of December 2011 (14.85± 9.87 ppt) and March 2011(14.55± 5.4 ppt). The annual station wise values showed an increase in salinity during second year (2011-12) compared to first year (Figure 6.4). The salinity ranged from 3.21± 3.42 ppt at St.5 (Valanthakad-Magranazhi) to 11.08± 9.92 ppt at St.3 (Puthuvypin) and from

8.07± 5.97 ppt at St.1 (Aroor South) to 17.60 ±11.96 ppt at St.3 during the first and second year respectively. Puthuvypin (St.3) always recorded higher salinity values compared to other stations. The highest salinity recorded was 37.9ppt at Puthuvypin in the month of February 2012.

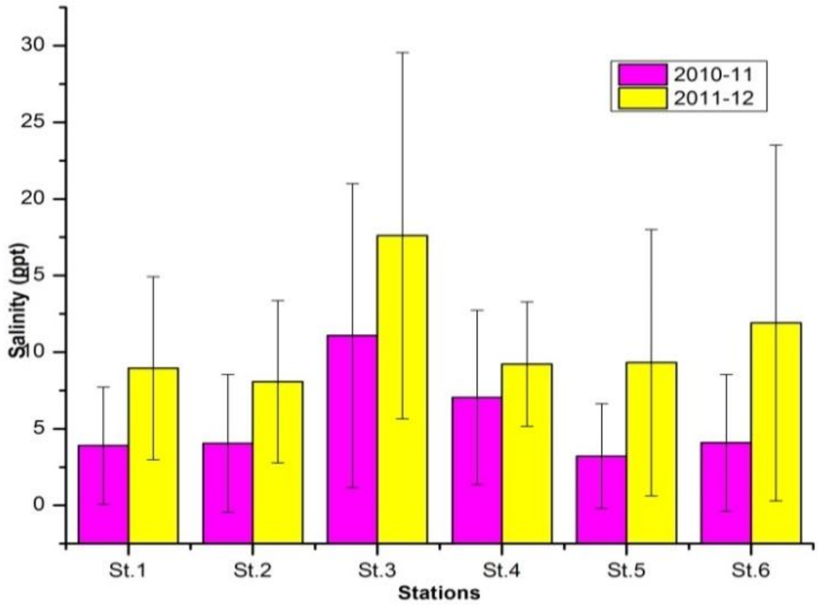

Figure 6.4 Annual variations in salinity in selected mangrove habitats of Ernakulam during 2010-12

Marked season wise variation was observed during the study period with minimum values recorded in the monsoon season of both years. The values in the monsoon period ranged from 0.34± 0.11 ppt to 5.40 ±5.15 ppt in the first year and 3.12 ±2.18 to 9.08 ±6.57 ppt in the second year. Post monsoon season recorded higher salinity compared to pre monsoon season. The post monsoon period of first year recorded 7.17± 2.87 to 20.85 ±6.73 ppt in salinity while the values were slightly higher in the second year, ranging from 11.95± 4.42 to 27 ±9.35ppt. The ANOVA results showed an overall significance at 1% level (R^2=0.916, p<0.001). The salinity was also significant at 1% level between stations (F=15.585, p=0.000), between months (F=12.675, p=0.000) and between years (F=76.635, p=0.000). The interaction between season x stations and station x year were also significant at 1% level.

iv. Conductivity

The mean monthly variation in conductivity ranged from 0.82 ± 0.78 mS (October 2010) to 27.36 ± 24.28mS (December2011). The highest value recorded was 62.3mS from St.4 (Malippuram) during December 2011. All the stations exhibited lower values during October 2011. The annual station wise values were higher in the second year compared to first year. During first year the conductivity ranged from 4.08± 5.16mS (St.5, Valanthakad-Magranazhi) to 12.51 ± 13.13mS (St.3, Puthuvypin) while in the second year the values ranged from 8.26 ± 5.88 mS (St.2, Aroor North) to 22.51± 17.53mS (St.3, Puthuvypin). In both years Puthuvypin station recorded higher values (Figure 6.5).The season wise variation showed lower values in monsoon followed by the pre monsoon period of 2010-11 and higher values during the post monsoon period of both years. The seasonal variation ranged from 0.40± 0.02mS at St.5 during the monsoon to 41.57± 8.20mS at St.3 during the post monsoon. During all the seasons, Station 3 (Puthuvypin) showed higher values followed by St.4 (Malippuram). The ANOVA results of the conductivity showed significant variation between stations (F=11.57, p=0.000) and between months (F=9.79, p=0.000). The significance between season was at 5% level (F=3.229, p=0.047) and an overall significance at 1% (R^2= 0.864, p<0.001).

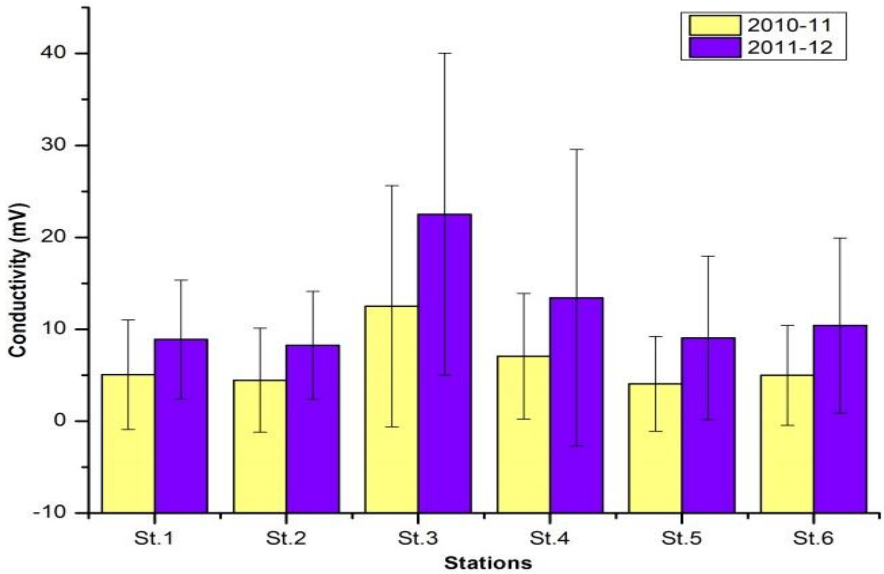

Figure 6.5 Annual variations in conductivity in selected mangrove habitats in Ernakulam during 2010-12

v. Total dissolved solids (TDS)

The mean monthly variation in total dissolved solids (TDS) ranged from 0.45± 0.41ppt during October 2010 to 16.12 ±13.89ppt in December 2011. The highest value recorded was 40.6ppt at St.4 followed by 20.9ppt at St.4 (December 2011). Mean station wise value ranged from 3.30 ± 2.96ppt (St.2) to 9.34± 7.90ppt (St.3). Similar to conductivity the annual station wise TDS values also showed higher values during second year (2011-12) than first year (Figure 6.6). Lowest value (2.18± 2.76 ppt) was recorded at St.5 during the first year and 3.89± 2.88 ppt at St.2 in the second year respectively. While St.3 recorded higher mean values (6.92 ±7.25 ppt; 11.19± 8.24 ppt) during both years.

The post monsoon period exhibited higher TDS values compared to monsoon and pre monsoon periods. The post monsoon TDS values ranged from 5.52± 2.28 ppt to 16.12 ±3.45 ppt during 2010-11 and from 6.79 ±2.86ppt to 20.22± 2.29ppt during 2011-12. Station 3 (Puthuvypin) showed peak values during both post monsoon periods. The significant variation was observed between stations (F=8.084, p<0.000), between months (F=8.360, p=0.000) and between years (F=26.58, p=0.000). The TDS also showed an overall significance at 1% level (R^2= 0.840, p<0.001).

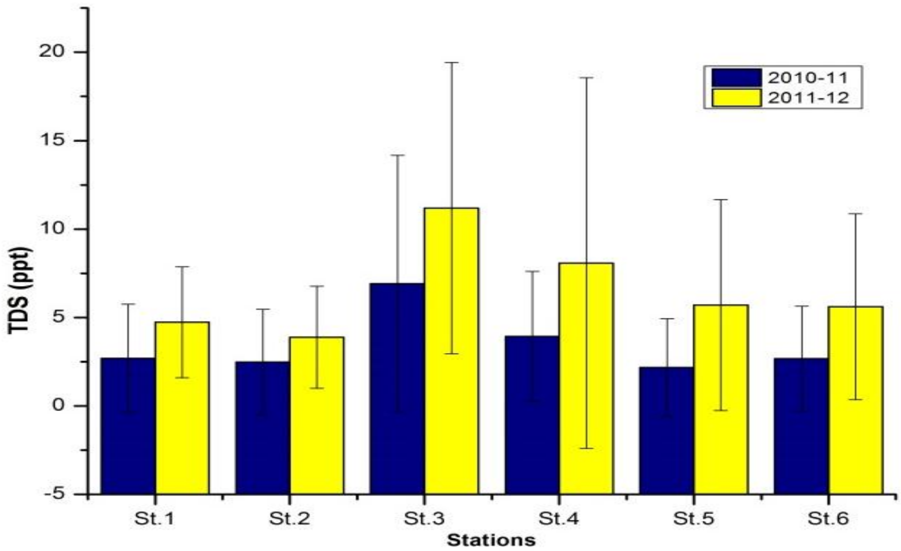

Figure 6.6 Annual variations in TDS in selected mangrove habitats in Ernakulam during 2010-12

vi. Turbidity

The monthly mean values ranged from 1.56±1.10 NTU (July 2012) to 10.85± 8.32 NTU (July 2011). The mean station wise values show that St.5 (Valanthakad-Magranazhi) is less turbid (2.37± 1.91NTU). St.1 (Aroor South) and St.3 (Puthuvypin) were highly turbid during the study period, with a mean value of 7.96± 9.73 NTU and 5.83 ± 6.60 NTU respectively. The highest turbidity recorded during the study period was 39NTU at St.1 in the month of April 2012.

The annual station wise variation in the first year ranged from 3.20 ±2.29 at St.5 to 6.28± 6.69 NTU at St.3. Station 5 also showed lower turbidity (1.59± 0.96NTU) during second year, peaking up to 10.14 ±12.48 NTU in St.1 (Figure 6.7). The seasonal variation showed that the turbidity values peaked in monsoon season of both the years. The turbidity ranged from 3.36 ±1.92 (St.4) to 10.6 ±7.87 NTU (St.1) and 1.9± 1.2 (St.6) to 10.2± 9.33 NTU (St.2) during the first and second year monsoon periods respectively. The post monsoon periods were less turbid, with the values ranging from 1.31± 0.86 to 5.62± 4.2 NTU (2010-11) and 1.98± 1.03 to 7.97 ± 12.02 NTU (2011-12). The ANOVA showed an overall significance at 1% level (R^2= 0.546, p<0.01) and exhibited significant spatial variations (F= 2.619, p=0.033).

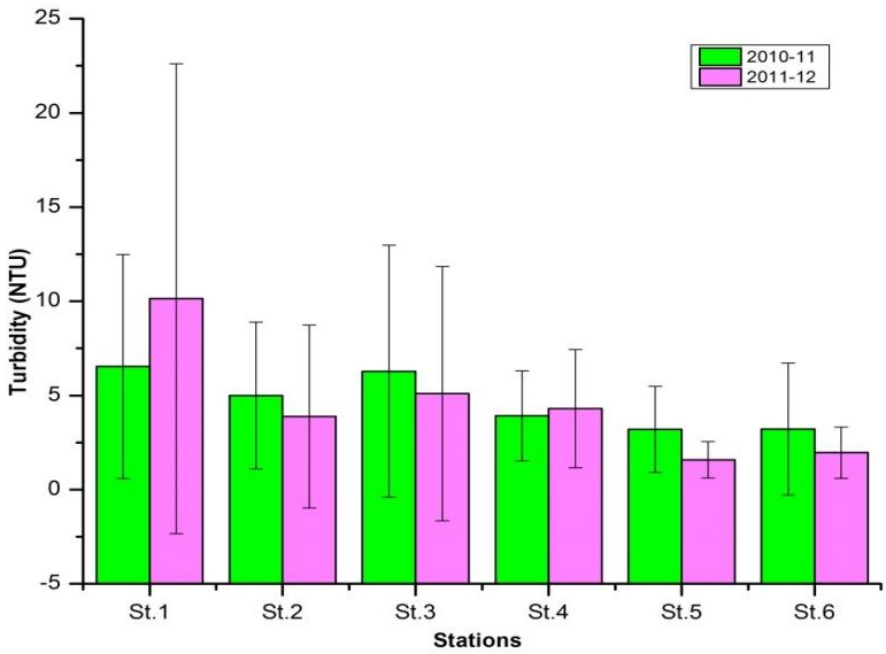

Figure 6.7 Annual variations in turbidity in selected mangrove habitats in Ernakulam during 2010-12

vii. Alkalinity

The mean monthly variation showed that the alkalinity was low during the month of May 2012 and peaked in January 2011. The values ranged from 14.67± 4.76 mg/L to 2981.67 ±232.17mg/L. During the first year, November 2010, December 2010 and January 2011 exhibited higher values of alkalinity.

The annual station wise mean values ranged from 77.75± 85.11 mg/L to 279.42 ±557.59 mg/L and 35.17 ±11.80 mg/L to 67.58±24.61 mg/L during the first and second year respectively (Figure 6.8). Station 2 (Aroor North) showed lower alkalinity in the first year whereas in the second year Station 5 (Valanthakad-Magranazhi) represented lower values. In both year St.3, Puthuvypin represented higher alkalinity trends. There was no marked season wise variation except in the monsoon period of first year. During first year monsoon period the values peaked from 147 ±168.23 mg/L to 910 ±952.92 mg/L, where the highest values were represented by St.3. All other seasons exhibited lower alkalinity trends below 100mg/L. Significant variation was observed between season (F=11.21, p=0.000), between year (F=22.22, p=0.000) and between months (F=3.941, 0.000). The interaction between seasons and stations also exhibited significant variation (F=2.547, p=0.029) indicating spatial variation in alkalinity levels in all seasons.

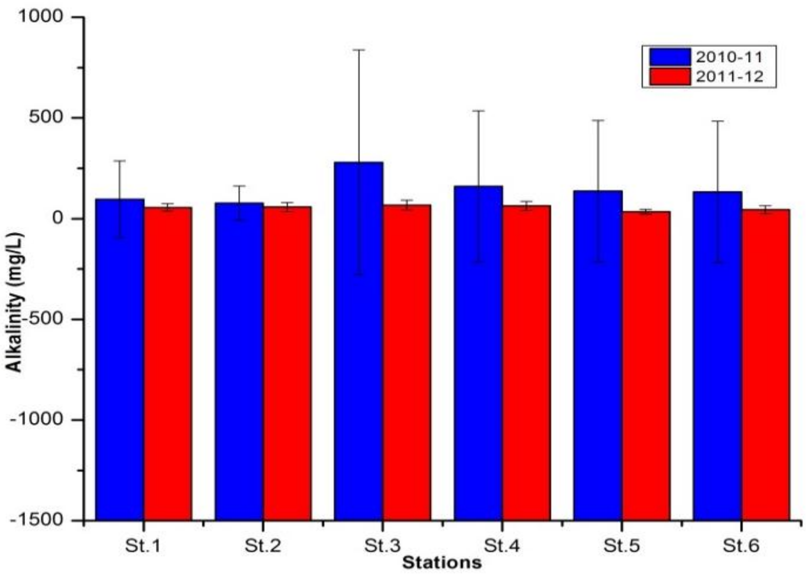

Figure 6.8 Annual variations in alkalinity in selected mangrove habitats of Ernakulam during 2010-12

viii. Hardness

The mean monthly values of total hardness ranged from 123.33 ±58.53mg$CaCO_3$/L to 2413.33± 1855.65 mg$CaCO_3$/L. The least values were recorded in the month of August 2011 and the highest in December 2010. The highest value recorded in December 2010 was 5900 mg$CaCO_3$/L in Puthuvypin station (St.3). The annual station wise mean were greater in the second year (Figure 6.9). The values ranged from 415.17± 458.79 mg$CaCO_3$/L to 1649.50± 1811.93 mg$CaCO_3$/L during first year and from 586.33± 454.72 mg$CaCO_3$/L to 1537.33± 1550.57 mg$CaCO_3$/L during second year respectively. In 2010-11 period, the higher values were recorded in the month of December 2010 whereas December 2011 and April 2012 showed greater values in the second year. The season wise variations showed higher values in the post monsoon seasons of both years. The highest value was recorded in the first post monsoon period, with values ranging from 805 ±502.03 mg$CaCO_3$/L (St.1) to 2940± 2674.62 mg$CaCO_3$/L (St.3). Slightly higher values were observed in the pre monsoon periods compared to monsoon periods. The total hardness in the pre monsoon periods ranged from 210.5 ±154.79 mg$CaCO_3$/L to 1043.5 ± 980.65 mg$CaCO_3$/L (2010-11) and from 360.8 ± 425.01 mg$CaCO_3$/L to 940.8 ± 919.41 mg$CaCO_3$/L (2011-12). Significant variation in hardness values between months (F=4.820, p=0.000) and between stations (F= 3.696, p=0.006) were clearly evident.

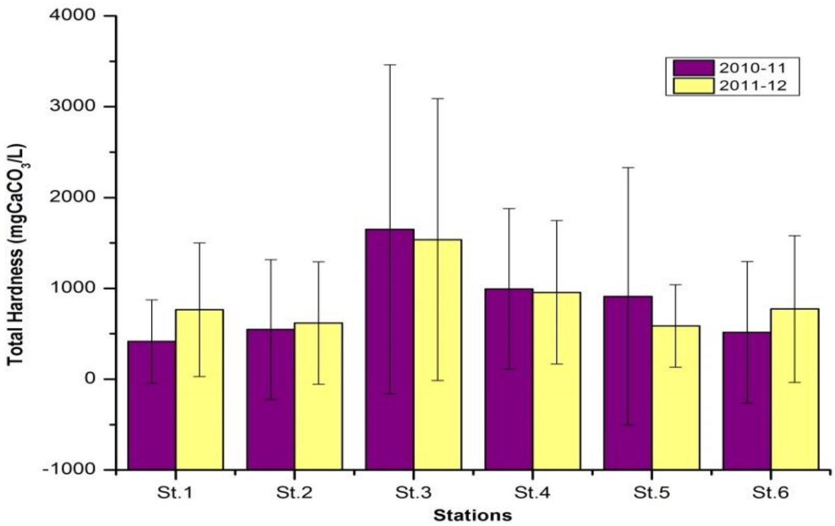

Figure 6.9 Annual variations in total hardness in selected mangrove habitats of Ernakulam during 2010-12

The monthly mean calcium hardness ranged from 22±12.06 mg$CaCO_3$/L to 606.66 ±358.14 mg$CaCO_3$/L during the study period. The hardness was low in the month of February 2011 and March 2012, while all the stations showed higher values in the month of December 2010. St.3 (Puthuvypin), St.5 (Valanthakad-Magranazhi) and St.6 (Valanthakad-Arkathadam) showed higher values of calcium hardness (900mg$CaCO_3$/L) during December 2010. The annual station wise mean was higher in 2011-12 period compared to 2010-11 (Figure 6.10). During first year St.1 showed the lowest mean value (114.17±129.82 mg$CaCO_3$/L) compared to other stations. The peak values were recorded from St.3 (Puthuvypin) during both years (329.50 ±288.76 mg$CaCO_3$/L; 2010-11and 342.33±280.25 mg$CaCO_3$/L; 2011-12). The season wise variations showed higher values recorded in the post monsoon season. The post monsoon, 2010-11 recorded the peak value 493.5± 423.8 mg$CaCO_3$/L at Puthuvypin station. The monsoon periods recorded the least values ranging from 13.33± 4.16 mg$CaCO_3$/L to 293.33± 41.63 mg$CaCO_3$/L. The calcium hardness showed an overall significance at 1% level (R^2= 0.747, p<0.01). The values showed significant variation between station (F=3.641, p=0.006) and between months (F=7.188, p=0.000).

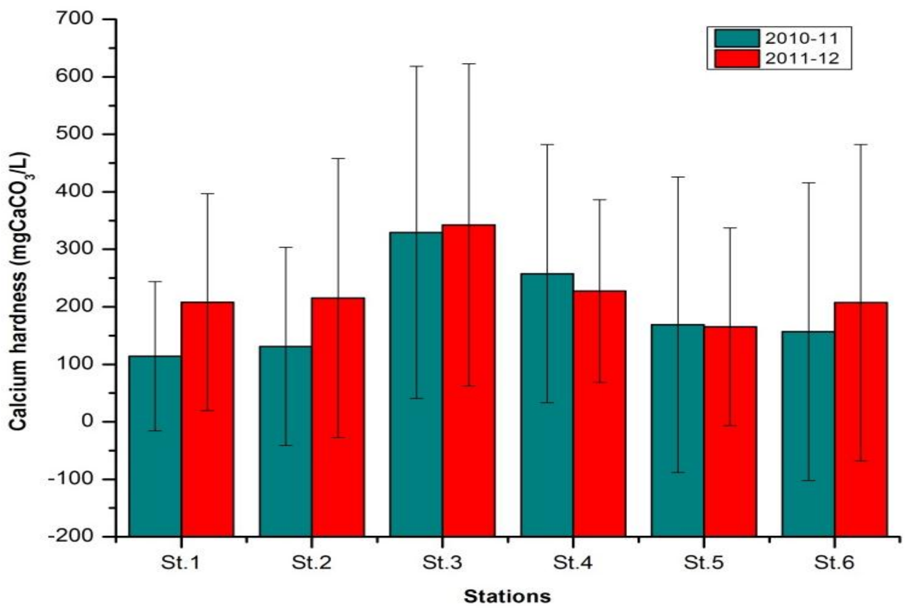

Figure 6.10 Annual variations in calcium hardness in selected mangrove habitats in Ernakulam during 2010-12

Magnesium hardness values showed a monthly mean variation from 60.33±89.84 mgCaCO$_3$/L (October 2010) to 1936.66± 910.59 mgCaCO$_3$/L (January 2011). During the first year, all the stations except St.3 exhibited lower values in the months of November 2010, December 2010 and July 2011. March 2012 showed lower values and December 2011, April 2012 recorded higher values during second year. The highest value was recorded in December 2010 at St.3 (5000 mgCaCO$_3$/L). The annual station wise mean represented lower values in St.1, Aroor North (308 ±346.84 mgCaCO$_3$/L) during first year and St.2, Aroor South (404.5 ± 516.52 mgCaCO$_3$/L) during second year. Puthuvypin (St.3) recorded higher values during both years (Figure 6.11).

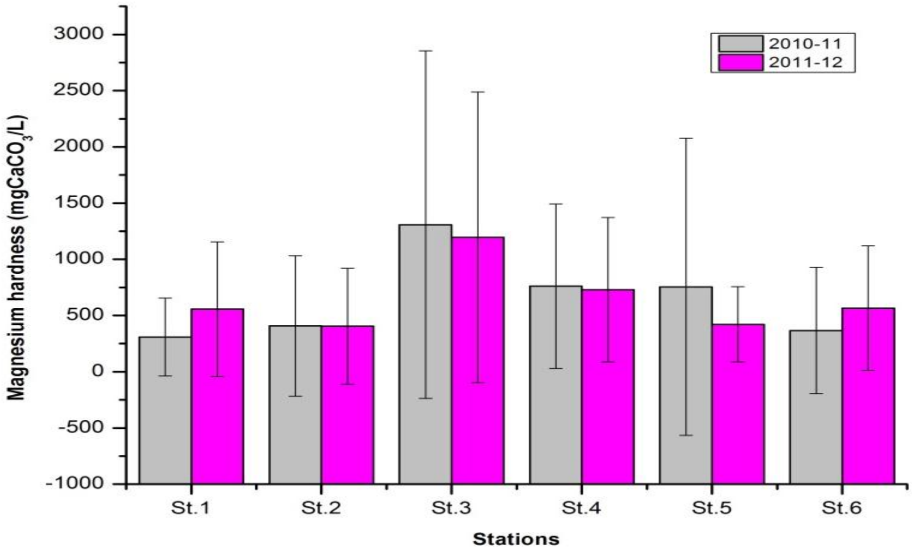

Figure 6.11 Annual variations in magnesium hardness in selected mangrove habitats of Ernakulam during 2010-12

The season wise variation exhibited higher values in the post monsoon periods of both years. The post monsoon values ranged from 635±368.97mgCaCO$_3$/L (St.1) to 2411±2301.08 mgCaCO$_3$/L (St.3) and 373 ±413.09 mgCaCO$_3$/L (St.2) to 1545.5± 1538.66 mgCaCO$_3$/L (St.3) during first and second year respectively. The monsoon season recorded lower values during both years. Significant spatial variation (F=3.194, p=0.013) was displayed in the ANOVA results. The values also showed variation with respect to months (F=3.930, p=0.000).

Table 6.1 Mean seasonal variation in various physical parameters during the period 2010-12

Parameters	2010-11			2011-12		
	MN	Post MN	Pre MN	MN	Post MN	Pre MN
Atm. Temp.	27.44±1.	27.67 ±1.98	27.56± 1.37	27.56± 1.37	27.59± 1.56	27.57± 1.43
Water Temp.	28.2 ±0.78	29.13± 0.91	29.37± 0.38	28.46± 0.49	29.13± 0.73	30.83± 0.31
Salinity	1.50±1.99	10.72±5.04	4.27±3.50	4.59±2.30	18.42± 6.47	8.08±3.03
Conductivity	1.95±2.32	14.80±7.25	2.38±1.15	4.16±2.22	22.42±10.52	8.09±3.32
TDS	1.01±1.35	7.99±4.07	1.40±0.66	2.15±1.23	12.38±4.99	4.27±1.62
Turbidity	5.31±2.71	3.24±1.63	5.71±2.27	4.67±3.12	3.73±2.20	4.96±3.70
Alkalinity	449.72±260.69	45.5±11.3	50.16±17.65	44±10.69	62.33±12.81	52.13±15.80
T.Hardness	402±5.14	1432.83±768	752.33±432	720±429.9	1113.58±468.89	653.4±254.76
Ca Hardness	76.66±109.3	334.25±134.8	172.25±80.15	221.08±92.1	265.66±92.103	168.86±61.12
Mg Hardness	325.33±419.0	1113.16±649	580.08±406.8	847.91±365.4	847.91±398.46	484.53±201.4

6.4.3 Chemical parameters

i. Carbon dioxide

The mean monthly values of carbon dioxide ranged from 0.54 ±0.49mg/L to 20.17± 7.01 mg/L. The lowest value was recorded in the month of February 2011 and highest in the month of August 2012. The annual station wise values were lower in the first year (2010-11) compared to second year (Figure 6.12). In 2010-11 period, the CO_2 level ranged from 3.22 ±2.92 mg/L to 5.70 ±5.79mg/L. The lowest value recorded at Valanthakad (St.6) and highest at Puthuvypin (St.3).The means values in the second year ranged from 8.69± 4.6 mg/L at Aroor South (St.1) to 12.24± 8.49 mg/L at Malippuram (St.4). The annual data showed higher values in the second year (2011-12). The season wise variation in the first year shows the lowest CO_2 concentration in the post monsoon period followed by the monsoon and pre monsoon seasons. In the second year the highest value (14.89± 12.55 mg/L) was recorded in the pre monsoon season. A significant variation in the CO_2 values were marked between years (F=39.074, p=0.000) and between months (F=4.262, p=0.000) with an overall significance of 73% (R^2=0.734, p<0.01).

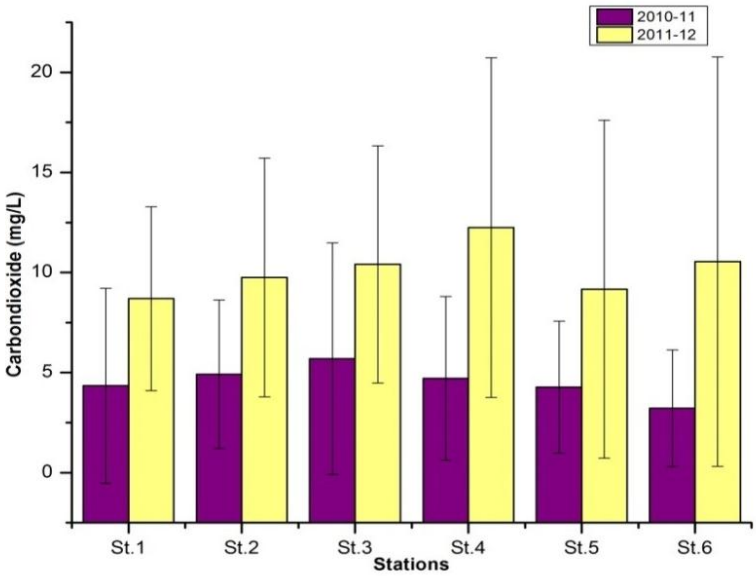

Figure 6.12 Annual variations in carbon dioxide in selected mangrove habitats in Ernakulam during 2010-12

ii. pH

The pH values during the study period indicate a neutral to alkaline nature of the study area. The monthly mean values during the study period ranged from 6.28± 0.08 (July 2012) to 7.9 ±0.33 (March 2012). Most the stations showed neutral to alkaline pH during all months except in May 2012 at St.1, where the pH was slightly acidic (4.6).

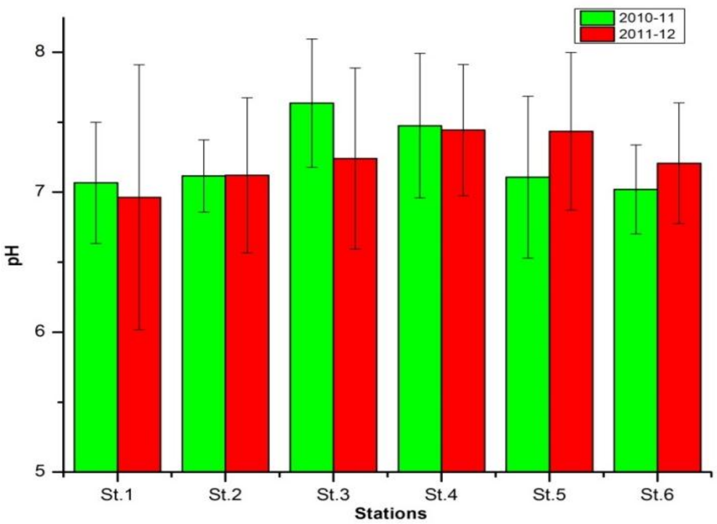

Figure 6.13 Annual variations in pH in selected mangrove habitats of Ernakulam during 2010-12

The annual station wise mean values showed not much variation between years (Figure 6.13). The values ranged from 7.02 ±0.32 at St.6 (Valanthakad – Arkathadam) to 7.64 ± 0.46 at St.3 (Puthuvypin) during first year and from 6.96± 0.95 at St.1 (Aroor South) to 7.44 ±0.47 at St.4 (Malippuram) during second year respectively. The season wise variations of pH showed higher values in the post monsoon seasons compared to pre monsoon and monsoon. During all the seasons, St.3 (Puthuvypin) showed higher values compared to other stations. The pH values did not exhibit any significant temporal or spatial variation.

iii. Redox Potential (Eh)

The mean monthly variation in the redox potential varied from -29±40.05mV (September 2010) to 30.66±21.77mV (July 2011). The mean station wise values ranged from -3.25±29.34 mV at St.3 (Puthuvypin) to 11.46±34.98 mV at St.1 (Aroor South).

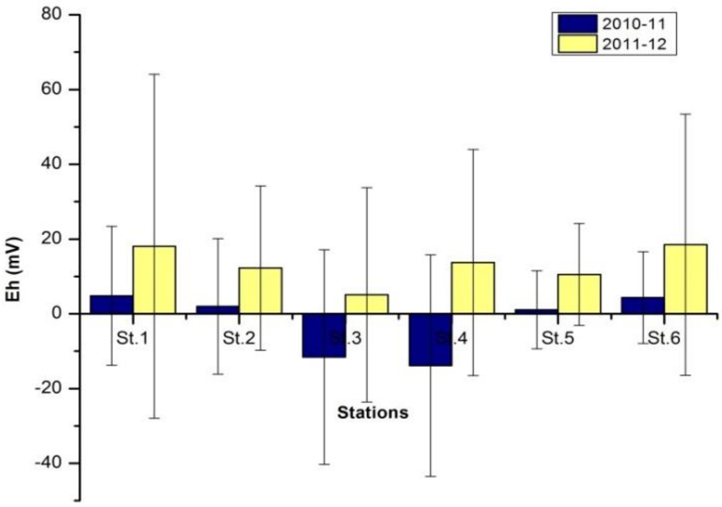

Figure 6.14 Annual variations in Eh in selected mangrove habitats in Ernakulam during 2010-12

The first year monsoon period recorded mostly negative values, with the highest recorded at St.4; Malippuram (-49.33 ±38.55mV). The post monsoon periods of both years recorded higher Eh compared to other seasons. The second year pre monsoon recorded the lowest values, ranging from 17.2±8.31 (St.3, Puthuvypin) to 49±33.14mV (St.6, Valanthakad –Arkathadam). The ANOVA results showed that the Eh was significant at 1% level (R^2= 0.688, p<0.01).

iv. Dissolved Oxygen

The dissolved oxygen values were found to be minimum in the month of December 2010 and maximum in March 2012. The mean monthly values ranged from 2.23± 0.48mg/L to 9.84± 5.96 mg/L. The annual station wise mean showed higher values in second year except at St.6 (Figure 6.15). In the first year the DO ranged from 2.79± 0.88 mg/L (St.1) to 4.59± 1.76 mg/L (St.6) while in the second year (2011-12) the mean values were slightly higher, ranging from 3.71± 1.30 mg/L (St.2,3) to 5.87± 5.24 mg/L (St.1). The season wise variations in DO did not display a particular trend. The DO were high in the post monsoon period during both years ranging from 1.67± 0.59 mg/L to 5.11±4.97 mg/L (2010-11) and 3.07± 1.61 mg/L to 5.66± 3.25 mg/L (2011-12). Station 1 (Aroor South) recorded higher DO values irrespective of seasons and the lowest DO values were recorded at St.3, Puthuvypin. The ANOVA results exhibited significant variation between months (F=2.616, p=0.009) and between years (F=6.230, p=0.015).

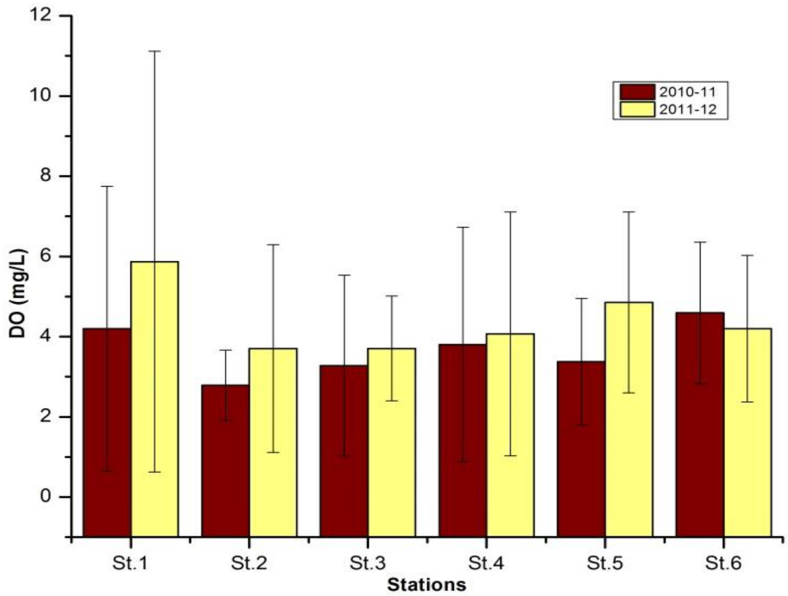

Figure 6.15 Annual variations in DO in selected mangrove habitats in Ernakulam during 2010-12

v. Biological Oxygen Demand

The monthly mean BOD values ranged from 0.92± 0.53mg/L to 13.45± 9.66mg/L. The BOD values were minimum in the month of October 2011 and maximum in May 2011. The mean seasonal variation ranged from 1.81± 1.16mg/L (monsoon 2010-11) to 9.33± 6.62mg/L (pre monsoon 2010-11). The seasonal mean values of 2010-11 period shows higher BOD in pre monsoon (9.33± 6.62mg/L) followed by post monsoon (2.29± 1.27mg/L) and monsoon season (1.81± 1.16mg/L). On the other hand higher BOD was recorded in the monsoon (6.87± 6.79mg/L) followed by pre monsoon (4.06± 3.70mg/L) and post monsoon seasons (3.93± 2.05mg/L) in the second year. The station wise mean values ranged from 1.28± 0.86mg/L (St. 5, Valanthakad-Magranazhi) to 8.10± 8.75mg/L (St. 4, Malippuram) during 2010-11 (Figure 6.16). While the second year, the values ranged from 1.67± 1.53mg/L (St.6, Valanthakad-Arkathadam) to 11.54± 10.07mg/L (St.4). Malippuram station recorded higher values whereas the stations at Valanthakad (St.5, St.6) recorded lower BOD compared to all other stations during both years. The ANOVA showed an overall significance at 1% level (R^2=0.593, p<0.01).

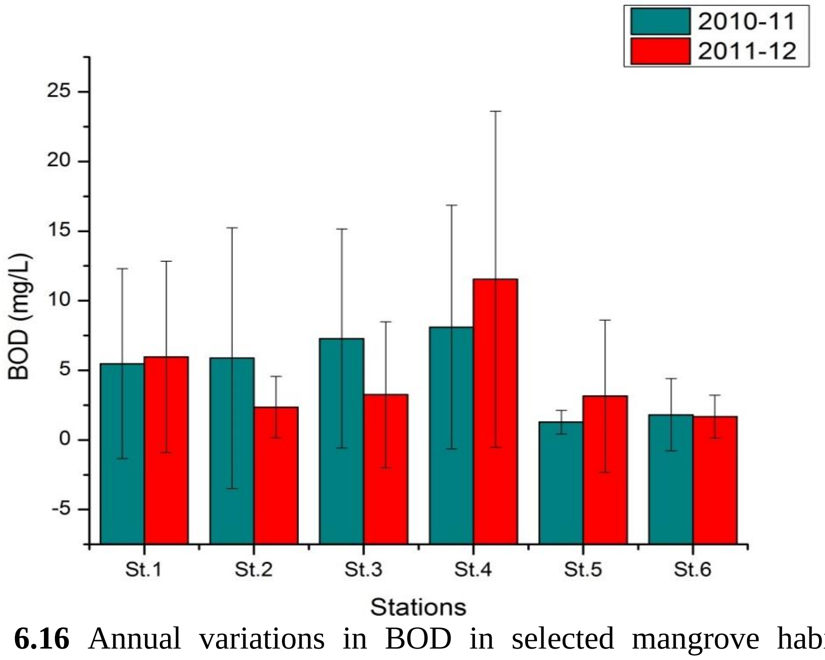

Figure 6.16 Annual variations in BOD in selected mangrove habitats in Ernakulam during 2010-12

vi. Hydrogen Sulphide

The mean monthly sulphide values ranged from 0-24.58± 11.84 µmol/L during the study period. Very low concentrations of sulphide were recorded in the months of November 2010, August 2011, October 2011 and April 2012. The annual station wise variations showed higher values in the second year compared to first year (Figure 6.17).

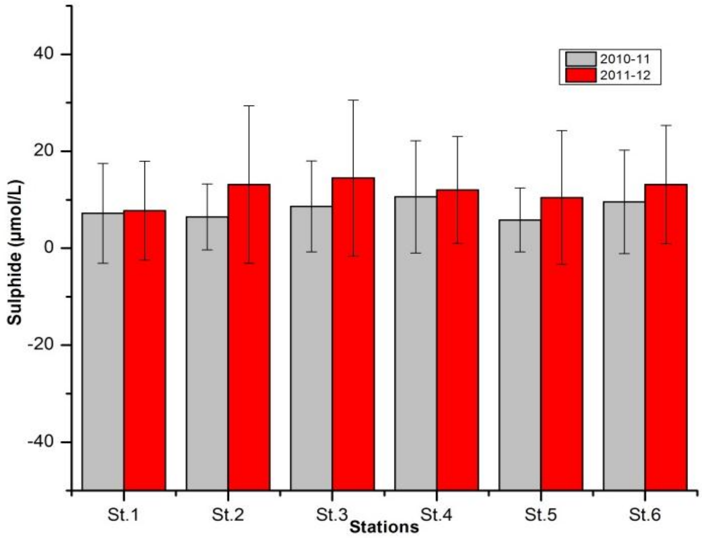

Figure 6.17 Annual variations in hydrogen sulphide in selected mangrove habitats of Ernakulam during 2010-12

The values ranged from 5.84± 6.59µmol/L (St.5) to 10.61± 11.58µmol/L (St.4) during 2010-11 and from 7.78± 10.20 µmol/L (St.1) to 14.49± 16.09 µmol/L (St.3) during 2011-12. The seasonal variation recorded highest value in the second post monsoon season (20.33± 3.33 µmol/L) at St.6. During first year the sulphide concentration was high in pre monsoon season followed by post monsoon and monsoon season. The pre monsoon values ranged from 9.71± 10.89 µmol/L (St.6) to 18.31± 8.76µmol/L (St.3). Almost a similar trend followed in the second year. The ANOVA results showed an overall significance at 1% level with an R^2 value of 0.542 ($p<0.01$).

vii. Ammonia- Nitrogen

The ammonia-nitrogen concentrations were high in all mangrove habitats. The mean monthly values ranged from 2.34± 1.86 µmol/L (February 2012) to 49.10± 83.21 µmol/L (April 2011). October 2010, April 2011 and May 2011 recorded higher values whereas the values were low in September 2010, November 2010 and February 2012. The annual station wise mean showed in the first year except at St.4 (Figure 6.18). The values ranged from 4.17± 3.06µmol/L (St.6) to 23.01± 34.13µmol/L (St.2) during 2010-11 and from 8.39± 9.30 µmol/L (St.6) to

27.49 ±17.97 µmol/L (St.4) during 2011-12 periods. Valanthakad –Arkathadam (St.6) recorded lower values during both years. The season wise variation showed highest values in the first pre monsoon period. The values ranged from 4.47± 1.69µmol/L (St.6) to 57.71± 106.66 µmol/L (St.5). In the first year the monsoon season recorded lowest values while in second year both monsoon and pre monsoon seasons recorded higher values. The second year post monsoon values were low ranging from 6.54± 8.85µmol/L (St.1) to 9.89± 6.99µmol/L (St.3, 4).

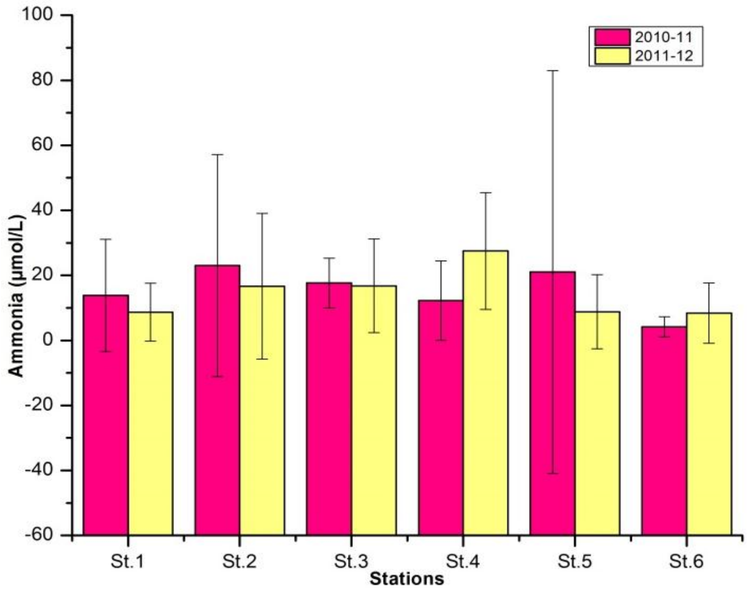

Figure 6.18 Annual variations in ammonia-nitrogen in selected mangrove habitats in Ernakulam during 2010-12

viii. Nitrate- Nitrogen

The nitrate concentration was comparatively higher than nitrite concentration in the study area. The mean monthly values ranged from 0.04±0.04µmol/L to 2.62 ±3.18 µmol/L. The lowest values were recorded in April 2011 and highest in September 2010. All the station except St.3 showed higher mean values during the first year (2010-11). The annual station wise values ranged from 0.68 ±0.64 µmol/L at St.1 to 1.49± 2.46 µmol/L at St.6 during the first year and from 0.61± 0.60 µmol/L at St.4 to 1.29± 1.15 µmol/L at St.3 during the second year respectively (Figure 6.19). The season wise variation in the first year showed higher values in the monsoon season followed by the pre monsoon and post monsoon seasons. The monsoon values ranged from 0.56± 0.51 µmol/L (St.5) to 3.81 ±14.49 µmol/L

(St.6). The post monsoon season recorded the higher values during the second year, ranging from 0.49± 0.48 µmol/L at St.4 to 1.72± 1.46 µmol/L at St.3. Valanthakad – Arkathadam (St.6) recorded the highest mean value (3.81 ±14.49 µmol/L) and Aroor North (St.1) recorded the lowest mean value (0.29 ±0.30 µmol/L).

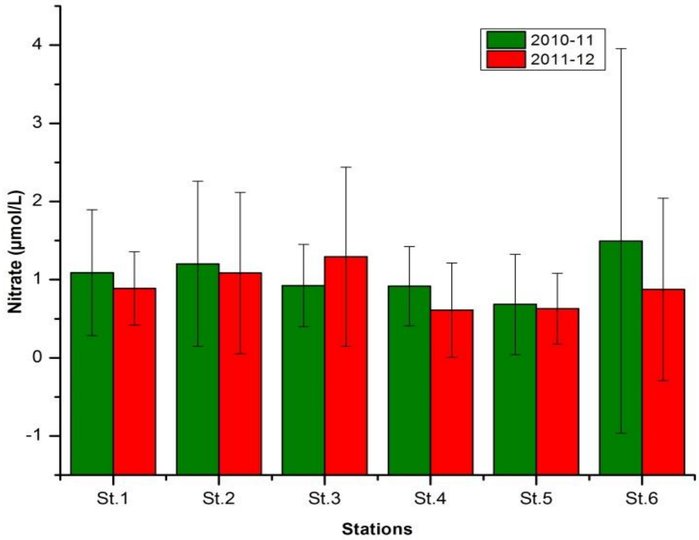

Figure 6.19 Annual variations in nitrate-nitrogen in selected mangrove habitats of Ernakulam during 2010-12

ix. Nitrite- Nitrogen

The nitrite concentration was found to be lowest in the study area compared to other nutrients. The mean monthly values ranged from 0.04± 0.03µmol/L to 0.06± 0.39 µmol/L with the lowest values recorded in the month of January 2012 and highest in May 2012. There was not much variation in the mean nitrite concentration between two years. The annual station wise nitrite values ranged from 0.17± 0.20 µmol/L (St.6) to 0.59± 0.38 µmol/L (St.3) during first year and from 0.09± 0.06 µmol/L (St.4) to 0.39± 0.23 µmol/L (St.3) during second year respectively (Figure 6.20). During both years St. 3, Puthuvypin recorded higher nitrite concentrations. All the stations showed higher values in the pre monsoon season except at St.3, which recorded a peak value in the post monsoon period (0.75 ±0.53µmol/L). The pre monsoon values ranged from 0.26± 0.10 µmol/L (St.2) to 0.62± 0.62 µmol/L(St.1). The nitrite values were low during the monsoon season with the lowest recorded in the first monsoon period. Puthuvypin (St.3) showed higher values during all the seasons.

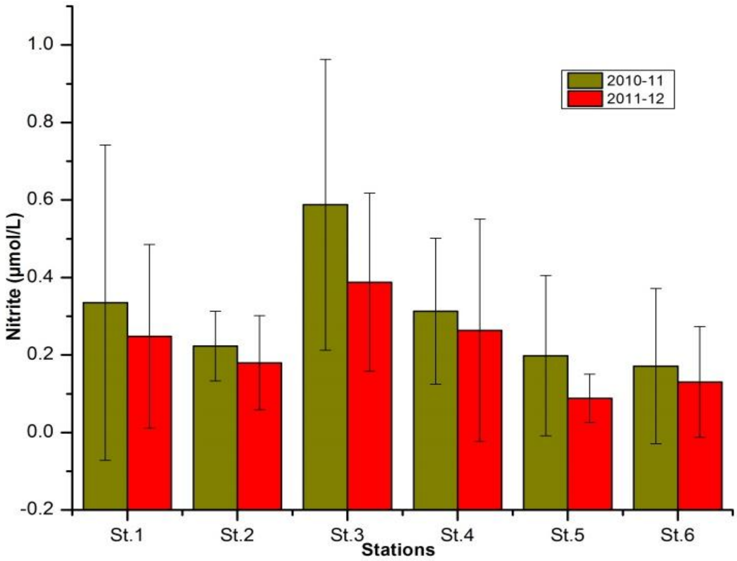

Figure 6.20 Annual variations in nitrite-nitrogen in selected mangrove habitats in Ernakulam during 2010-12

x. Dissolved Inorganic Nitrogen

Dissolved Inorganic Nitrogen (DIN) is the sum of ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen. The mean monthly DIN values ranged from 3.32± 1.76 µmol/L to 49.32± 83.12 µmol/L. Similar to ammonia, the DIN values were also higher in April 2011 and low in the month of February 2012. The annual station wise values ranged from 5.84± 3.15µmol/L (St.6) to 24.43± 34.09µmol/L (St.2) during first year and from 9.39± 946 µmol/L (St.6) to 38.37± 18.32µmol/L (St.4) (Figure 6.21). The seasonal variation also showed a similar trend of ammonia. The highest value recorded in the first pre monsoon season, ranging from 5.24± 1.55µmol/L (St.6) to 58.98± 105.85µmol/L (St.5). The monsoon period (2010-11) recorded lowest values, from 1.60 ±0.93µmol/L (St.5) to 13.97± 4.47µmol/L (St.6).

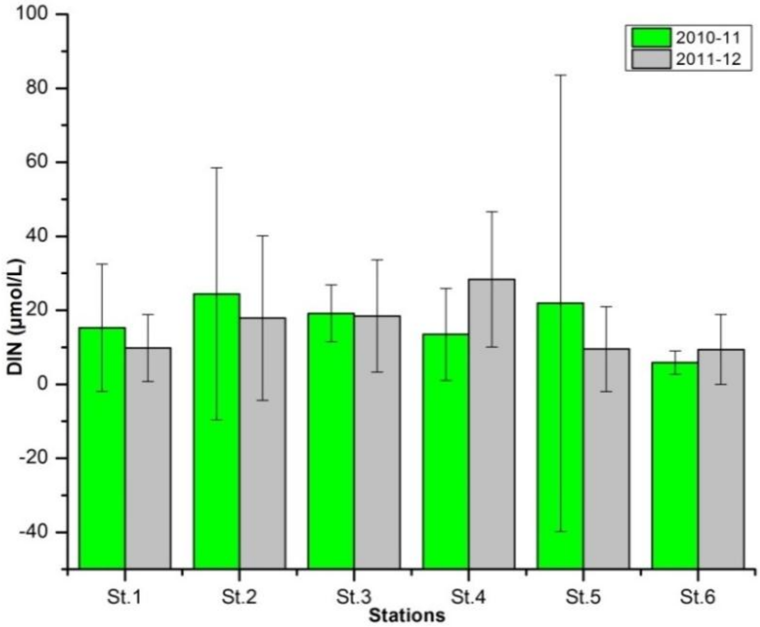

Figure 6.21 Annual variations in DIN in selected mangrove habitats in Ernakulam during 2010-12

xii. Phosphate- Phosphorus

The mean monthly concentrations of phosphate ranged from 1.28± 0.96 µmol/L to 11.33 ±10.28 µmol/L. The values were low in the month of September 2010 and high in May 2012. The highest value recorded was 26.72 µmol/L at St.3 (Puthuvypin) in December 2010. The annual station wise values were higher in second year except at St.1 and St.5. The phosphate concentrations ranged from 2.60 ±1.09 µmol/L to 9.01± 5.69 µmol/L (St.2) during 2010-11 and from 2.12±1.17 µmol/L (St.5) to 9.50±8.74 µmol/L (St.3) during 2011-12 (Figure 6.22).

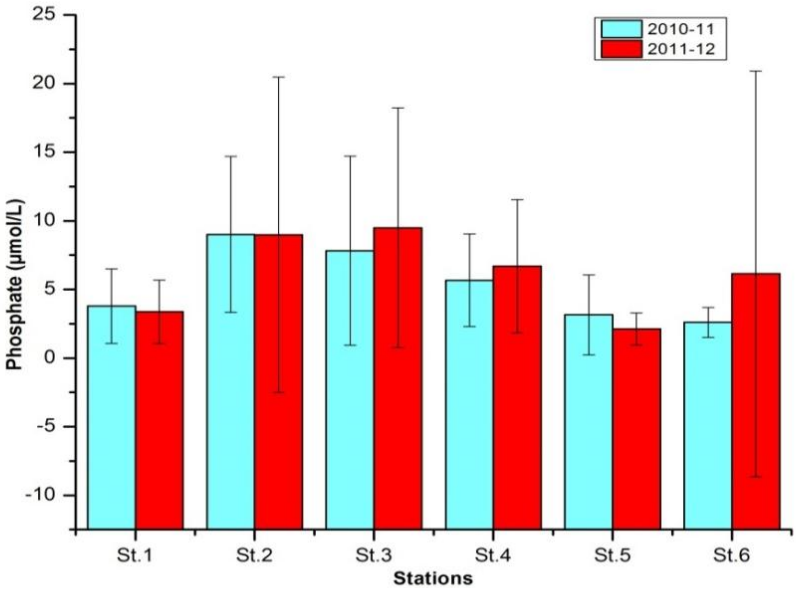

Figure 6.22 Annual variations in phosphate- phosphorus in selected mangrove habitats in Ernakulam during 2010-12

The season wise variations showed highest values in the second post monsoon season followed by the pre monsoon of first year. The monsoon season generally recorded lower values. The mean season wise variation during the post monsoon (2011-12) ranged from 3.21 ±0.45 µmol/L (St.5) to 17.06 ±17.03 µmol/L (St.2). During first year the pre monsoon season showed the highest values, followed by pre monsoon and monsoon seasons. But during second year the post monsoon values were higher compared to other seasons. Station 2 (Aroor South) recorded the highest values and St.5 (Valanthakad- Magranazhi) recorded the lowest values irrespective of seasons.

xiii. Silicate- silicon

The silicate concentrations were higher compared to the other nutrients in the study area. The mean monthly values ranged from 9.90 ±1.74 µmol/L in the month of October 2011 to 90.38± 2.92µmol/L in September 2010. The silicate concentrations were low in the months of November 2010, February 2011 and May 2011 during first year and in October 2011, May 2012 during second year. All the stations exhibited higher values in the month of September 2010, with the highest value recorded at St.2 (119.65 µmol/L). The annual station wise silicate concentrations were higher in the 2010-11 period compared to 2011-12 (Figure 6.23). The values ranged from 38.24 ±25.81 µmol/L to 48.08± 23.34 µmol/L (2010-11) and from 16.15± 7.79 µmol/L to 2.9± 16.08 µmol/L (2011-12). The season wise variations of silicate concentration were high in the monsoon season followed by pre monsoon and post monsoon seasons. The first year monsoon values ranged from 46.36 ± 50.42 µmol/L to 68.22± 46.59 µmol/L in St.1 and St.4 respectively. The highest value recorded in the first pre monsoon was 46.80± 18.53 µmol/L at St.5.

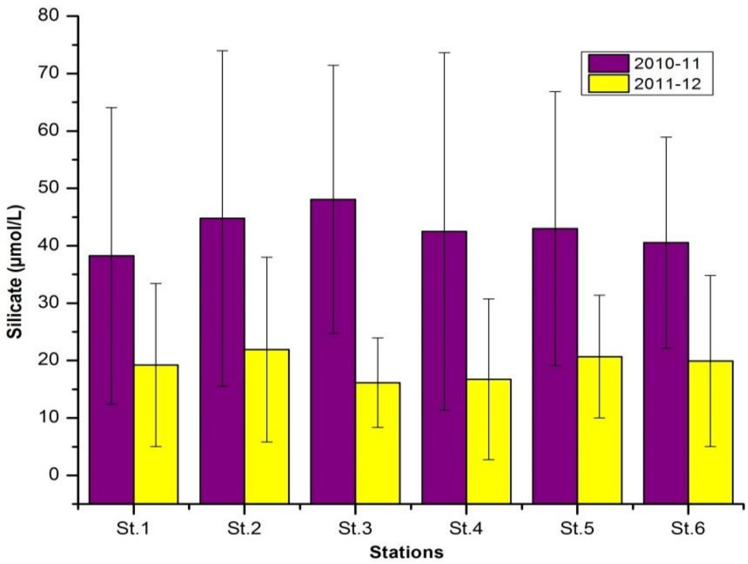

Figure 6.23 Annual variations in silicate- silicon in selected mangrove habitats in Ernakulam during 2010-12

Table 6.2 Mean seasonal variation of various chemical parameters during the period 2010-12

Parameters	2010-11			2011-12		
	MN	Post MN	Pre MN	MN	Post MN	Pre MN
CO_2	6.08±1.77	3.06±0.47	4.10±1.67	7.44±2.02	9.53±1.52	12.22±2.55
pH	7.19± 0.56	7.47± 0.30	7.20 ±0.13	6.89± 0.21	7.70± 0.20	7.16± 0.06
DO	4.06± 1.48	3.21±1.19	4.18±1.32	3.39±0.21	4.96±1.51	4.32±1.07
BOD	1.81± 1.16	2.29± 1.27	9.33± 6.62	6.87± 6.79	3.93± 2.05	4.06± 3.70
Sulphide	7.42±4.40	6.22±2.82	12.37±3.67	6.48±5.47	13.45±5.86	12.46±4.50
Ammonia	4.38±4.37	7.54±4.81	31.00±21.14	16.64±11.44	8.36±1.51	18.01±9.89
Nitrate	1.68±1.12	0.66±0.21	0.82±0.21	0.73±0.29	0.95±0.45	1.14±0.43
Nitrite	0.17±0.16	0.33±0.2	0.38±0.18	0.23±0.09	0.17±0.09	0.26±0.16
DIN	6.23±4.35	8.54±5.16	32.21±21.24	17.60±11.66	9.47±1.71	19.41±9.92
Phosphate	2.93±1.87	5.81±3.04	6.39±3.32	4.08±2.58	9.06±6.25	5.51±3.86
Silicate	54.66±9.02	35.56±4.35	39.83±9.46	31.82±5.40	16.98±2.34	16.55±3.06

6.4.4 Data Analysis

i. Cluster and MDS analysis

Cluster analysis is an important tool for analysing water quality data to understand the relationship between stations and seasons. The season wise cluster analysis of hydrographic parameters showed two major clusters. The monsoon season of 2010-11 period (MN-10) formed the cluster 1 which stood apart from the cluster 2 formed by all other seasons (Figure 6.24). In cluster 2 the minimum distance was obtained between pre monsoon season of the first year (Pre MN-10) and monsoon season of the second year (MN-11) with a distance of 4.3. The distance value gradually increased to 8.6, exhibiting similarity with the pre monsoon season of second year (Pre MN-11). The post monsoon season of both the years formed a single cluster with a distance value of 8.6.

The MDS plot depicts the similar inference with groupings. All the seasons of both years formed a single group except monsoon season of first year which stood apart. Thus the present study shows that the monsoon season of the first year is different from the other seasons indicating considerable variations in hydrographic parameters in that particular season.

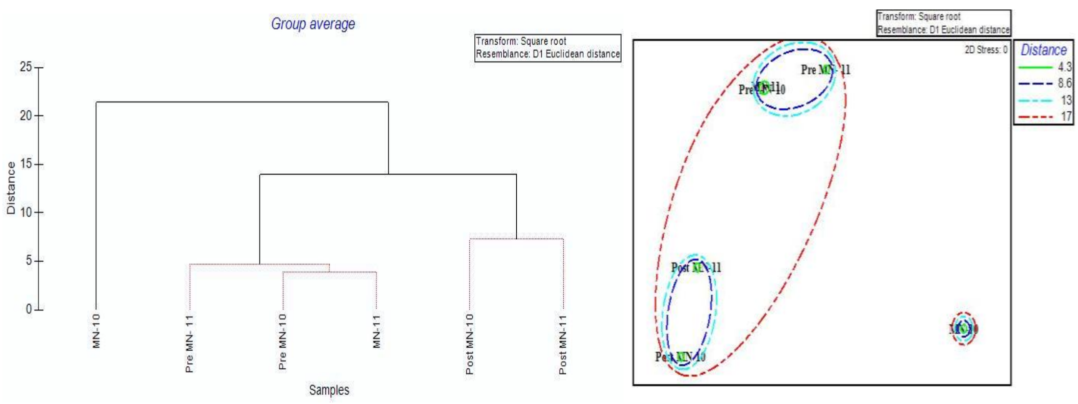

Figure 6.24 Dendrogram and MDS depicting similarity clusters formed by mean seasonal hydrographic parameters in mangrove of Ernakulam during 2010-12

The station wise cluster analysis based on hydrographic parameters was carried out separately for two years. During 2010-11period, two major clusters were formed. Stations 3 and 4 together formed Cluster I and other stations (St. 1, 2, 5, 6) formed the Cluster II (Figure 6.25). Stations 3 and 4 showed a distance of 5.7. In cluster II the minimum distance was observed between station 2 and 5 with a value of 2.8 and the distance value gradually showed an increase toward station1 and 6 respectively. The station wise MDS analysis of the first year showed three distinct groups. Station 6, Valanthakad- Arkathadam stood apart from the other groups. Stations 3 and 4 were grouped together (Group I), while stations 1, 2 and 5 formed the other group (Group II).

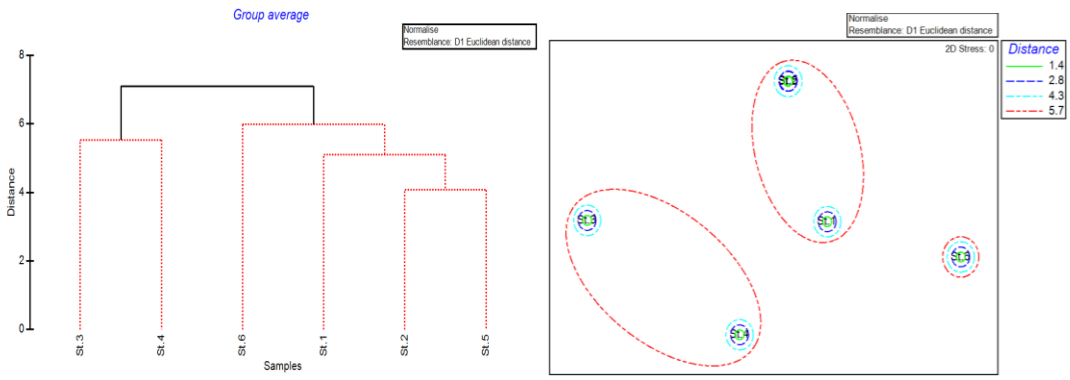

Figure 6.25 Dendrogram and MDS depicting similarity clusters formed by mean spatial hydrographic parameters in mangrove of Ernakulam during 2010-11

The station wise clustering of hydrographic parameters revealed a different picture for the second year (Figure 6.26). Two clusters were formed at a distance value of 8, where station 3 (Cluster I) stood apart from all other stations (Cluster II). The minimum distance value was obtained between station 2 and 6 (3.2) and increased towards station 5, 1 and 4. In MDS analysis the major group was formed by stations 1, 2, 5 and 6 while station 3 and 4 were separated from the group. In the present study station 3 and 4 were set apart from other stations. Station 3, Puthuvypin is situated in the vicinity of sea exhibiting higher salinity ranges. The water quality parameters are greatly affected by the pollution from the nearby construction sites of LNG terminal. On the other hand Malippuram Station (St.4) showed a higher load of organic matter, which was depicted in the higher ammonia concentration and higher BOD values during the study.

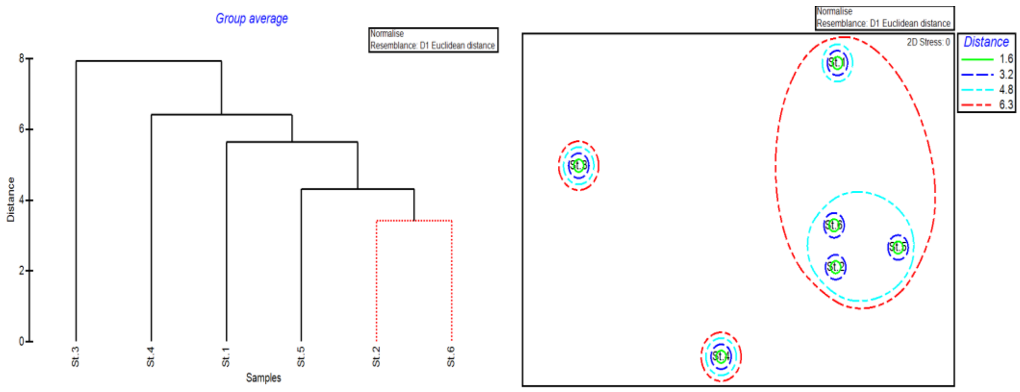

Figure 6.26 Dendrogram and MDS depicting similarity clusters formed by mean spatial hydrographic parameters in mangrove of Ernakulam during 2011-12

The cluster analysis based on mangrove plant density showed two major clusters: cluster I formed by stations 5, 1, 2, 6 and cluster 2 formed by stations 3 and 4 (Figure 6.27). The maximum similarity was observed between stations 2 and 6 (80%) and gradually decreased toward St. 1 and St. 5 (60%). Station 3 and 4 were only 40% similar and stood apart from other stations. In the present study, stations 3 and 4 were *Avicennia* dominated habitats and located at the proximity of the sea. Thus the stations exhibited higher influence of salinity. Valanthakad- Arkathadam (St. 6) and Aroor North (St.2) exhibited 80% similarity in mangrove species composition. Matured trees of *Sonneratia caseolaris* and rare species of *Kandelia candel* were dominant species of both the stations. All the four stations (St. 5, 1, 2, and 3) were away from sea hence had more influence of fresh water.

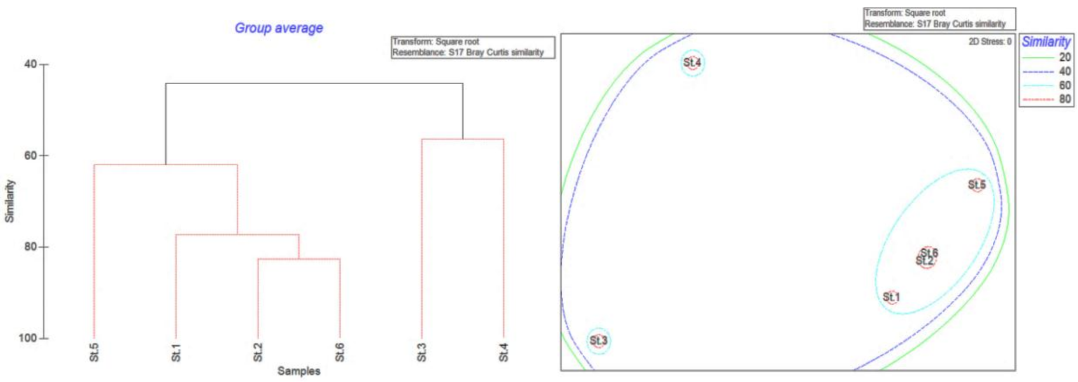

Figure 6.27 Dendrogram and MDS depicting similarity clusters formed by spatial density of mangroves in the study area

ii. Principal Component Analysis (PCA)

The principal component analysis extracted four principal components with 93.1% of percentage variance (Table 6.4). The eigen value for the first and second principal component (PC1 and 2) was 12.14 and 3.35 respectively. The component loading measures the degree of closeness between the variables. The largest loading (positive or negative) indicates the meaning of dimension; positive loading indicates that the contribution of the variables increases with the increasing loading in dimension; and negative loading indicates a decrease.

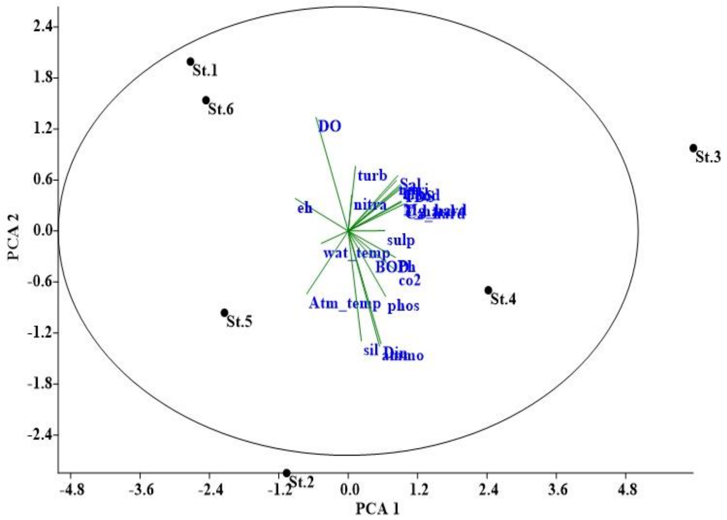

Figure 6.28 PCA plot of hydrographic parameters in different seasons during 2010-12

The highest factor loading values obtained for PC1 was for calcium hardness followed by TDS and total hardness. Various other parameters such as atmospheric temperature, water temperature, Eh and DO exhibited a negative correlation in axis 1. The parameters such as ammonia, DO and silicate were positively influential along axis 2. In PCA of the water quality parameters showed that pH, CO_2, BOD, phosphate, silicate and ammonia were the principal components influencing the hydrography of station 4 while DO played a major role in St. 1 and St.6. Station 3 was characterised by higher salinity, turbidity, nitrate and hardness values while St.5 represented negative correlation to salinity indicating more of fresh water influence.

iii. BIOENV

The BIOENV analysis is used to identify the role of environmental variables on biotic factors. In the present study the analysis was used to identify the major the water quality parameters influencing the distribution of mangrove vegetation. The analysis was significant at 1% level with number of permutation equal to ρ = 0.923 and maximum permutation of 999.

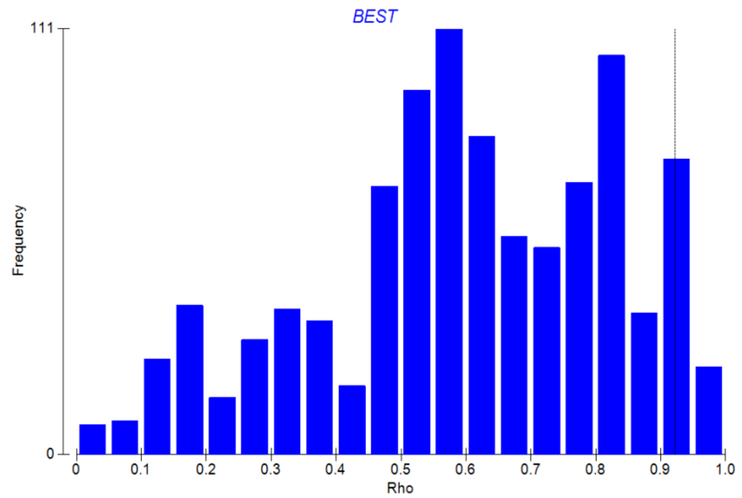

Figure 6.29 Histogram depicting the BIOENV analysis of mangrove plant density

Various water quality parameters influencing the density of mangrove species are depicted in Table 6.3.The analysis showed that nitrite is the most influencing variable affecting the diversity of mangroves with a ρ value 0.923. Besides nitrite, water temperature, silicate, phosphate and ammonia concentration showed maximum correlation to plant density (ρ= 0.900). Other parameters like pH, DIN and sulphide were least significant.

Table 6.3 BIOENV table showing the list hydrographic parameters that affecting the density of mangrove species in Ernakulam

1	Water temp	5	BOD	9	Nitrite
2	pH	6	Silicate	10	Ammonia
3	Salinity	7	Phosphate	11	DIN
4	DO	8	Nitrate	12	Sulphide

Variables	Rho	Parameters
1	0.923	9
5	0.900	1,6,7,9,10
5	0.886	1,6,7,9,11
4	0.882	2,6,7,9
3	0.881	7,9,11
5	0.875	6,7,8,9,10
3	0.874	1,7,9
4	0.871	6,8,9,11
3	0.868	9,11,12
3	0.861	9,10,12

6.5 Discussion

The hydrology is an important variable which directly or indirectly controls the structure and function of a mangrove ecosystem. The salinity, nutrients, water level etc. plays a major role in plant community structure (Odum and Mclvor, 1998) and primary productivity patters (Cardona-Olarte et al. 2006; Lovelock et al. 2007). According to many ecologists (Wolanski et al., 1980; Kjerfve, 1986; Ovalle et al., 1990; Ong et al., 1991) the dynamic process in a mangrove ecosystem is controlled by various hydrological changes along with the micro- variation in topography. Mangroves are always subjected to frequent inundation by water. Besides these natural hydrologic patterns, the ecology of mangrove ecosystems is modified by various other anthropogenic reasons.

6.5.1 Physical parameters

Temperature is one of the prime water quality parameter, which has both biological and chemical effects in a water body. The temperature influences the chemistry of many compounds in natural waters and the variations in temperature affects various physical properties of water such as vapour pressure, density, surface tension, viscosity, diffusion of gasses, solubility etc. It is also reported that the global warming and the increasing temperature also effects various physical and biological interactions in an estuary (Gabler et al., 2017). Among the various climatic factors temperature is one of the major factors controlling the distribution of mangrove species. The atmospheric temperature in the study area varied from day to day with a temperature ranging from 21^0C -33^0C. The inter-annual variation in temperature was negligible. April 2012 was the hottest month recorded during the study period. Valanthakad- Arkathadam (St.6) and Aroor South (St.2) showed higher temperature. The seasonal variation in atmospheric temperature was minimum and ranged from 25.3± 0.57^0C- 29.6± 1.7^0C which was in accordance with the views of Walsh (1974) and Chapman (1975, 1977). According to them, the seasonal range of temperature fluctuation in a mangrove ecosystem does not exceed 10^0C. During the investigation period all the study stations recorded temperature above 20^0C which clearly indicate the higher temperature preference of mangroves.

According to Sherrod et al. (1986), the global distribution of mangrove species is limited by its tolerance to low temperature and the mangroves are restricted to areas where the mean atmospheric temperature is higher than 20^0C even in the coldest months. Waisel (1972) reported that rapid temperature fluctuations and exposure to short-term freezing temperatures affects the viability of mangroves. The seasonal variation showed lower temperature during monsoon and higher during the pre monsoon periods clearly indicating a distinct tropical condition. A similar pattern was observed by Jayachandran et al., 2012 (Kodungallur –Azhikode estuary). The increase in atmospheric temperature correspondingly increased the water temperature (r^2= 0.666, $p<0.01$) as the water column was easily heated up due to shallow depth.

The **water temperature** was higher than atmospheric temperature during the study period. The atmospheric temperature had great influence on the water temperature since all the stations were shallow in nature, having marginal difference between the surface and bottom waters. Anilakumary et al. (2007) and Meera and Bijoy Nandan (2010) also reported similar observations in various studies in the Cochin backwaters, where the water bodies are shallow or with minimum depth is easily heated up. The highest temperature recorded was 35^0C at St.4 during May. The April- May months were hottest compared to other months. This is possibly due to the higher atmospheric temperature influencing the shallow depth of the stations resulting in the higher thermal conductivity of water (Islam et al., 2004). The season wise variation showed a lower temperature in the monsoon season similar to the studies of Kitheka et al., 1996. According to Kitheka et al., the shallow mangrove zones show both diurnal and seasonal temperature variations. Even though the temperature was high in pre-monsoon season due to the characteristic dry weather and low rainfall prevailing in the season, the variation in temperature between seasons were low. This is possibly because of the frequent inundation of tidal water in mangrove habitats, as the influx of cold sea water brings down the water temperature even in the pre monsoon periods. The high solar radiation attributing to higher water temperature were also observed in the studies of Das et al., 1997; Karuppasamy and Perumal, 2000; Senthilkumar et al., 2002; Santhanam and Perumal, 2003 and Ashok Prabu et al, 2008. According to Nair (1983), the tropical regions exhibit minimal variation in temperature between seasons. Similar observations were clearly depicted in the present study, indicating the tropical nature of the ecosystem. The water temperature and atmospheric temperature showed a positive correlation significant at (r^2= 0.666, $p<0.01$), which was clearly evident in the pre monsoon season during which the high solar radiation influenced the water body (Ashok Prabu et al., 2008).

The **salinity** is an important factor determining the distribution of living organisms in an ecosystem. Gibson (1982) reported that the variations in salinity, caused by dilution or evaporation have a great influence on the fauna in the intertidal zone. Generally, changes in the salinity in the brackish water habitats such as estuaries, backwaters and mangroves are due to the influx of freshwater from land run off, caused by monsoon or by tidal variations and rate of evaporation. The salinity in the study area was mixo-mesohaline in the nature. During both the years the stations were less saline in the monsoon period which could be due to the dilution by the rain water. Similar observations were reported by Meera and Bijoy Nandan, 2010 (Valanthakad mangroves), Paramasivam and Kannan, 2005 (Muthupet mangroves), Saravanakumar et al., 2008 (Gulf of Kachchh), Raut et al., 2005 (Godavari estuary), Ashok Prabu et al., 2008 (Pichavaram mangroves) and Vineetha et al., 2015 (Cochin estuary). The higher salinity recorded in the post monsoon season could be due to the relatively dry period of the approaching pre monsoon season resulting in higher rates of evaporation (Wolanski et al., 1980; Hughes et al., 1998 and Twilley and Chen, 1998). Kathiresan (1996) also reported that higher rate of evaporation leads to higher salinity in the dry seasons. Kitheka et al., (1996) in the study on the water circulation dynamics in the tropical bay of Kenya also reported that the spatial variation in salinity occurs as a result of processes such as evaporation, fresh water input and sea water influx. Station 3 (Puthuvypin) recorded higher salinity values compared to other stations which could be due to the sea water influx during the time of high tide. Anitha and Sugirtha, 2013 also reported that the stations in close proximity to sea showed higher salinity compared to other stations. The present study established a positive relation between salinity and conductivity (r^2=0.777, p<0.01) as the salt particles have electrolytes that hold negative and positive charges, thus higher the salinity, higher will be the conductivity (Pawar, 2013).

A negative correlation was observed with silicate concentration (r^2= -0.246, p<0.01). Thus low salinity values accompanied with high silicate concentration indicates prevalence of fresh water condition in most of the study sites. In the present study the BIOENV analysis did not exhibit a significant influence of salinity in the diversity of mangroves. Even though mangrove plants are tolerant to a salinity ranging from 2ppt to 90ppt, various field observation and laboratory experiments shows that the mangrove plants attain maximum growth only in low salinity conditions. For instance, *Avicennia marina* and *Aegiceras corniculatum* are tolerant to salinity up to 35ppt but shows maximum growth rate only between 7- 14ppt of salinity. This is mainly because higher salinity reduces the rate of ion transport to the shoots and also reduces the photosynthetic capacity of the mangrove plants resulting in low growth rate.

The **conductivity** of a water body is the capacity of the water to conduct an electric flow (Kumar and Prabhahar, 2012). This ability is purely based on the concentration of dissolved ions in water which is derived from the dissolved salts, inorganic materials like alkalis, chlorides, sulphides and carbonate compounds (Langland and Cronin, 2003). The monthly variation in conductivity ranged from 0.82 ± 0.78 mS to 27.36 ± 24.28mS in the present investigation, which was similar to the observations of Fakir et al., 2013 in the Bhitarkanika mangroves and Satheeshkumar et al., 2011 in Pondicherry mangroves. The season wise variation showed lower values in monsoon followed by the pre monsoon period and higher values during the post monsoon period of both years which could be due to the mixing of fresh water and increased salinity concentrations in the respective seasons. The conductivity pattern in the study area showed direct proportionality to the concentration of salinity (r^2=0.777, p<0.01). This was also evident in Puthuvypin station (St.3), which showed higher conductivity compared to other stations due to the higher salt concentration from sea water intrusion and from the disposal of effluents from the nearby LNG construction sites. Higher conductivity due to disposal of untreated effluents was reported by Trivedy (1987), Khatavkar and Trivedi (1992), Prabhahar et al. (2011). **Total dissolved solids** (TDS) are the dissolved solids (inorganic and organic) in the water body in molecular, ionized or colloidal form. The agricultural and residential runoff, discharges from industries and sewage treatment plants are primary sources of TDS. Thus they are important factor in the water quality studies to determine the health of a water body. In general the TDS were high in the monsoon season due to the input of suspended matters through surface run off but a similar observation was not found in the present investigation. Instead total dissolved solids were high in the post monsoon season. Similar to conductivity, the TDS was also high in St.3, which could be due to the continuous flushing of sea water as the station is located in the vicinity of sea. Both conductivity and TDS showed a linear trend (r^2=0.973, $p<0.01$) and was evident in the reports of McNeely et al. (1979) and Deekae et al., (2010). The **turbidity** is the measure of water clarity which is dependent on the concentration of suspended materials in it, determining the degree of light penetration (Davies and Smith, 2001). The monthly mean turbidity ranged from 1.56±1.10 NTU to 10.85± 8.32 NTU. Aroor North (St.1) was the most turbid station followed by Puthuvypin (St.3). Station 1 was shallowest among the selected study sites, thus even small disturbances caused the stirring up of muddy bottom sediments (Meera and Bijoy Nandan, 2010). Station 3 (Puthuvypin) was invariably turbid during all seasons, as the area was subjected to discharges of contaminated waste water and surface runoff from the nearby LNG terminal construction site. Besides this, the station was also close to sea facing more tidal disturbances than other stations. The studies by Nair et al., 1984 also reported that the maximum turbid zones were observed near the seaward edge. All the stations were turbid during the monsoon season due to the increased volumes of suspended solids carried through rain water and surface runoff (Kalaiarasi et al., 2012; Jayachandran et al., 2012).

The hydrogen ion concentration (**pH**) value has significant influence on the health and survival of flora and fauna, both in the natural waters and in the culture production systems. Most aquatic organisms are adapted to survive in pH ranging between 5.0 and 9.0, hence the knowledge on pH is important as it affects both chemical and biological process of a water body and also has indirect correlation to a number of other hydrographical parameters. The pH values indicated a neutral to alkaline nature of the study area. The alkaline nature of water body were also reported in Pondicherry mangroves (7.05–8.36) by Satheeshkumar et al., 2011; Thengapattanam estuary (7.2-7.96) by Anitha and Sugirtha, 2013; Cochin estuary (7-8.4) by Jhingran, 1982; in Pichavaram mangroves (7.2- 8.2) by Ashok Prabu et al., 2008 and in Mangalavanam mangroves (6-6.9) by Madhusudhanan and Jayesh, 2011. However much lower ranges were reported by Verma et al. (1984) due to more acidic waste disposal in mangrove habitats. Aroor South (St.1) and Aroor North (St.2) experienced more acidic pH values, which might be due to the discharge from nearby seafood industries. The pH was low in monsoon season and high in post monsoon seasons. Murugan and Ayyakkannu, (1991) and Ananthan (1995) also reported similar results and opined that the low pH in the monsoon season could be the result of fresh water influx through rain, low temperature and decomposition of organic matter. The carbon dioxide uptake by the organism for the process of photosynthesis, decrease in salinity due to rain water dilution could also be the reason for low pH during the seasons (Rajasegar, 2003). Station 3 (Puthuvypin) was more or less alkaline in nature which could be due to the vicinity of sea. Studies have also shown that stations progressively closer towards the estuary and the open sea and with high biological activity, showed more alkaline pH (Saravanakumar et al., 2008; Nirmal Kumar et al., 2009). Higher pH in highly biologically active systems is mainly because the carbon dioxide in the water body is removed during the process of photosynthesis. Since carbonic acid is formed by the dissolution of CO_2, their removal results in higher pH. The alkaline nature of the mangrove ecosystem is also comparable with the studies of Geetha et al., 2009. The narrow limits in the change of pH in the present study can also be due to extensive buffering capacity of seawater i.e. the chemical components of seawater react with ions capable of changing pH thereby resisting larger changes in pH. Changes in pH is also an important indicator of industrial pollutants. The pH followed a similar trend to that of salinity (r^2=0.307, p<0.01) and conductivity (r^2=0.270, p<0.01). The **redox potential** or the oxidation-reduction potential (Eh) is the measure of tendency of a solution to lose or gain electrons. It is expressed in millivolt (mV). The present study portrayed negative Eh in most of the stations indicating a highly reduced condition due to the heavy organic enrichment and its degradation. The redox potential is inversely affected by pH, which was clearly evident in the study. The seasonal variation recorded higher values in the monsoon compared to other seasons possibly due to the high organic input through surface runoff and low pH due to rain water dilution which was evident in the negative correlation between Eh and pH (r^2=-0.377, p<0.01).

The **carbon dioxide** is an important factor in an ecosystem, controlling the rate of photosynthesis and pH of a water body. The monthly mean values of carbon dioxide ranged from 0.54 ±0.49mg/L to 20.17± 7.01 mg/L, which was similar to studies of Jayachandran et al.,2012 (14mg/L) in the Kodungallur Azhikode estuary. The increased values of carbon dioxide could be due to the organic enrichment from mangrove litter. A similar rise in CO_2 values from the retting grounds due to organic enrichment was reported by Bijoy Nandan (2004). Station 4 (Malippuram) recorded higher values of carbon dioxide. CO_2 concentrations were low in the post monsoon period and high in the pre monsoon seasons. There was a decrease in CO_2 concentration with increase in atmospheric temperature (r^2= -0.214, p<0.01) and water temperature (r^2= -0.210, p<0.01) indicating the higher rate of photosynthesis in summer days compared to rainy or cloudy days of the year. The **alkalinity** of surface water is primarily a function of carbonates, bicarbonates and hydroxide content and it is taken as an indication of the concentration of these constituents. The alkalinity values greater than 100 mg/l was classified as highly productive and those with less than 50 mg/l as oligotrophic. During the study, most of the stations recorded greater alkalinity values (greater than 100mg/l) except at St.2 (Aroor North), indicating the highly productive nature of mangrove ecosystem. The lower alkalinity in St.2 indicates a slight shift to oligotrophic nature. The increased alkalinity in Puthuvypin (St.3) could be due to higher rates of industrial discharge, evaporation and sea water intrusion (Rahman et al., 2013). The hardness of a water body is due to the concentration of total calcium and magnesium ions present in the water and is expressed as milligram calcium carbonate per litre of water. The total hardness values were higher during post monsoon season of both the years compared to monsoon and pre-monsoon seasons. Similar trend was followed by calcium and magnesium hardness. This could be due to higher evaporation rates and reduced freshwater input. Higher values of calcium, magnesium and total hardness were observed at station 3 (Puthuvypin) which could be possibly due to large scale discharge from the LNG terminal. The hardness was comparatively lower during monsoon season of both years that might be due to the dilution from rain and surface run off.

6.5.2 Chemical parameters

Dissolved oxygen (DO) is an important physico- chemical factor controlling the sustainability of an ecosystem. The amount of dissolved oxygen in water is very important for aquatic organisms. Oxygen distribution also strongly affects the solubility of inorganic nutrients since it helps to change the redox potential of the medium. It can determine whether the environment is aerobic or anaerobic (Beadle, 1981). The dissolved oxygen concentration is mainly controlled by fresh water runoff, tidal ingress and water temperature. In general higher DO values were observed in the monsoon season and minimum during the pre monsoon season (Qasim et al., 1969; Pillai et al., 1975; Kitheka et al., 1996; Satheesh Kumar et al., 2011; Vineetha et al., 2015). The higher DO in the monsoon season could be due to the cumulative effect of higher wind velocity coupled with heavy rainfall resulting in freshwater mixing (Manikannan et al., 2011; Damotharan et al., 2010). The lower dissolved oxygen concentration in the pre monsoon is possibly due to the warming of water due to the prevailing high temperature. The oxygen saturated warm water can thus hold only less DO (Wu et al., 2009). In the present investigation higher DO values were recorded in the post monsoon season similar to the observations of Anitha and Sugirtha (2013). The higher DO values in the post monsoon could be due to less saline and colder water enhancing higher solubility of oxygen (Anilakumary et al., 2007). In contrast to the observations of the present study, peak values were recorded in the monsoon season by Janakiraman et al. (2013); Jayachandran et al. (2013) and Bijoy Nandan et al. (2014). The mean monthly values ranged from 2.23± 0.48mg/L to 9.84± 5.96 mg/L, similar to the observations of Kitheka et al., 1996 (3-6.8mg/L), S et al., 2011 (3.71-5.33mg/L), Wahid et al., 2007 (4.90 to 6.90 mg/L), Anitha and Sugirtha, 2013 (4-7.6mg/L), Ashok Prabhu et al., 2008 (2.4-5mg/L), Fakir et al., 2014 (3.25-8.58mg/L), Jayachandran et al., 2012 (4.7-5.9mg/L). Station 1 (Aroor South) recorded higher mean values of DO which could be due to higher primary productivity occurring in the surface waters (Qasim et al.,1969 and Haridas et al.,1973). The DO values were higher when aquatic weeds (*Eichhornia* spp.) were found to grow influencing an increase in the dissolved oxygen content through photosynthesis. The atmospheric oxygen is supplied to natural water bodies mainly by natural process of diffusion of oxygen from air to water and by photosynthetic activity of phytoplankton and other aquatic macrophytes. The DO values with an average of 5mg/L and above are considered to be healthy, where the aquatic organism can perform normal life activities. Below 5mg/l the ecosystem is in stressed condition (Whitfield and Elliott, 2002). The lower DO concentrations observed during the investigation period was possibly due to the large scale decomposition of mangrove litter and aquatic weeds such as *Eichhornia* spp. Similar depletion of oxygen was reported from the retting zones due to oxidation of organic matter associated with retting process (Bijoy Nandan, 1997; Sunilkumar, 2004; Suja, 2014). Increasing waste load in the mangrove environment results in almost stagnant and non- flushing conditions of water body there by leading to low DO.

The **Biological Oxygen Demand** or biochemical oxygen demand (BOD) is the amount of oxygen required for the breakdown of organic matter by aerobic organisms present in a water body at certain temperature for specific period of time. It is used as an important measure of the degree of organic pollution in water (APHA, 2005). It is expressed as milligrams of oxygen consumed per litre of water during 5 days of incubation. The values of BOD were in contrast with the values of DO in the present study. The values were lower in the monsoon season, which was in contrast with the DO values. The DO was lower at St.1 during first year and compared to second year. In contrast to this the BOD values were high in first year than second year. Enhanced biological production coupled with sinking of organic matter could be the reason for higher BOD values. The BOD was low during monsoon period except at St. 1. During monsoon period the influx of fresh water through rain probably diluted the organic load along with higher concentration of dissolved oxygen. Besides these the lower temperature also decreased the bacterial and microbial activities contributing lower BOD values (Mohammad et al., 2013). The higher BOD values also occur due to the higher waste load from surrounding industries. In mangroves the rise in BOD values are observed when there is higher amount of organic matter such as leaves and wood (Seca Gandaseca et al., 2011). The highest mean value recorded was 71.43 ± 99.98 mg/L which is high compared to the studies of Vijayakumar et al.,2014 (3.8mg/L in Thengaithittu estuary), Toriman et al., 2013 (2.65-4.46mg/L in Indonesian mangroves), Mohammad et al., 2013 (20.2-28mg/L in Sundarban mangroves), Fakir et al.,2014 (3.65mg/L in Bhitarkanika mangroves). But higher BOD values such as 190mg/L was reported by Zingde and Desai (1980) from Mahim Creek, Bombay and 280ppm from Cochin backwaters by Unnithan et al., (1975). Even higher BOD ranging from 1.5-5000mg/L were reported by Balchand (1984) at the industrial discharge points in the estuary. The permissible level of BOD in inland waters is 20mg/L according to BSI standards and 5mg/L as per ICMR standards (Meera and Bijoy Nandan, 2010). In the present study most of the values were above 10mg/L, indicating a heavy organic load in the ecosystem. The higher BOD in contrast to lower DO values (r^2=-0.233, $p<0.01$) were clearly evident in the present study similar to the values in Coringa river mangrove systems where contamination by inflow of waste from terrestrial run off and from anthropogenic origin resulted in high BOD values. All the stations showed higher **sulphide** values compared to other ecosystems as mangroves generally exihibit higher sulphide values due to the large scale decomposition of mangrove litter (Meera and Bijoy Nandan, 2010; Manju et al., 2012). In mangroves the higher sulphide concentration is evident through the blackening of sediment, where the sulphate gets converted to sulphides due to chemical reactions (Hynes, 1966). The elevated amount of sulphide recorded during the pre monsoon period which could be due to high temperature and reduction in rain enchance higher rate of litter decompsition. Studies of Ramanathan et al., 1993; Kumar et al., 2009 reported higher sulphide concentration during monsoon periods due to huge runoff from the river and from surrounding agricultural areas.

Nutrients are considered as one of the most important parameters in the mangrove environment influencing its productivity. Distribution of nutrients is mainly based on the season, tidal conditions and freshwater flow from land sources. Variations in rainfall and differences between dry and wet climates result in various physico-chemical changes in mangrove waters, especially with respect to concentrations of nutrients, such as phosphate, silicate, ammonia, and nitrate (Kjerfve et al.,1999).The inorganic nutrients analysed in the present investigation include ammonia- nitrogen, nitrate-nitrogen, nitrite-nitrogen, phosphate-phosphorus, silicate- silicon.

The **ammonia-nitrogen** being the primary decomposing product from the organic matter was found in higher concentrations compared to nitrites and nitrates in the present study. Ammonia is the most abundant form of inorganic nitrogen left in the surface waters after the utilisation of nitrate and phosphate by phytoplankton. The denitrification process also leads to the formation of molecular nitrogen and ammonia in the mangrove environment. Miranda et al. (2008) reported a linear correlation between salinity and ammonia. It is also observed that factors such as temperature, suspended particulate matter, dissolved oxygen and pH also influences the nitrification process. In the present study higher values of ammonia were recorded in the pre-monsoon season followed by post monsoon and monsoon seasons. Low levels of dissolved oxygen may be the reason for the less oxidation of ammonia and ultimately its high level in water column. The high temperature (r^2=0.200, $p<0.01$) concomitant with low DO resulted in higher ammonia concentration during pre- monsoon season. Ammonia also revealed a positive correlation with phosphate (r^2=0.193, $p<0.01$) and sulphide (r^2=0.709, $p<0.01$) but did not portray any correlation with nitrate possibly reflecting the complex processes of nitrogen cycle in mangrove habitats. **Nitrate** is an important micronutrient, formed by the oxidation of nitrogen compounds in the aquatic ecosystem and plays a significant role in growth of phytoplankton. Various interconversion reactions within water body, tides, fresh water discharge, denitrification process etc. are various factors controlling the nitrate concentration in the mangrove environment. The mean monthly values of nitrate- nitrogen ranged from 0.04±0.04µmol/L to 2.62 ±3.18 µmol/L. The season wise variation showed higher values in the monsoon season followed by the pre monsoon and post monsoon seasons. The maximum values in the rainy season could be due to discharge of nitrogenous substance from surface runoff (Muthukumaravel et al., 2012; Damotharan et al., 2010). The average low values recorded in the study area could be due to its utilization by phytoplankton as evidenced by high photosynthetic activity and also due to the neritic water dominance, which contained negligible amount of nitrate (Rajashree Gouda and Panigrahy, 1995; Das et al., 1997; Govindasamy et al., 2000). The **nitrite- nitrogen** values were lower compared to nitrate–nitrogen, ranging from 0-1.53 µmol/l. The pre-monsoon season showed a hike in nitrite concentration compared to other seasons which was in contrast to the studies of Anitha and Sugirtha, 2013; Thirunavukkarasu et al.,2011 where lower values were recorded during the pre monsoon season due to less fresh water input, higher salinity, higher pH and uptake by phytoplankton. The factors possibly contributing to nitrite concentrations are riverine input, sewage discharge and wastes from industries. Station 3, Puthuvypin showed a gradual increase in nitrite concentration compared to other stations during all the seasons of the study period. The low value recorded for nitrites could possibly due to high salinity (Mani and Krishnamurthy, 1989; Murugan and Ayyakkannu, 1991). Bijoy Nandan (2004) reported that higher nitrate content concomitant with low nitrite could also result from the nitrification process. The **dissolved inorganic nitrogen** (DIN) is the sum total of ammonium-nitrogen, nitrite-nitrogen and nitrate-nitrogen. The seasonal variation in DIN marked higher concentration during pre monsoon and showed a similar trend that of ammonia. Unlike nitrite and nitrate concentrations, the DIN showed a lower concentration during monsoon season which was in accordance with the higher concentrations of ammonia. DIN displayed a positive correlation with ammonia (r^2=0.999, $p<0.01$) and phosphate (r^2= 0.199, $p<0.05$). The lower concentration of dissolved inorganic nitrogen indicates a nitrogen limiting condition in the present study.

Phosphate is one of the major nutrient controlling the growth and production of phytoplankton in a water body and thus its concentration levels can be used to estimate the total biomass of phytoplankton. The enormous loads of weathering products are major contributors of phosphate concentration and generally mangroves and estuaries mediate the transfer of phosphates from land to ocean. The mean monthly concentrations of phosphate ranged from 1.28± 0.96 µmol/L to 11.33 ±10.28 µmol/L in the present study. Alongi et al. (1992) also opines relatively lower stocks of inorganic phosphorus and nitrogen in mangrove waters. The phosphate values were lower during the monsoon season in both years in contrast to the studies by Rajasegar et al., (2003), Anitha and Sugirtha (2013) were the monsoon season recorded higher values due to land runoff from agriculture fields contaminated with alkyl and super phosphates. The low value recorded could be attributed to uptake of phosphate by phytoplankton for their biological activity and fresh water dilution (Mishra et al., 1993). Station 3 (Puthuvypin), a highly industrialised area generally exhibited high concentrations of phosphate probably due to various anthropogenic activities occurring in the area. Studies by Nixon et al. (1984) shows that the nutrient profiles are greatly controlled by human impacts. The phosphate concentration exhibited a positive correlation with the hardness of the water body. The **silicate** is an important factor regulating the phytoplankton distribution in water and its concentrations was found to be higher in the mangrove ecosystem compared to other nutrients. The main source of dissolved silicates is from the weathering of silicate containing minerals (Vijayakumar et al., 2014). The dissolved silicates are comparatively low in rain water thus the terrestrial run off is the main source of silicate input in a water body. The spatio- temporal variations in silicate concentration in mangroves is mainly influenced by the physical mixing of seawater with fresh water, chemical interaction with clay substratum and finally by the biological removal by phytoplankton especially the diatoms and silicoflagellates. Aroor North (St.2) and Valanthakad-Arkathadam (St.6) showed comparatively higher concentrations of silicate. The higher silicate level during monsoon season was comparable with studies of Rajkumar et al., 2009 and it could be due to heavy inflow of monsoonal fresh water. The turbulence of water can also result in exchange of silicate from bottom sediment with overlying water in mangrove environments (Rajasegar, 2003). The higher concentrations of silicate during the monsoon season clearly indicate the fresh water influence in the entry of silicate into the study sites, mainly through the silicate rich land drainage.

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Chapter 7

Productivity Pattern in the Mangroves of Ernakulam

Contents

7.1 Introduction

Massive populations of organisms are supported in the pelagic and benthic realms of marine environment and the plankton community constitutes the major share of organisms in the pelagic column. Plankton as the word indicates are "drifters" including both phytoplankton and zooplankton which drift with the ocean currents as inhabitants of the open waters of the sea (also in fresh waters). Phytoplankton are free-floating microscopic plants that are mostly unicellular. Phytoplankton are mostly pelagic and are mostly motile, but the movement is mainly caused by currents (Dawes, 1998). They are grouped into three category based on size: picoplankton (<2 µm in diameter), nanoplankton (2-20 µm), microplankton (>20 µm-200µm), mesophytoplankton (0.2mm-20mm) and macrophytoplankton (> 20mm). Microphytoplankton exhibits a universal taxonomic distribution, even though the species diversity is high among diatoms and dinoflagellates (Lee, 1999). Diatoms are the most diverse group and contribute up to 40% of the total oceanic primary production.

The changes in plankton communities in open sea according to the seasonal changes are quite interesting phenomenon. During the winter, the open waters of the sea are mixed by the strong winds causing the upwelling of nutrients. While in spring the water becomes warm due to prolonged days resulting in most ideal condition for growth. Thus the plankton utilise the upwelled nutrients and forms blooms. Subsequently they result in higher numbers of zooplankton and top carnivores. As the summer falls most of the top carnivores attain size by utilizing the phytoplankton, they migrate to tropics and the annual cycle repeats on the onset of winter season. Various physico- chemical factors such as temperature (Goldman and Mann, 1980), illumination (Ryther, 1956), turbidity (Estrada and Berdalet, 1997) and nutrients (Sanders et al., 1987) influences the distribution pattern of phytoplankton.

They occur on the surface of the water body and utilise the light energy for photosynthesis, which is termed as primary production. Dillon and Rodgers (1980) stated that primary productivity is the rate at which solar energy is converted into chemical energy by photosynthetic and chemosynthetic organisms. A significant proportion of the primary production in aquatic ecosystems is contributed by phytoplankton; thereby play a critical role in nutrient cycling and food webs (Dawes 1998).The mangrove waters are more productive than the backwaters and estuaries (Bhattathiri, 1992). This is attributed to high production of plankton in the mangrove waters as the phytoplankton are one of the initial biological components, from which energy is transferred into higher organisms through food web.

7.2 Review of Literature

7.2.1 Phytoplankton distribution in mangrove habitats

The global photosynthetic biomass of phytoplankton is only 2% but they are responsible for more than 50% of the annual carbon fixation. They affect the atmospheric CO_2 concentrations, thereby influencing the global surface temperatures (Valencar and Desai, 2004). Anthropogenic interference in estuaries and coastal waters has altered the nutrient ratio and the productivity patterns of these ecosystems (Chang et al., 2009). The study of phytoplankton diversity is of prime importance to understand the ecosystem dynamics as variations in their distribution reflects the physical and chemical processes of an ecosystem (Odum, 1971; Hillebrand and Sommer, 2000). Adequate amount of literature has been added during the last decade in the context of phtyoplankton distribution, species diversity and various factors affecting the same. Thus the present review highlights the most relevant reports of past ten year, pertaining to the present study.

The fantastic diversity in size and structural aspects have greatly attracted taxonomist to study the morpho-taxonomy of phytoplankton along various habitats.

An elaborate morpho- taxonomic study of phytoplankton along Sundarbans was reported by Mandal and Naskar (1994), Sen et al. (2003) and Satpati et al. (2012). Vachhrajani and Mankodi (2008) studied the plankton diversity of coastal area in Gulf of Khambhat and reported 38 phytoplankton and 25 zooplankton species from the area. Saravanakumar et al. (2008) also monitored the mangrove waters of Kachchh, Gujarat and reported 82spp. of diatoms, 16spp. of dinoflagellates, 3spp. of blue green algae and 2spp. of green algae. Even though phytoplankton diversity along Pichavaram mangroves was well documented by Kathiresan and Bingham (2001), similar study on phytoplankton diversity was attempted by Rajkumar et al. (2009). Madhu et al. (2010) monsoon influenced changes in size fraction of phytoplankton biomass and production rates along Cochin estuary. Phytoplankton composition and abundance of tropical mangrove ecosystem were studied by Biswas et al., 2010. The phytoplankton abundance and diversity of Kalpakkam coastal waters was monitored by Smita et al. (2010). The diversity of phytoplankton and zooplankton of Narmada River in Gujarat was studied by Sharma and Mankodi (2011). They observed that the Bacillariophyceae was the most dominant group of phytoplankton studied among the different sites. Abdul Aziz and Rahman (2011) monitored the mangrove waters of Sundarbans and reported 85spp. of phytoplankton. Diversity, distribution and density of phytoplankton in the Sundarbans were studied by Aziz et al., 2012. Rahman et al., 2013 carried out the studies on spatio-temporal variation in phytoplankton abundance in Sundarbans. The plankton community structure from the mangrove waters of Oman was reported by Khalid et al., 2013. Avik Kumar et al., 2014 estimated the cell biovolume of phytoplankton in Sundarban mangroves. Saifullah et al., 2014 reported the phytoplankton composition and diversity from the mangrove waters of Sarawak, Malaysia. Kamaruzaman et al., 2017 evaluated the biomass and net primary productivity of mangrove communities along the oligohaline zone of Sundarbans. Mahwish et al. (2017) monitored the phytoplankton composition in the mangrove habitats of Sandpit, Karachi.

7.2.2 Factors affecting phytoplankton distribution

Various physical parameters play an important role in phytoplankton distribution. Each species of phytoplankton in an ecosystem has its own environmental preferences. Based on the variations in these environmental preferences the biomass, distribution and composition of phytoplankton also show variations. The various environmental factors controlling the distribution of phytoplankton are: temperature, light, nutrient availability, zooplankton grazing, tidal actions etc. the seasonal and even daily changes in these parameters influences the distribution of phytoplankton in a water body (George et al., 2012; Canini et al., 2013). Nitrate, silicate, phosphate and sulphur are the major inorganic nutrients influencing algal growth. The redfield ratio proposed by Redfield (1958) is the proportion of nutrients required for ideal algal growth. The atomic ratio of carbon, nitrogen, silicate and phosphate are given as C:N:Si:P=106:16:15:1. Based on this, the concentration of nitrogen to phosphorus in the ratio of 16:1 controls the phytoplankton growth.

Sankaranarayanan and Qasim (1969) observed no firm basis for believing that the instantaneous concentrations of nutrients on inorganic salts in the estuary provide a significant source of phytoplankton bloom. Seasonal variability of phytoplankton in relation to hydrological factors was studied by Dhawan (1970). Availability of nutrients has been recognised as one of the major factors controlling primary production (Qasim, 1979). The increasing nutrient requirements and phytoplankton diversity was studied by Aktan et al., 2005. Biswas et al., 2007 studied the inter-annual variations of phytoplankton abundance and community organization over a two-decade period along with the ancillary parameters at the land ocean boundary associated with the Sundarban estuarine ecosystem. Their study revealed that phytoplankton bio-volume showed seasonality, with the highest levels during post-monsoon periods and the lowest levels during the monsoon period. Phytoplankton abundance in the Sundarbans estuary in relation to various physico-chemical conditions were also studied by Hossain and Chowdhury (2008), Shah et al. (2008). The role of environmental variables determining the phytoplankton abundance was also reported by Nirmal Kumar et al. (2009) and Pelleyi and Panda (2008).

Harnstrom et al., 2009 investigated the relationship of phytoplankton with several environmental variables at a coastal area near Mangalore. Similar type of work was carried out by Naik et al., 2009 in Mahanadi estuary in east coast of India to understand the effect of chemical factors, especially salinity and nutrient composition on phytoplankton. Rajagopal et al., 2010 investigated the diversity of phytoplankton in relation to physico-chemical parameters of two perennial ponds of Sattur area, Tamil Nadu. Assessment of phytoplankton community and nutrient dynamics of shallow coastal station at Bay of Bengal was studied by Choudhury and Pal (2010). A study was carried out on the dynamic relationship of physico-chemical characteristics with phytoplankton at the Dhamra river estuary of Bay of Bengal, India by Palleyi et al., 2011. Chok chai et al. (2011) studied the influence of salinity and turbidity gradients in the distribution and abundance phytoplankton along the Na Thap river of Thailand. The fresh water influence on phytoplankton was also reported by Suraksha et al. (2011) while the effect of water column turbidity along Mandovi and Zuari estuary were studied by Shetye et al. (2007) and Vijith et al. (2009).

Various physico-chemical characters of water influencing the phytoplankton abundance and distribution along various estuaries of Kerala were reported by Balakrishnan Nair and Abdul Azis (1987); Joseph and Kurup, (1990); Anilakumary and Abdul Azis (1992) and Menon et al. (2000). The diversity of phytoplankton in relation to physico-chemical parameters in two perennial ponds of Kulasekharam area, Kanyakumari district, Tamil Nadu was worked out by Mary (2011). An investigation was made on the influence of physico-chemical parameters on zooplankton composition of Ayyampatinam coastal region situated in southeast coast of India by Santhosh and Perumal (2011). Vinithkumar et al., 2011 and Siva and Padmavati, 2012 studied the phytoplankton abundance and biodiversity of Andaman and Nicobar Island coastal waters. Prabhahar et al. (2011) carried out hydrobiological investigation on plankton diversity along Vellar estuary. Sushma et al. (2013) also studied the effect of fresh water influx on phytoplankton of Mandovi estuary, Goa. Nelpha et al. (2013) reported the influence of monsoon in the phytoplankton structure along the Philippine mangroves. The effects of various environmental parameters on the abundance and diversity of phytoplankton was reported by Silambarasan et al. (2016) from the mangrove waters of Pichavaram.

7.2.3 Phytoplankton pigments and productivity of mangroves

The mangroves shows rapid growth, high primary productivity, metabolism and turnover, which results in the huge demand for nutrients (Yang et al., 2008). These open ecosystems provide energy and matter to the adjacent ecosystems by the process of litter fall and decomposition (Lugo and Snedaker, 1975). The export of these organic and inorganic nutrients from the mangrove swamps to adjacent coastal bodies has an important role in productivity of coastal fisheries. The studies by Qasim and Wafar (1990), says that the nutrients in the tropical marine ecosystems are generally low, but the pristine mangrove ecosystems are considered to be the most productive and complex ecosystems by Naskar and Mandal (1999). Thus besides hydrographic parameters and nutrient cycling, productivity pattern of mangroves also became an important aspect of study in these ecosystem.

In the natural environment mangroves play a major role in regulating the nutrient balance by absorbing excess nutrients and sequestering other pollutants from the water entering these ecosystems. The function of mangrove ecosystem as nutrient sink or a nutrient source was clearly elucidated in the studies of Twilley (1988). Ketchum et al., 1955; Ho and Barrett, 1977 studied the freshwater input, seasonal variations in nutrient input and their reflection on the plankton productivity. Globally, various studies have been conducted on the temporal variations of phytoplankton biomass, species composition, productivity and various physical, chemical and biological effects on them (Takahashi et al., 1978; Takahashi and Hoskins, 1978; Koeller et al., 1979).

Primary production, being first link in the food web in the sea, is the main criterion in assessing the relative fertility of waters. Chlorophyll-*a* concentration is a measure of the abundance of algae, which account for most of the plant production in the ocean. Chlorophyll-*a* is capable of channeling the energy of sunlight into chemical energy through the process of photosynthesis. The chemical energy stored by photosynthesis in carbohydrates drives biochemical reactions in nearly all living organisms. Chlorophyll-*a* value can be used to determine the trophic status of an aquatic body and it is the most commonly used parameter for monitoring phytoplankton biomass and nutrient status, as an index of water quality. Chl. 'a' was used as biomass indicator in studies by Rakocevic and Hollert (2005) and Krivokapic (2008). Although increasing algae growth tends to support larger fish populations, excessive growth often leads to degraded water quality-for example, decreases in water clarity, noxious odors, oxygen depletion and fish kills and may be linked to harmful algal blooms. Excessive algal growth appears to occur as a consequence of increases in nutrient inputs (especially nitrogen) and in response to declines in the abundance of filter-feeding organisms like oysters, clams, and mussels.

The water quality status and primary productivity of Valanthakad mangroves was reported by Meera and Bijoy Nandan (2010). The phtyoplankton productivity among the mangroves, seagrass and coral reefs in Gulf of Mannar Biosphere reserve was monitored by Nabeel and Kathiresan (2011). Banerjee et al., 2013 provided a detailed study on the nutrient dynamics and productivity pattern in the mangroves of Andamans. Edward et al. (2013) studied the biomass and net primary productivity in mangrove forests of Florida. Suganthi et al., 2015 studied the primary productivity of Muthupet mangroves. Kamaruzzaman et al. (2017) reported the biomass and net productivity of mangroves of Sundarbans. Wyan et al., 2018 reviewed the changes in gross primary productivity over the last two decades along the mangroves of Indonesia.

7.3 Methodology

The water samples for the estimation of primary productivity and chlorophyll was collected on monthly basis for two years (September 2010- August 2012) from six mangrove habitats of Ernakulam (detailed description of study site given in Chapter 2).

7.3.1 Primary Productivity (Gross and Net production)

The gross and net production was measured using Light and dark bottle method (Strickland and Parsons, 1972). The samples for each experiments were collected in different three BOD bottles of 250ml capacity (initial, light and dark bottles). The initial bottle was fixed immediately using Winkler A and B solution, while light and dark bottles were incubated for 3-4 hours insitu at same depth. After the incubation period both the bottles were fixed using same fixative. All the bottles were bought to laboratory and the oxygen content in each bottle was determined by modified Winkler's method. The principle is based on the process of photosynthesis, during which oxygen is liberated and this oxygen is considered as measure of primary production. The rate at which oxygen is released was converted into carbon units, assuming a photosynthetic quotient of 1.2 and a respiratory quotient (RQ) of 1. But during the nitrification process a considerable quantity of oxygen is consumed by bacterial population. This oxygen consumption during nitrification is effectively removed by Modified Winkler's method (APHA, 2005; Chaudhuri et al., 2012). The gross productivity is the difference in oxygen concentration between light bottle and dark bottle, whereas the difference between light bottle and initial bottle provides the net productivity. The productivity was expressed in the unit mgC/L/day.

7.3.2 Chlorophyll estimation

The water samples for the estimation of Chlorophyll-a, b, c and the accessory pigments like phaeophytin and carotenoids were collected and freezed in 250ml dark coloured bottles. Vacuum filtration acetone extraction method was used for the estimation of these pigments (Parsons et al., 1984; APHA, 2005). To a known volume of water sample, 1 ml of 1% $MgCO_3$ solution was added and filtered through GF/C filters (47mm, pore size 0.7 µm). $MgCO_3$ inhibits the development of any acidity and prevents degradation of pigments. The filter paper was transferred to test tubes containing 90% acetone and was incubated for 24 hours in dark in refrigerator. The extraction was stirred and centrifuged for about twenty minutes at 5000 rpm. The supernatant was decanted and made up to 10 ml using acetone and was measured at 750 nm, 665 nm, 664 nm, 647 nm, 630 nm, 510 nm and 480 nm in a spectrophotometer before and after acidification. Acetone (90%) was used as reference path and the pigments were expressed in mg/m^3 (APHA, 2005; Parson et al., 1984). Algal biomass was estimated by multiplying the chlorophyll a content by a factor of 67 (APHA, 2005).

7.3.3 Microphytoplankton composition and abundance

The microphytoplankton composition and abundance were studied seasonally along the six mangroves stations of Ernakulam district. Water samples for microphytoplankton identification were collected using plankton net of mesh size 20μm and preserved in 3% buffered formalin. The concentrated sample was transferred to 15ml graduated test tube and was allowed to stand for 24 hours for settling. The settling volume was used for the calculation of biomass. Standing crop was estimated by enumeration method using Sedgewick-Rafter counting cell (Verlenkar and Desai, 2004; APHA, 2005; Santhanam et al., 1987). One ml of sample was transferred to a Sedgewick- Rafter counting cell and left for proper settling. The number of phytoplankton was counted from one corner of the counting cell to the other end and was expressed in individual/m^3. The counting was repeated and the average values were taken to calculate phytoplankton species composition, distribution, abundance and community structure. The enumeration and identification of species was done using a binocular microscope, Leica DM 500 using standard identification keys (Allen and Cupp, 1935; Venkataraman, 1939; Cupp, 1943; Subramanyan, 1946; Hustedt, 1955; Desikachary, 1959; Hendey, 1964; Simonsen, 1974; Davis, 1955; Gopinathan, 1972; Jin Dexiang et al., 1985; Tomas, 1997; Ward and Whipple, 1959; Smith and Johnson, 1996; Botes, 2001).

7.3.4 Redfield ratio of various mangrove habitats of Ernakulam

The Redfield ratio is the ratio of relative concentration of nitrogen and phosphorus is used to provide information on the limiting nutrients in an aquatic system that influences the growth of algae in it (Redfield, 1963; Brzezinski, 1985). The molecular C: N: P ratio of 106:16:1 (50:7:1 by weight) is considered as the redfield ratio of marine phytoplankton. A positive or negative deviation from this ratio indicates a deficiency or excess of nutrients respectively in the aquatic system. While considering the need for silicates in frustule formation in diatoms the ratio was modified as C: Si: N: P ratio of 106:15:16:1 (Redfield, 1963; Piehler et al., 2004).

7.3.5 Data analysis

The statistical analysis was carried out using SPSS Vs.16.0 (Statistical Programme for Social Sciences) and PRIMER v6.1 (Plymouth Routines in Multivariate Ecological Research). The univariate analysis like species diversity, species richness, species evenness and species dominance were done to understand the diversity and community pattern of microphytoplankton (detailed methodology mentioned in Chapter 4). Multivariate analysis such as cluster analysis, multi-dimensional scaling, BEST analysis (BIO-ENV) and Canonical Correspondence Analysis were also carried out. ORIGIN v8.0 was used for the graphical representation of data. Significant differences between the groups were determined by one –way analysis of variance (ANOVA). BEST analysis (Clarke and Gorley, 2006) was done to find the best match between the available environmental variable and it explains the patterns in the biological data.

7.4 Results

7.4.1 Microphytoplankton composition and abundance

The seasonal variation in microphytoplankton composition, distribution and mean cell density in various mangrove habitats of Enrakulam was studied during the period 2010-12. In the present study 85 species of microphytoplankton belonging to 60 genera under 40 families were identified. The microphytoplankton mainly composed of six classes: Bacillariophyceae, Myxophyceae, Chlorophyceae, Euglenophyceae, Charophyceae and Dinophyceae. The number of families, genera and species identified under each class showed the dominance of Bacillariophycean members in the present investigation (Figure 7.1). The class Bacillariophyceae represented the major group with 50species belonging to 33 genera and 22 families. The class Chlorophyceae formed the second group with 16 species (13 genera) followed by Myxophyceae (8 species, 7 genera) and Euglenophyceae (7 species, 3 genera). The class Dinophyceae had only three representatives (3 species, 3 genera) and only a single species was identified from class Charophyceae.

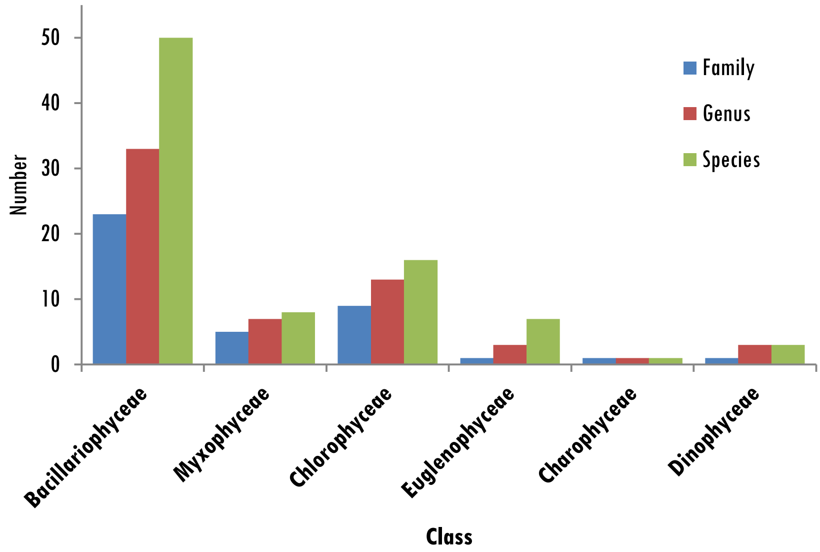

Figure 7.1 Microphytoplankton composition in various mangrove habitats of Ernakulam during 2010-12 period

i. Class: Bacillariophyceae

The Bacillariophycean members included 50 species belonging to 33 genera and 22 families from study sites in Ernakulam. The Bacillariaceae family included the maximum number of species (12 spp.) placed under 7 genera; *Nitzschia*, *Cylindrotheca*, *Pseudonitzschia*, *Ceratium*, *Bacillaria*, *Ankistrodesmus* and *Achnanthus.* The family Coscinodiscaeae formed the second dominant group of diatoms with 5 species of *Coscinodiscus*. Family Fragilariaceae (*Asterionella* spp., *Lichmophora* spp. and *Fragillaria* spp.) and Surirellaceae (*Campylodiscus* spp., *Surirella straiatula*, *Surirella* spp.) were represented by three genera each. *Navicula* (Naviculaceae), *Amphiphora* (Amphipleuraceae), *Gyrosigma*, *Pleurosigma* (Pleurosigmataceae), *Diplonis* (Diploneidaceae), *Pinnularia* (Pinnulariaceae), *Amphora* (Catenulaceae) were the other genera identified from respective families. Other families such as Cocconeidaceae, Cymbellaceae, Hemidiscaceae, Stephanodiscaceae, Thalassiosiraceae, Melosiraceae, Hemiaulaceae, Biddulphiaceae, Triceratiaceae and Chaetocerotaceae were represented by single members. The genus Coscinodiscus represented the maximum number of species (*C. eccentricus*, *C. marginatus*, *C. nodulifera*, *C. radiates* and *Coscinodiscus* spp.) followed by genus *Nitzschia* (*N. closterium*, *N. navicularis*, *N. sigma*, *N. palea* and *Nitzschia* spp.)

ii. Class: Myxophyceae

The class Myxophyceae was represented by five families: Merismopediacaeae, Nostocaceae, Oscillatoriaceae, Phormidiaceae and Spirulinaceae. Nostocaceae and Phormidiaceae family represented two genera each; *Nostoc* and *Anabena; Arthrospira* and *Gleotricha* respectively. *Oscillatoria limosa* (Family: Oscillatoriaceae) was the most common species identified from this class. *Merismopedia* and *Spirulina* were the single genus representing the respective families Merismopediacaeae and Spirulinaceae.

iii. Class: Chlorophyceae

This class included 16 species coming under 13 genera and 9 families. Family Scenedesmaceae (*Scenedesmus* spp., *S. acuminatus, S. carinatus* and *Tetrastrum* spp.) and Hydrodictyaceae (*Pediastrum duplex, P. simplex* and *Tetrastrum* spp.) formed the major representatives of the class. Other genera were: *Oedogonium* (Oedogoniaceae); *Ankistrodesmus* (Selenastraceae); *Chlorella, Actinastrum* (Chlorellaceae); *Chlamydomonas* (Chlamydomonaceae); *Spirogyra* (Zygnemataceae); *Micrasterias* (Desmidiaceae); *Oocystis, Chodatella* (Oocystaceae).

iv. Other Families

Family Euglenaceae was the single representative of the class Euglenophyceae. It included 7 species belonging to 3 genera; *Euglena, Trachelomonas* and *Phacus.* Genus Euglena showed the maximum diversity with four species namely; *E. acus, E.limnophila* and *E. proxima.* Class Charophyceae was represented by a single species of *Closterium* while the class Dinophyceae had three species; *Ceratium* spp., *Protoperidinium* spp. and *Peridinium* spp.

7.4.2 Distribution of microphytoplankton

i. Spatial variation in distribution of microphytoplankton

The spatial distribution of microphytoplankton marked highest number of species at St. 6, Valanthakad-Arkathadam; 57spp. in the first year and 60spp. in the second year respectively. Puthuvypin (St.3) recorded 54 spp. (2010-11) and 51spp. (2011-12) respectively (Figures 7.2, 7.3). However St.4, Malippuram recorded lower number of species during both years (29spp.and 33spp.). All the stations recorded higher numbers of Bacillariophycean members followed by Chlorophyceae and Myxophyceae.

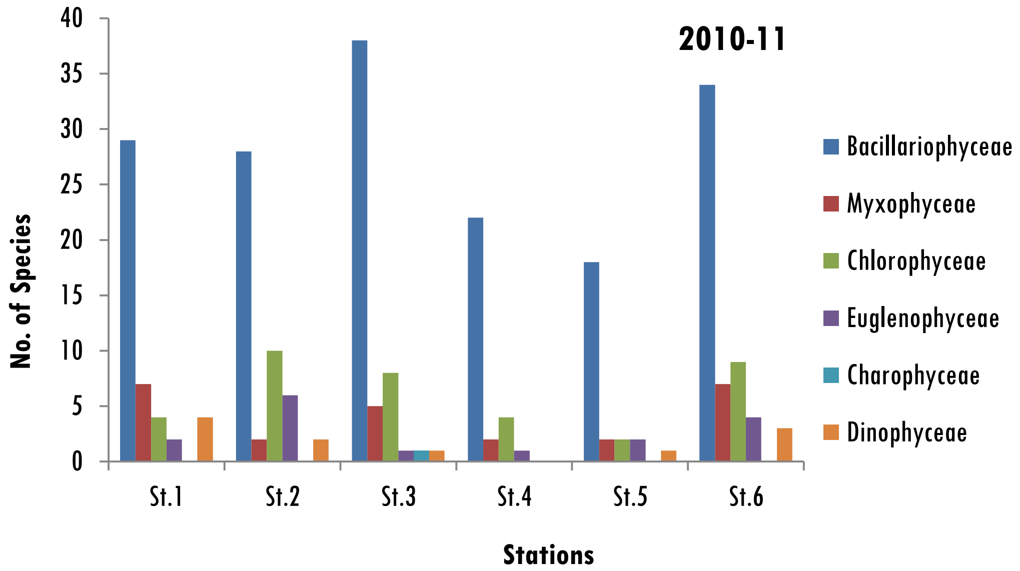

Figure 7.2 Station wise species diversity of microphytoplankton during 2010-11 period

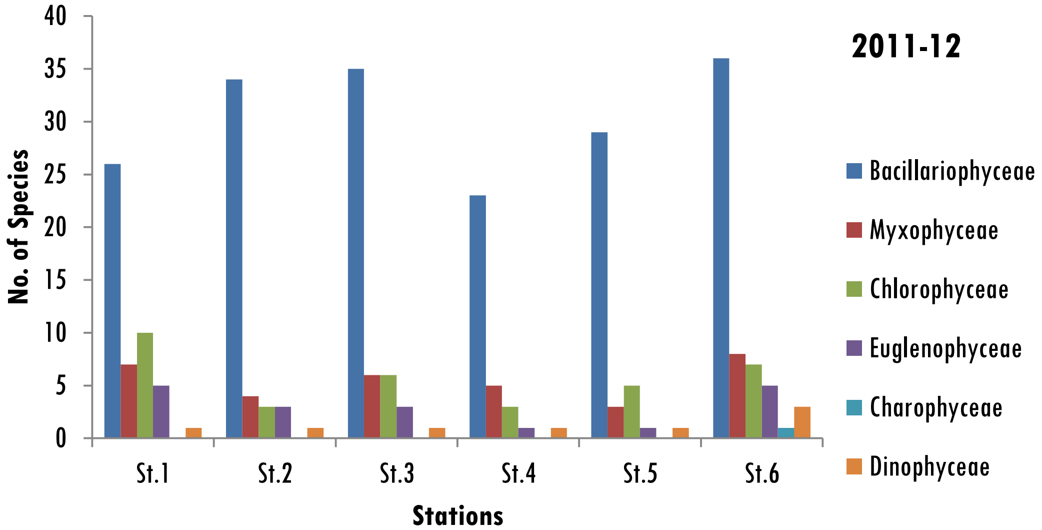

Figure 7.3 Station wise species diversity of microphytoplankton during 2011-12 period

Among the 85 species of phytoplankton identified, 13 species were commonly distributed in all six stations, while the rest of the species marked variations in occurrence (Table 7.1). From class Bacillariophyceae, 8spp. of phytoplankton were common in all stations while *Oscillatoria limosa* was the only common species from the class Myxophyceae. Both Chlorophyceae (*Scenedesmus acuminatus, Pediastrum simplex*) and Euglenophyceae (*Euglene* spp., *Phacus* spp.) had two species each displaying common occurrence.

Table 7.1 List of microphytoplankton species recurrently occurring in mangrove stations of Ernakulam during 2010-12

Class	Species
Bacillariophyceae	*Nitzschia closterium, Cylindrotheca gracilis, Nitzschia sigma, Navicula* spp., *Pleurosigma* spp., *Diploneis* spp., *Coscinodiscus eccentricus*, *Melosira* spp.
Myxophyceae	*Oscillatoria limosa*
Chlorophyceae	*Scenedesmus acuminatus, Pediastrum simplex*
Euglenophyceae	*Euglene limnophila*, *Phacus* spp.

ii. Seasonal variation in distribution of microphytoplankton

The annual variation in phytoplankton diversity revealed the presence of 79 spp. in the first year (2010-11) and 81 spp. in the second year (2011-12) respectively. During 2010-11 period, highest species diversity was observed in monsoon season (79spp.) followed by post monsoon (63spp.) and pre monsoon seasons (55spp.). While in second year, pre monsoon season marked higher species diversity (81spp.) followed by monsoon (69spp.) and post monsoon (52spp.). Among the 85spp. of phytoplankton identified, 40spp. were common in all seasons with highest species diversity observed in second pre monsoon season (81spp.). Bacillariophycean members were the most dominant group with almost 30spp. commonly observed in all seasons.

Out of the 50spp. of Bacillariophycean members, 49spp. were recorded in both first monsoon and second pre monsoon seasons. Myxophycean members were more dominant in monsoon seasons than other seasons. Species of *Merismopoedia, Nostoc*, *Oscillatoria*, *Arthrospira* and *Spirulina* portrayed a uniform distribution in all seasons. Among the 13spp. of Chlorophycean members, 4spp. (*Ankistrodesmus* spp., *Spirogyra* spp., *Pediastrum simplex*, *Scenedesmus acuminatus*) were recorded in all seasons. All the three genera of Euglenophyceae were observed in monsoon season, while *Euglena limnophila* were observed throughout the study period irrespective of seasons. The species of *Closterium,* single representative of class Charophyceae was restricted to the first monsoon and second pre monsoon seasons only. Among the three species of Dinophyceae, *Protoperidinium* marked the uniform distribution in all seasons.

7.4.3 Abundance of microphytoplankton

i. Biomass of microphytoplankton

The mean monthly variation in biomass ranged from 11.91±5.50ml/m^3 in the month of December 2010 to 45.05± 55.05 ml/m^3 in April 2011. Comparatively lower values were also recorded in the months of November 2010, July 2011 and June 2010. The spatial variation in biomass exhibited higher values in second year except at St.1, 5 and 6 (Figure 7.4).The spatial variation in the first year ranged from 17.98± 7.76 ml/m^3 (St.3) to 28.72± 26.66 ml/m^3 (St.1) and from 13.56± 7.3 ml/m^3 (St.6) to 37.03± 25.31 ml/m^3 (St. 4) during second year respectively. In general St.4, Malippuram recorded higher values and St.5 Valanthakad- Magranazhi recorded lower biomass values during both years.

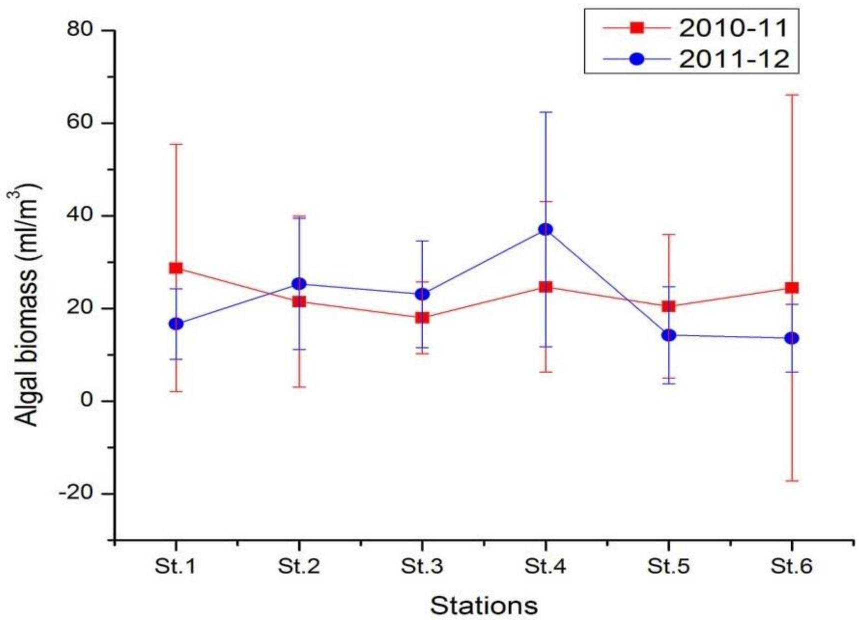

Figure 7.4 Mean spatial variation in biomass of microphytoplankton in mangrove stations of Ernakulam during 2010-12 period

The seasonal variation in biomass exhibited higher values in the monsoon season during both years, followed by pre monsoon and post monsoon season in first year (2010-11). While during second year post monsoon recorded higher values than pre monsoon even though there was no much significant variation (Figure 7.5). In the first year the biomass volume decreased from monsoon (26.57± 16.03 ml/m^3) to pre monsoon season (23.23± 21.81 ml/m^3) followed by post monsoon season (18.63± 8.18 ml/m^3) respectively. In the second year higher value was recorded in the monsoon season (23.56±14.55 ml/m^3) followed by post monsoon season (22.08± 10.80 ml/m^3) and pre monsoon season (21.04±9.9 ml/m^3) respectively.

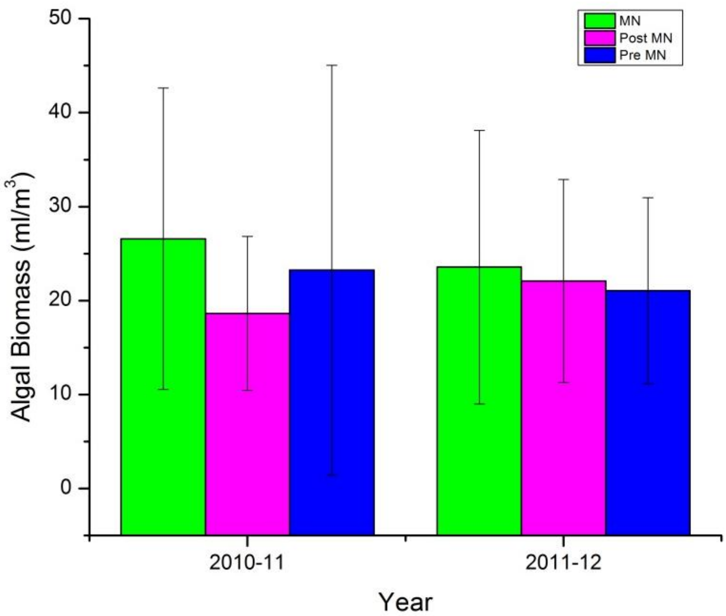

Figure 7.5 Mean seasonal variation in biomass of microphytoplankton in mangrove stations of Ernakulam during 2010-12 period

ii. Percentage abundance

The seasonal variation in percentage abundance of various microphytoplankton communities in the mangrove habitats of Ernakulam marked a peak value during the monsoon season of both years (Figure 7.6). Except the monsoon season of 2010-11 period all other seasons recorded lower percentage abundance of phytoplankton than second year (2011-12). The highest percentage was observed in monsoon season (55%, 42%) followed by post monsoon (30.4%, 36.8%) and pre monsoon seasons (14.5%, 21%) of both years respectively.

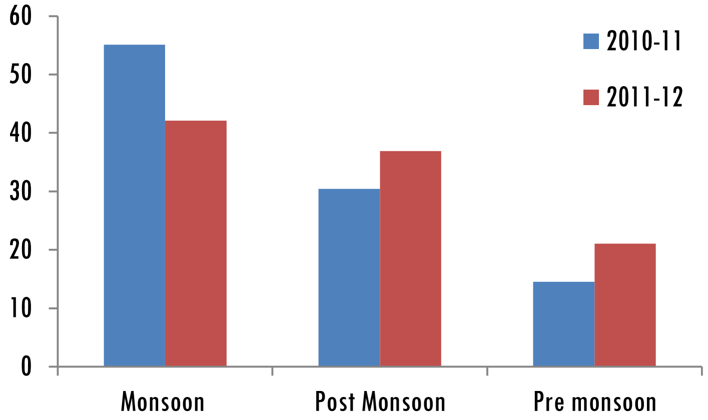

Figure 7.6 Seasonal percentage abundance of microphytoplankton in mangrove station of Ernakulam during 2010-12 period

The class wise percentage abundance of microphytoplankton shows the dominance of class Bacillariophyceae (more than 80%) in all seasons during the study period (Figure 7.7). In the year 2010-11, the maximum abundance of Bacillariophycean members were recorded in the post monsoon season (96.43%) followed by pre monsoon (91.36%) and monsoon season (83.71%) respectively. Myxophyceae formed the second dominant class (10.99%) followed by Euglenophyceae (2.11%). All the six classes were represented in the monsoon season of 2010-11, while the members of Charophyceae were not recorded in the post monsoon and pre monsoon seasons respectively. The abundance of Bacillariophycean members showed a declining trend from monsoon (87.6%) to post monsoon seasons (73.47%) in the second year. The class Charophyceae was not represented in the monsoon and post monsoon seasons 2011-12 period, whereas the pre monsoon season recorded the representatives of all six classes. The members of Myxophyceae were abundant in the monsoon (7.7%) and pre monsoon seasons (6.8%), while they were replaced by Dinophycean members in the post monsoon season (12.85%) of second year. Abundance of Euglenophycean members were also marked in the post monsoon season (9.7%) compared to monsoon (2.41%) and pre monsoon seasons (2.78%) respectively.

The station wise percentage abundance also showed the dominance of class Bacillariophyceae in all stations contributing about 80% of the total population

(Figure 7.8). Myxophyceae formed the next abundant class at St.5 (9.18%) and St.6 (16.71%) while it was replaced by Euglenophycean members at St.2 (4.79%) and St.3 (6.61%). Station 6 marked comparatively lower percentage abundance of Bacillariophycean members (65.95%), but exhibited an abundance of Dinophyceae (14.55%). Charophyceae was the least represented class and was recorded only from St.3 and St.6. comparatively a higher percentage of unidentified species were also recorded at St.3 (6.05%).

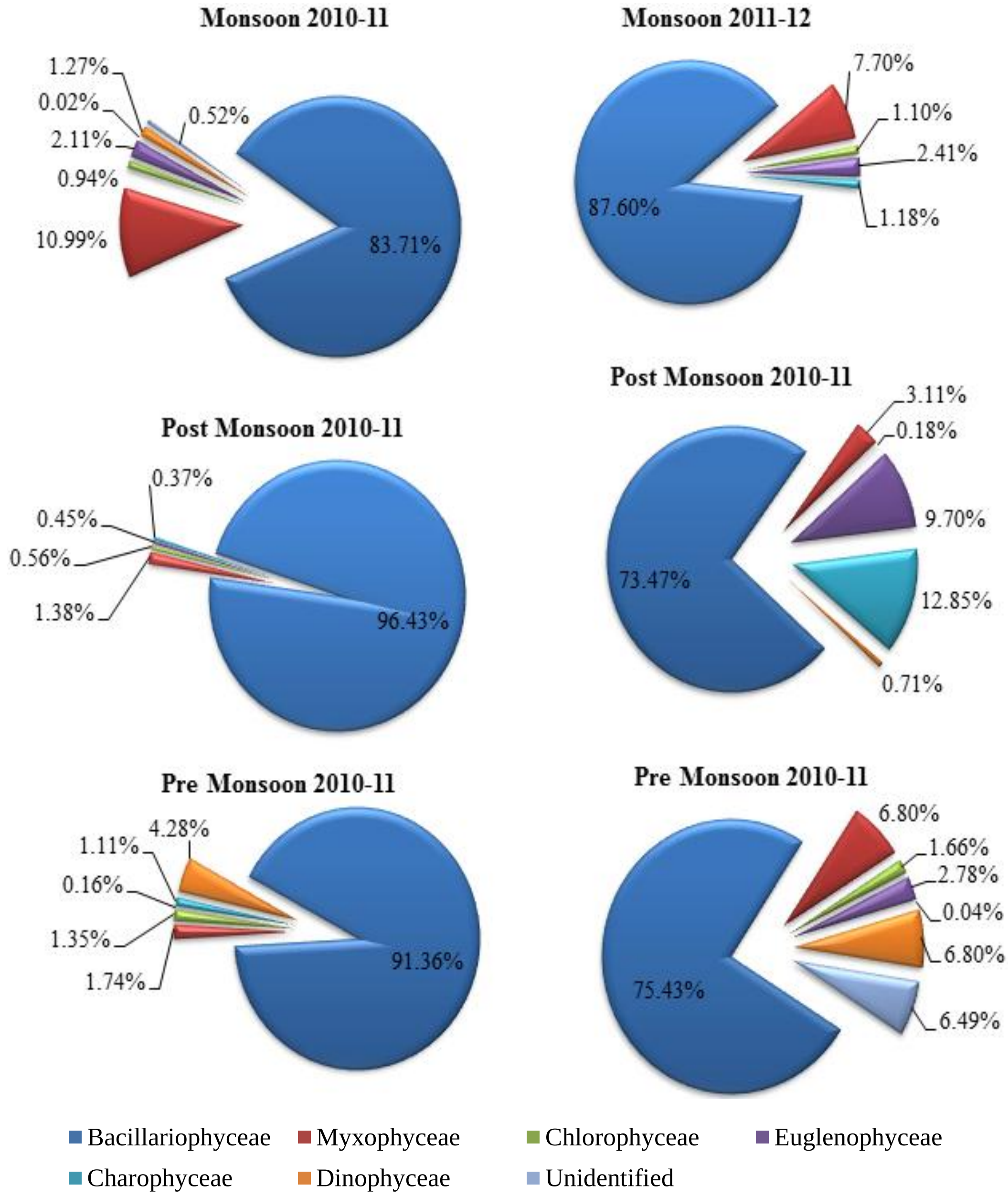

Figure 7.7 Seasonal variation in percentage abundance of microphytoplankton in mangrove stations of Ernakulam during 2010-12 period

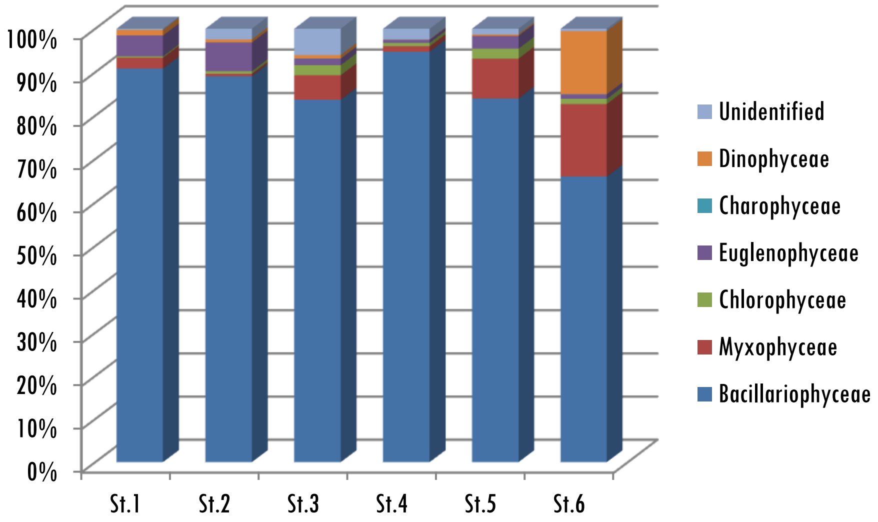

Figure 7.8 Spatial variation in percentage abundance of microphytoplankton in mangrove stations of Ernakulam during 2010-12 period

iii. Cell density of microphytoplankton

The seasonal variation in cell density of microphytoplankton ranged from 6.30×10^3 cell/m^3 to 218.19×10^3 cell/m^3 during the study period. The cell density was found to be higher during second year (2011-12) than the first year (Figure 7.9). Maximum cell density was recorded in the monsoon season followed by post monsoon and pre monsoon seasons of both years respectively. In the first year monsoon season recorded the maximum density (83.94×10^3 cell/m^3) followed by post monsoon (46.37×10^3 cell/m^3) and pre monsoon seasons (22.09×10^3 cell/m^3) respectively. Similar trend was followed in the second year, with maximum cell density in monsoon (90.76×10^3 cell/m^3) followed by post monsoon (79.53×10^3 cell/m^3) and pre monsoon (45.35×10^3 cell/m^3).

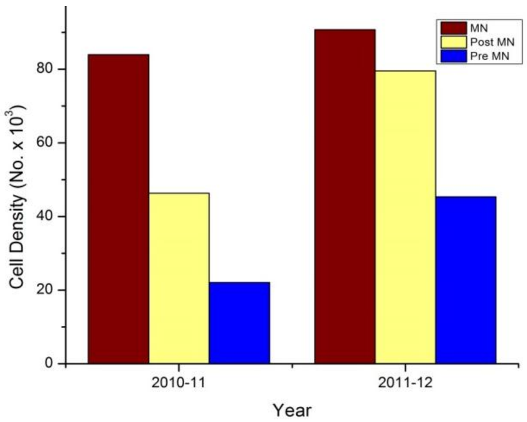

Figure 7.9 Seasonal variation in cell density of microphytoplankton in mangrove stations of Ernakulam during 2010-12 period

The mean spatial variation in cell density marked maximum density at St.1 (140.71×10^3 cell/m^3) followed by St.6 (91.64×10^3 cell/m^3) and St.2 (65.93×10^3 cell/m^3) during the study period (Figure 7.10). Except St.3, Puthuvypin all other stations recorded higher cell density during second year (2011-12). The mean cell density recorded at St.1 during the two consecutive years was 132.45×10^3 cell/m^3 and 148.96×10^3 cell/m^3 respectively. The minimum cell density was recorded at St.5 (10.90×10^3 cell/m^3) during first year.

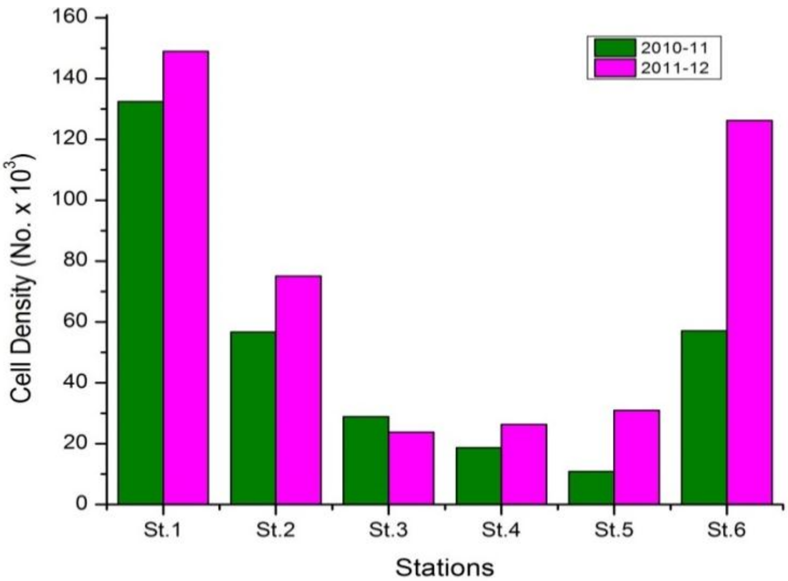

Figure7.10 Spatial variation in cell density of microphytoplankton in mangrove stations of Ernakulam during 2010-12 period

iv. Biodiversity indices

The seasonal variation in various diversity indices reveled, highest species richness (d) in the pre monsoon season of both years followed by post monsoon and monsoon seasons. Species richness exhibited only marginal variation between seasons during the study period. Species evenness was marginal between the post monsoon and monsoon seasons while comparatively higher values were recorded in pre monsoon seasons. Pre monsoon season also exhibited higher species diversity compared to other seasons during both the years. Shannon index value greater than 4 is considered as a species divers system but none of the seasons exhibited higher values during the study period.

Table 7.2 Seasonal variation in diversity indices of based on microphytoplankton cell density in mangrove stations of Ernakulam during 2010-12 period

Seasons	2010-11				2011-12			
	d	J'	H'	λ	d	J'	H'	λ
Monsoon	0.38	0.81	2.11	0.72	0.38	0.80	2.06	0.71
Post Monsoon	0.40	0.78	2.01	0.67	0.38	0.78	2.01	0.71
Pre Monsoon	0.42	0.90	2.34	0.78	0.40	0.98	2.54	0.82

Margalef species richness (d), Pielou's evenness (J'), Shannon index (H') Simpson dominance (λ')

The spatial variation in diversity indices marked higher species diversity in St.5 and St.6 along Valanthakad mangroves during first year while in second year St .3 (Puthuvypin) also marked higher species diversity. Species richness was found to be higher at St.3 and lower along the mangroves of Aroor (St.1). However the evenness values showed higher values for St.5 and St.6 during first year and for St.6 and St.3 during second year respectively.

Table 7.3 Spatial variation in diversity indices of microphytoplankton cell density in mangrove stations of Ernakulam during 2010-12 period

	2010-11				2011-12			
Stations	d	J'	H'	λ	d	J'	H'	λ
St.1	0.39	0.16	0.37	0.10	0.49	0.30	0.77	0.23
St.2	0.54	0.14	0.37	0.09	0.52	0.31	0.80	0.27
St.3	0.69	0.30	0.85	0.26	0.59	0.42	1.09	0.33
St.4	0.36	0.11	0.21	0.05	0.58	0.19	0.49	0.14
St.5	0.51	0.57	1.31	0.49	0.57	0.25	0.64	0.18
St.6	0.32	0.53	1.06	0.42	0.59	0.53	1.50	0.55

Margalef species richness (d), Pielou's evenness (J'), Shannon index (H') Simpson dominance (λ')

7.4.4 Phytoplankton pigment analysis

i. Chlorophyll 'a'

The mean monthly variation ranged from 9.34±12.27mg/m^3 (March 2012) to 75.83± 133.84 mg/m^3 (February 2011). Station 4, Malippuram recorded the higher concentrations of Chlorophyll-a (here after chl. 'a') during all the months, with highest value recorded in the month of September 2011 (342.90 mg/m^3). The mean spatial variation in chl. 'a' showed higher values in St.4 during both years (Figure 7.11). The values ranged from 4.43± 2.80 mg/m^3 at St.6 to 89.16± 90.50 mg/m^3 at St.4 during the first year (2010-11) and from 4.49± 2.39 mg/m^3 at St.6 to 90.96± 91.04 mg/m^3 at St.4 during second year (2011-12). Station 6, Valanthakad-Arkathadam recorded lower chl.'a' concentrations.

Significant seasonal variation in chl. 'a' was not observed during the study. During the year 2010-11, higher values were recorded in the pre monsoon season (32.25± 36.60 mg/m^3) followed by post monsoon season (30.52± 38.61 mg/m^3) and monsoon season (18.43± 21.13 mg/m^3). While during second year (2011-12), higher values were recorded in pre monsoon season (27.46± 33.21 mg/m^3) followed by monsoon season (27.08± 48.04 mg/m^3) and post monsoon season (20.34± 19.33 mg/m^3).

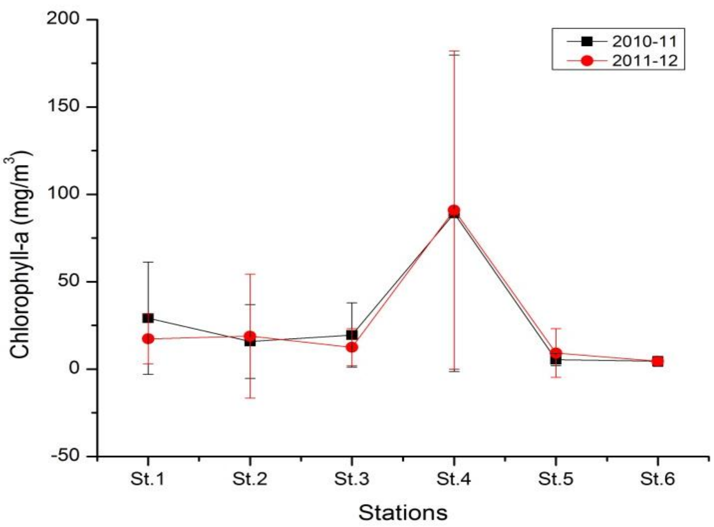

Figure 7.11 Mean spatial variation in chlorophyll-a concentration in mangrove habitats of Ernakulam during 2010-12 periods

ii. Chlorophyll 'b'

The chl. 'b' variation during the study period ranged from 0.08 mg/m^3 at St.5 to 14.09 mg/m^3 at St.4.The mean monthly variation ranged from 0.22± 0.35 mg/m^3 during November 2010 to 5.167± 5.52 mg/m^3 during August 2012. The seasonal variation marked higher values during pre monsoon season of the second year for all the stations. During 2010-11 period, monsoon season recorded peak values (1.45± 1.28 mg/m^3) followed by pre monsoon (0.83± 1.34 mg/m^3) and post monsoon seasons (0.42± 0.50 mg/m^3). While during second year (2011-12), pre monsoon season (1.92± 1.90 mg/m^3) recorded the highest value followed by post monsoon season (1.66 ± 1.27 mg/m^3). The lowest chl. 'b' concentrations were recorded in the monsoon season (0.86± 0.63 mg/m^3). In general, St.4, Malippuram marked higher values during most of the seasons, but the chl. 'b' concentrations dropped almost to zero values during the first pre monsoon and second monsoon periods.

Except St.4, all other stations did not exhibit much variation during the study period. The mean spatial variation in chl. 'b' ranged from 0.18± 0.30mg/m^3 (St.6) to 1.44± 2.26mg/m^3 (St.4) during the first year (Figure 7.12). This was followed by St.5 (1.33± 3.85 mg/m^3) compared to other stations. Similar to the first year, St.6 recorded lower concentration (0.91± 1.28 mg/m^3) andSt.6 with higher value of 2.34± 4.34 mg/m^3). In contrast to first year, stations 1, 2 and 3 recorded higher values than St.5.

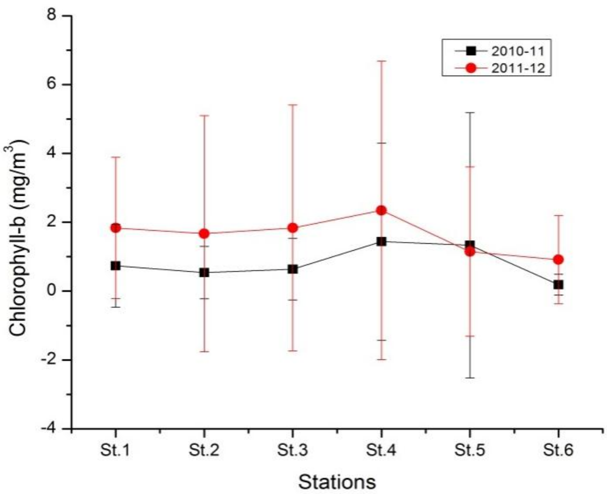

Figure 7.12 Mean spatial variation in chlorophyll-b concentration in mangrove habitats of Ernakulam during 2010-12 periods

iii. Chlorophyll 'c'

The chl. 'c' values ranged from 0- 66.411 mg/m^3 during the study period. The mean monthly variation exhibited a range between 0.58± 0.93 mg/m^3 during June, 2012 to 20.24± 24.10 mg/m^3 in December 2010. Comparatively higher values were also exhibited during the month of February 2011 (13.13± 25.76 mg/m^3) while except St.4 (4.79 mg/m^3) most of the stations recorded lower values (almost zero) with a mean value of 0.81± 1.94 mg/m^3.The mean spatial variation in chl. 'c' varied from 0.50± 1.14 mg/m^3 (St.6) to 18.26± 22.95 mg/m^3 (St.4) and from 1.13± 1.34 mg/m^3 (St.5) to 11.29± 12.06 mg/m^3 (St.4) during first and second year respectively (Figure 7.13). Similar to chl. 'a' and 'b' concentrations, the Malippuram station exhibited higher values while Valanthakad- Magranazhi (St.5) and Valanthakad-Arkathadam (St.6) displayed lower concentrations.

The seasonal variation in chl. 'c' showed higher values in post monsoon period of both years. The seasonal variations ranged from 0.14± 0.17 mg/m^3 at St.6 during first pre monsoon (2010-11) to 36.10± 34.56 mg/m^3 at St.4 during first post monsoon season (2010-11). During 2010-11 period the chl. 'c' values peaked in the post monsoon season (9.92± 13.17 mg/m^3) and showed a gradual decrease during pre monsoon (4.39± 4.64 mg/m^3) and monsoon seasons (1.48± 1.96 mg/m^3). On the other hand, during second year post monsoon (3.95± 2.73 mg/m^3) recorded higher values followed by monsoon (3.80±2.73 mg/m^3) and pre monsoon seasons (2.70± 3.45 mg/m^3). St. 4 recorded higher values throughout the study period irrespective of seasonal variations, followed by St.2 and St.1 while St.5 and St.6 always recorded lower concentrations.

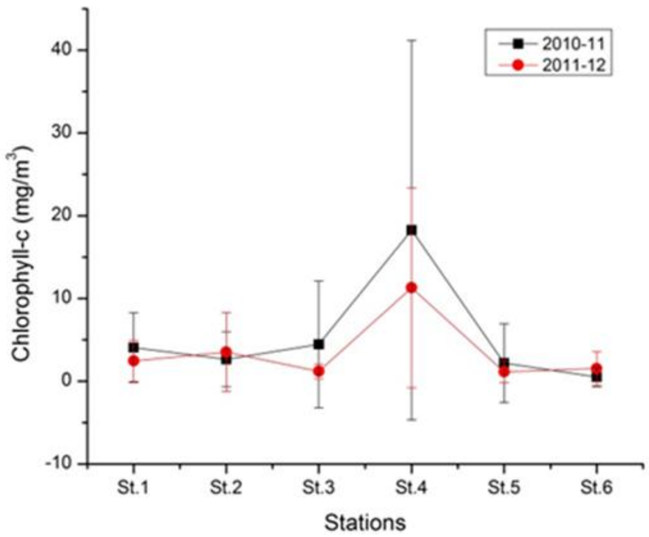

Figure 7.13 Mean spatial variation in chlorophyll-c concentration in mangrove habitats of Ernakulam during 2010-12 periods

iv. Carotenoid

The carotenoid values ranged from 0.59mg/m^3 (St.1, August 2012) to 142.40mg/m^3 (St.4, September 2011) during the study period. The monthly mean values ranged from 6.25± 6.00 mg/m^3 to 44.24±77.42mg/m^3. The higher carotenoid values were observed in the month of December 2010 while February 2011 displayed lower values. The spatial variation in carotenoid ranged from 3.79± 1.81 mg/m^3 at St.6 to 53.21± 49.96 mg/m^3 at St. 4 during 2010-11period and from 4.74± 2.51mg/m^3 at St.6 to 43.57± 38.75 mg/m^3 at St.4 during 2011-12 period respectively (Figure 7.14). During first year St.1 and St.3 showed higher concentrations of carotenoid (20.32± 21.56 mg/m^3 and 13.63± 11.98 mg/m^3) but the second year reflected much lower concentrations (11.79± 9.72 mg/m^3 and 8.21± 6.14 mg/m^3). In contrast, St.2 recorded higher values in second year (24.33± 40.24 mg/m^3) than first year (10.51± 10.47 mg/m^3). Malippuram station (St.4) consistently marked higher concentration while St.5 and 6 were marked with lower concentration throughout the study period. Similar to chl. ‘c’ values, carotenoid also displayed higher concentrations (67.26± 89.34 mg/m^3) during first post monsoon season at St.4. the highest mean seasonal value recorded were 20.35± 23.76 mg/m^3 (post monsoon) followed by 19.77± 19.78 mg/m^3 (pre monsoon) and 12.75± 13.53 mg/m^3 (monsoon season) in2010-11. While in the second year the values gradually decreased from monsoon (20.60± 23.67 mg/m^3) to pre monsoon (16.02± 15.03 mg/m^3) and post monsoon (11.46± 9.23 mg/m^3).

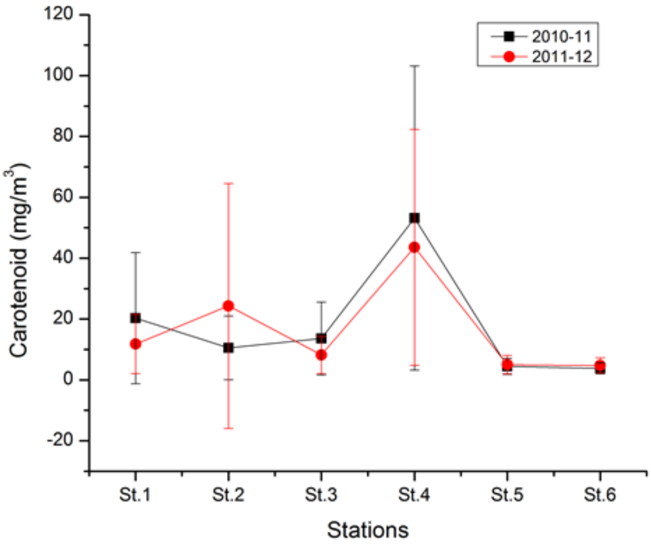

Figure 7.14 Mean spatial variation in carotenoid concentration in mangrove habitats of Ernakulam during 2010-12 periods

v. Phaeophytin

The mean monthly phaeophytin concentrations ranged from 0.76±1.45 mg/m^3 (August 2011) to 44.02± 46.58 mg/m^3 (March 2011) during the study period. Comparatively higher values were also recorded in the months of August 2011 (43.87± 60.74 mg/m^3), September 2010 (29.35± 31.18 mg/m^3) and June 2012 (22.84± 29.08 mg/m^3). While the months of July 2011 (1.51± 3.28 mg/m^3), November 2011 (2.11± 4.79 mg/m^3), January 2012 (2.75± 3.11 mg/m^3) and May 2012 (3.17±3.61 mg/m^3) recorded lower concentrations of phaeophytin. The spatial variation showed higher phaeophytin concentrations in the first year than second year (Figure 7.15). The values ranged from 2.50± 3.36 mg/m^3 at St.6 to 42.97± 33.44 mg/m^3 at St.4 during 2010-11 period and from 5.75± 13.27 mg/m^3 at St.5 to 27.23± 31.88 mg/m^3 at St.4 during second year (2011-12).

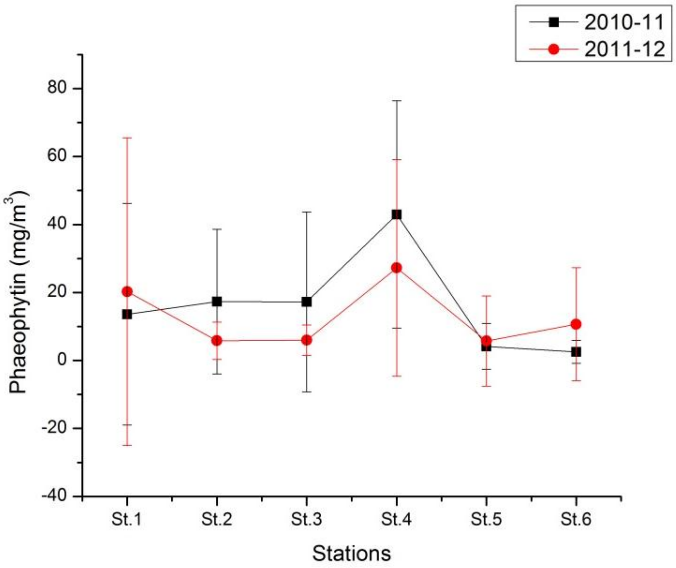

Figure 7.15 Mean spatial variation in phaeophytin concentration in mangrove habitats of Ernakulam during 2010-12 periods

The seasonal variations ranged from 0.22 mg/m^3 at St.5 during post monsoon (2010-11) to 63.84 mg/m^3 at St.4 during monsoon season (2010-11). During first year the maximum phaeophytin were recorded in post monsoon season (26.93± 24.11 mg/m^3) followed by monsoon (20.82± 23.13 mg/m^3) and pre monsoon season (6.15± 6.33 mg/m^3). While pre monsoon recorded peak values (19.30± 16.55 mg/m^3) during second year followed by post monsoon (9.94±12.56 mg/m^3) and monsoon seasons (3.97± 2.80 mg/m^3) respectively. Most of the stations recorded higher values during the post monsoon seasons of both years except St.1 in which the phaeophytin concentration peaked in the pre monsoon season of 2011-12 period.

vi. Active Chlorophyll

The active chlorophyll concentration ranged from 0.534 mg/m^3 (St.1) to 98.64 mg/m^3 (St.4) during the study period. The mean monthly variation ranged from 2.40± 1.90 mg/m^3 in the month of May 2011 to 32.48± 49.27 mg/m^3 in December 2011. The seasonal variation ranged from 1.869± 1.60 mg/m^3 (St.6) during first pre monsoon to 53.57± 27.10 mg/m^3 (St.4) during second pre monsoon period respectively. The post monsoon season recorded highest value (16.82± 13.50 mg/m^3) during the first year followed by monsoon (12.25± 13.61 mg/m^3) and pre monsoon seasons (6.98± 6.18 mg/m^3). While during second year (2011-12), pre monsoon season exhibited peak values (20.99± 19.96 mg/m^3) followed by post monsoon (15.95± 15.88 mg/m^3) and monsoon seasons (11.81± 15.98 mg/m^3) respectively. Station 4 displayed higher values irrespective of seasons followed by St.2 and St.5. All the stations exhibited lower values during the pre monsoon (2010-11) and monsoon (2011-12) seasons.

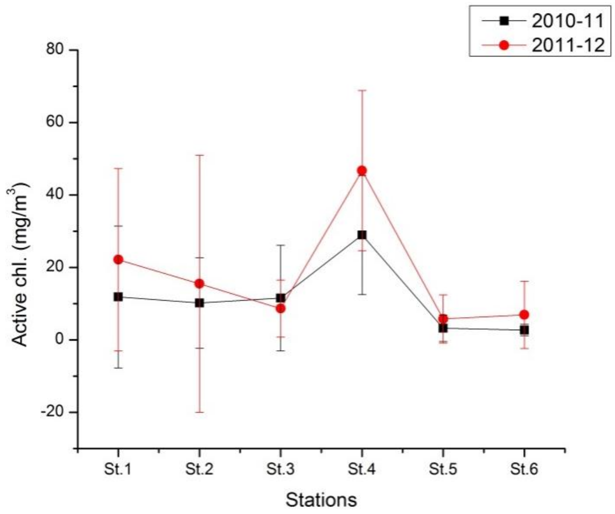

Figure 7.16 Mean spatial variation in active chlorophyll concentration in mangrove habitats of Ernakulam during 2010-12 periods

The spatial variation ranged from 2.71±1.57mg/m^3 (St.6) to 28.93± 16.43 mg/m^3 (St.4) and from 5.79±6.68mg/m^3 (St.5) to 46.71±22.08mg/m^3 (St.4) during the first and second year respectively (Figure 7.16). Similar to other pigments, active chlorophyll values were also higher at St.4 and low at St.5 and St.6.

7.4.5 Primary productivity

i. Gross primary productivity

The mean monthly GPP values ranged from 0.492±0.381 mgC/L/day during January 2011 to 1.722±1.29 mgC/L/day in May 2012. The seasonal variation in GPP showed peak values in the post monsoon season of the second year (2.07± 0.53 mgC/L/day). The average seasonal GPP in the first year recorded 0.98±0.19 mgC/L/day in monsoon, 0.79±0.13 mgC/L/day in post monsoon and 0.90±0.33 mgC/L/day in the pre monsoon seasons. Comparatively higher values were recorded in the second year. The highest values were recorded in second post monsoon followed by pre monsoon (1.34± 0.25mgC/L/day) and monsoon season (1.16±0.39 mgC/L/day) respectively. The spatial variation in gross primary productivity (GPP) ranged from 0.74±0.42 mgC/L/day (St.6) to 1.29±0.69 mgC/L/day (St.1) during first year and from 1.23±0.55 mgC/L/day (St.5) to 1.88± 1.45 mgC/L/day (St.1, 3) during second year respectively (Figure 7.17).

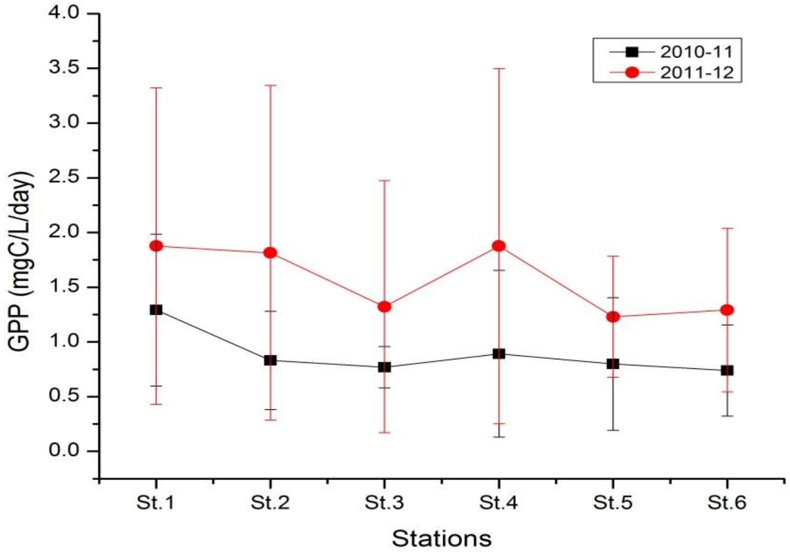

Figure 7.17 Mean spatial variation in GPP in mangrove habitats of Ernakulam during 2010-12 periods

ii. Net primary productivity

The seasonal variation in NPP ranged from 0.36±0.18 mgC/L/day to 1.66±2.58 mgC/L/day. The highest average value was recorded in the second post monsoon (1.01±0.39 mgC/L/day) followed by monsoon seasons of both year (0.67± 0.30 mgC/L/day and 0.59±0.29 mgC/L/day during first and second year respectively). The pre monsoon season recorded lower values during both years. The NPP values ranged from 0.34± 0.19mgC/L/day (St.4) to 0.77± 0.56 mgC/L/day (St.1) during the first year and from 0.59±0.29 mgC/L/day (St. 5) to 1.08± 1.62mgC/L/day (St.4) respectively (Figure 7.18).

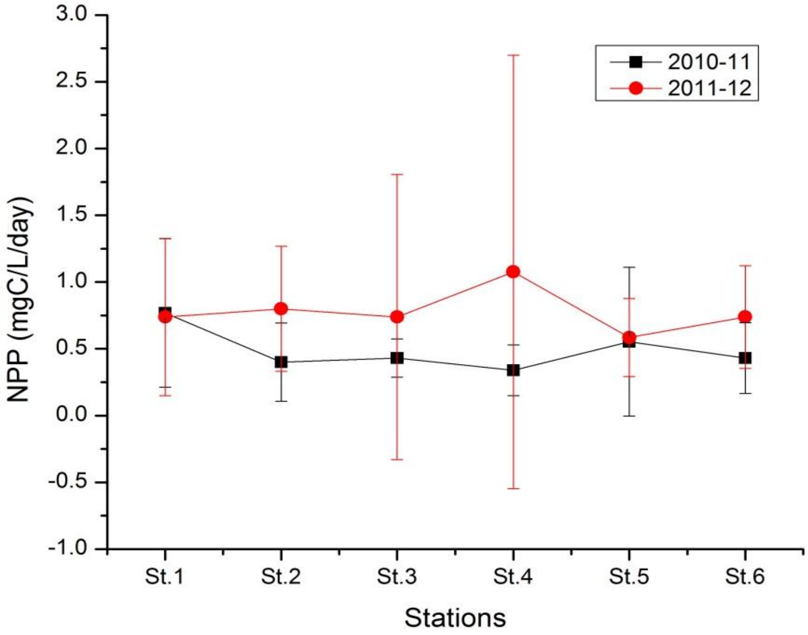

Figure 7.18 Mean spatial variation in NPP in mangrove habitats of Ernakulam during 2010-12 periods

7.4.6 Redfield ratio

The spatial variation in N: P ratio ranged from 2.24±1.88 (St.6) to 6.96±2.11 (St.5) and from 1.53±0.64 (St.6) to 4.49±3.84 (St.5) during first and second year respectively (Table 7.4). While considering the Si: P ratio the St.2 recorded the lowest value (4.96±5.14) and St.6 recorded the highest value (13.66±8.17) during 2010-11 period. However during second year, Puthuvypin station (St.3) recorded the lowest value (1.70±0.89) and St.5 recorded highest value (9.77±9.15). The Si: N ratio ranged from 1.83± 0.85 (St.2) to6.94± 5.83(St.5) and from 0.58±0.76 (St.4) to 2.17±0.93 (St.5) during first and second year respectively. The redfield ratio did not show any definite pattern in spatial distribution but the average values displayed higher Si: P ratio followed by N: P and Si: N ratios during both years. This was in favour with the present investigation, indicating a dominance of diatoms in all the stations. The spatial variation in N: P ratio showed values lower than the predicted ratio, indicating a nitrogen limiting environment. The Si: P and Si: N ratios also exhibited a similar trend except at St.6 during 2010-11 period where the ratio was equivalent to the predicted ratio.

Table 7.4 Mean spatial variation of Redfield ratios in mangroves of Ernakulam during 2010-2012 periods

Stations	2010-11			2011-12		
	N:P	Si:P	Si:N	N:P	Si:P	Si:N
St.1	4.02±6.33	10.10±9.47	2.50± 1.49	2.91±0.90	5.70±6.12	1.95±1.56
St.2	2.71±5.99	4.96±5.14	1.83± 0.85	1.99±1.93	2.44±1.39	1.22±0.72
St.3	2.44±1.11	6.14±3.38	2.51± 3.03	1.94±1.73	1.70±0.89	0.87±0.51
St.4	2.37±3.68	7.50±9.24	3.15± 2.50	4.23±3.77	2.49±2.88	0.58±0.76
St.5	6.96±2.11	13.66±8.17	1.96± 0.38	4.49±3.84	9.77±9.15	2.17±0.93
St.6	2.24±1.88	15.60±6.87	6.94± 5.83	1.53±0.64	3.24±1.00	2.12±1.57

The seasonal variation in N: P ratio showed higher values in pre monsoon season followed by monsoon and post monsoon seasons during both years (Table 7.5). Similar to the spatial variation, the seasonal variation in ratios marked a higher Si: P ratio followed by Si: P and N: P ratios. The Si: P ratio was slightly higher than the predicted ratio in the monsoon season of the year 2010-11, while all other seasons recorded lower ratio. The lower values of N: P ratio than the predicted values indicated the nitrogen limiting condition during all the seasons.

Table 7.5 Mean seasonal variation of Redfield ratios in mangroves of Ernakulam during 2010-2012 periods

	2010-11			2011-12		
Ratio	MN	Post MN	Pre MN	MN	Post MN	Pre MN
N:P	2.12±2.32	1.47±1.09	5.04±0.39	4.31±1.51	1.04±0.27	3.52±2.56
Si:P	18.62±4.81	6.12±1.42	6.23±2.84	7.79±2.09	1.87±0.37	3.00±0.79
Si:N	8.77±2.07	4.16±0.84	1.23±0.44	1.80±0.46	1.79±1.36	0.85±0.30

7.4.7 Data Analysis

i. Cluster analysis

The seasonal cluster analysis revealed two major clusters with more than 70% similarity (Figure 7.19). The cluster- I grouped the pre monsoon seasons of both years. The second cluster was subdivided into two; with post monsoon season of the first year separated out from rest of the seasons. The post monsoon season of 2011-12 periods, and the monsoon seasons of both years were grouped together with more than 80% similarity. The analysis showed more similarity between different seasons, which could be due to dominance of diatoms during all the seasons. The pre monsoon seasons of both years showed close similarity than other seasons as the cell density was comparatively low during pre monsoon than other seasons.

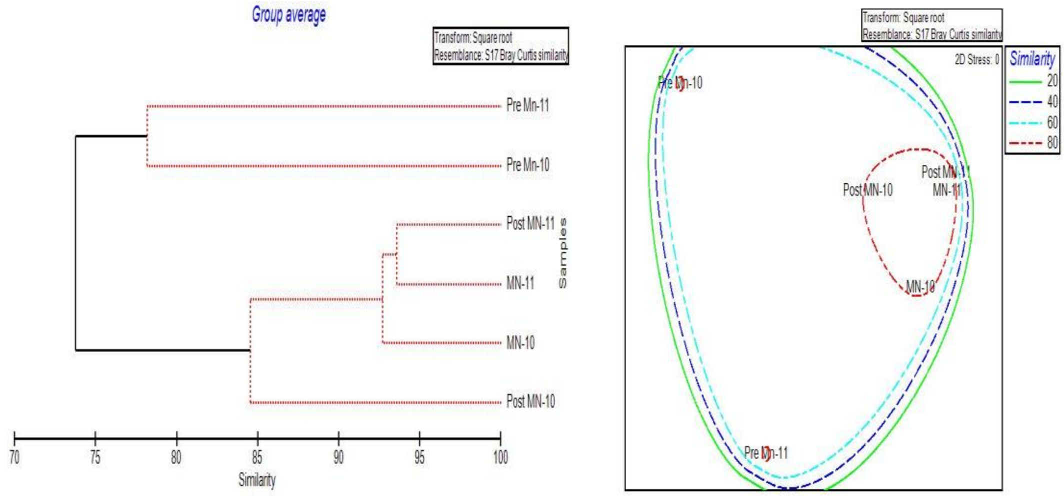

Figure 7.19 Seasonal cluster and MDS based on cell density of microphytoplankton

The station wise cluster analysis of both years also showed two major clusters (I, II) (Figure 7.20 & 7.21). During the first year, the cluster-I grouped St.5 and St.4 together with 70% similarity and all other stations were grouped together in cluster-II. Within cluster-II, stations 2 and 3 showed close similarity (80%). St.6 and St.1 were 70% similar due to higher cell density compared to other stations. On the other hand, the second year reveled two clusters grouping three stations in each cluster. Cluster –I included St.3, St.4 and St.5 with more than 80% similarity. All the three stations exhibited lower cell density during second year than other stations. The other cluster included St.1, St. and St.6 together.

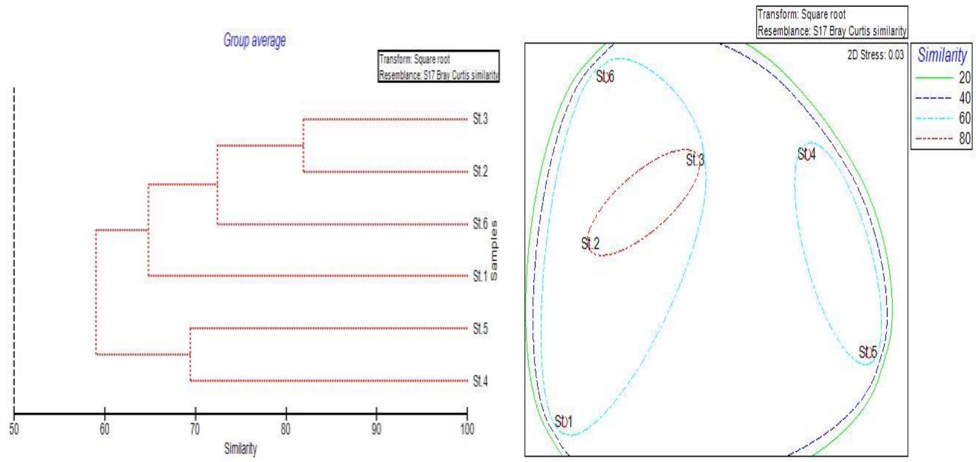

Figure 7.20 Spatial cluster and MDS based on cell density of microphytoplankton groups during 2010-11period

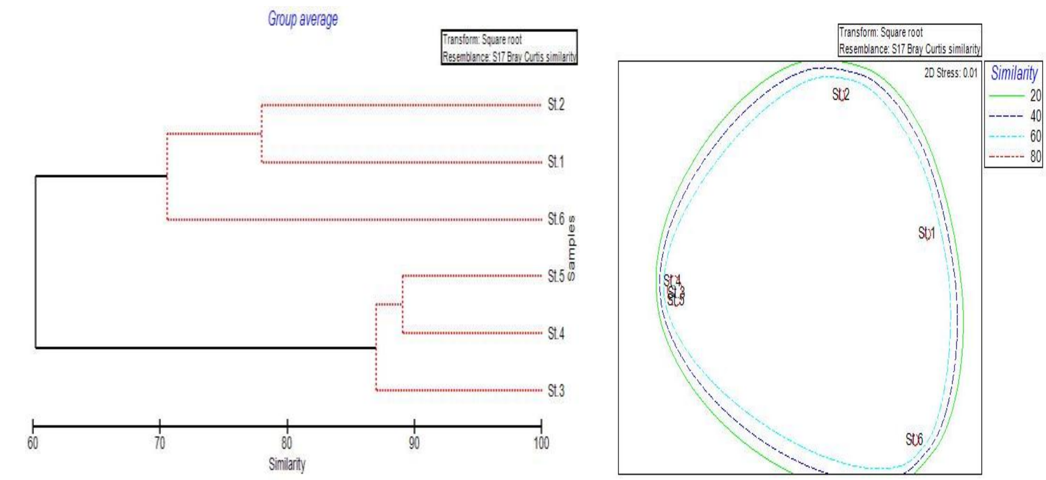

Figure7.21 Spatial cluster and MDS based on cell density of microphytoplankton groups during 2011-12 period

ii. BIOENV analysis

The BIOENV analysis was carried out to identify various environmental variables influencing the abundance of phytoplankton groups. The spearman rank correlation was done with maximum permutation (999) and a total of ten water quality parameters were used for the analysis (Table 7.8). pH was found to be most influencing factor in phytoplankton distribution (ρ=0.607). A combination of pH and dissolved oxygen also exhibited ρ=0.571 that determined the phytoplankton abundance. Besides these phosphates, ammonia dissolved inorganic nitrogen and sulphide concentrations were found to be major influencing factors.

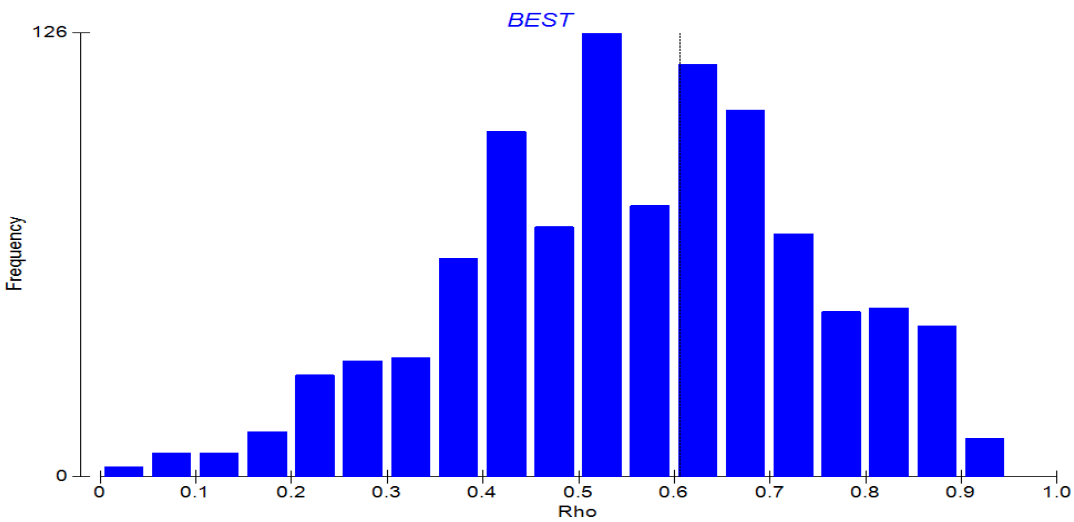

Figure 7.22 Histogram showing the BIOENV analysis of microphytoplankton with environmental parameters during 2010-12 period

Table 7.6 List hydrological parameters affecting the distribution of phytoplankton

Sl.No.	Variables	Variables selected	Rho values
1	Water temp.	2	0.607
2	pH	2,4	0.571
3	Salinity	2,10	0.479
4	DO	2,4,9	0.464
5	BOD	2,4,8	0.457
6	Phosphate	2,6	0.443
7	Nitrate	1,2	0.429
8	Ammonia	2,8,10	0.425
9	DIN	2,4,6,8	0.418
10	Sulphide	2,8	0.416

iii. Canonical Correspondence Analysis (CCA)

The CCA analysis was carried out to find the possible relation between spatial changes in phytoplankton groups and various hydrographic parameters in mangrove ecosystems of Ernakulam district. The Eigen values obtained for the axis were; 1 (0.062), 2(0.024) and 3(0.014) for 14 environmental parameters along six stations (Table 7.9). The vector length of given variables showed 60% relation between phytoplankton groups and various hydrographic parameters. The longer vector of Bacillariophyceae in axis 1 denotes the dominance of diatom groups than other phytoplankton. Water temperature (-0.847), salinity (-0.159) and pH (-0.106) showed a negative correlation with axis 1 and while salinity (0.545) and pH (0.730) exhibited a positive correlation at axis 2. Comparatively longer vectors of water temperature and pH indicate their influence on phytoplankton community. Axis 1 also exhibits a positive relation with BOD (2.735), DO (0.061), turbidity (0.618), phosphate (0.157), nitrate (0.032), nitrite (0 .101), ammonia (0.095) and chlorophyll-a concentration (0.044) indicating their role in shaping the phytoplankton community structure. Salinity, water temperature and pH are the major controlling factors at St.3, St.5 and St.6 which marked the prevalence of members of Myxophyceae, Chlorophyceae and Dinophyceae than other stations. The species of Euglenophyceae and Bacillariophyceae were more dominant at station 1 and 2, which were favoured by hydrographic parameters such as nitrite, nitrate, ammonia and silicate concentrations.

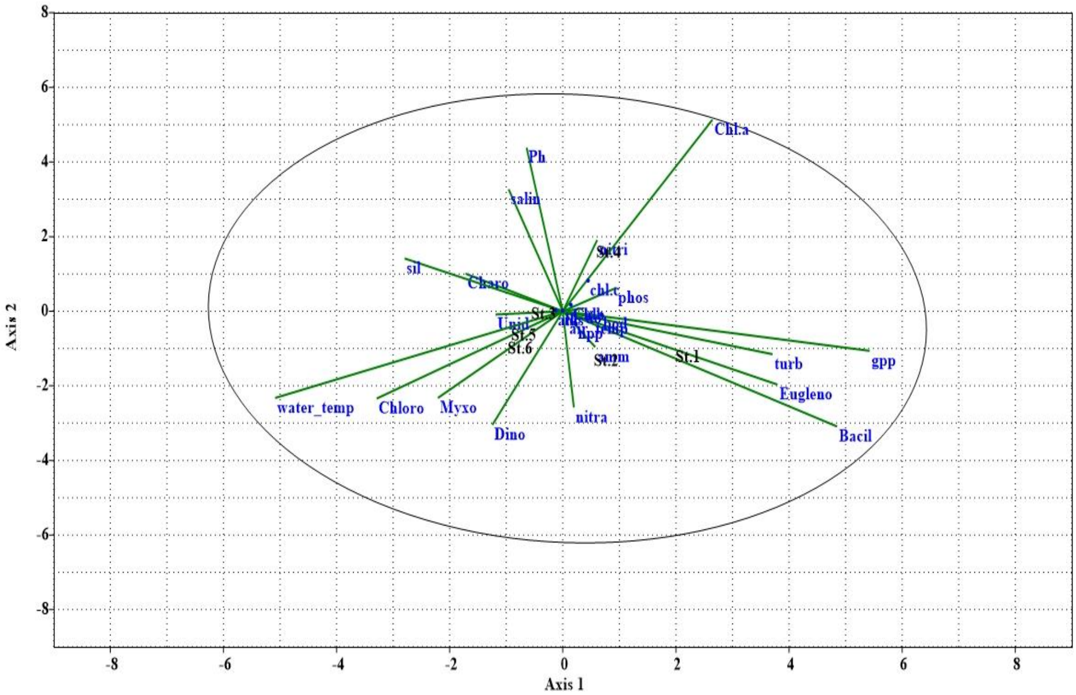

Figure 7.23 CCA analysis of microphytoplankton with environmental parameters during 2010-12 period

7.5 Discussion

7.5.1 Microphytoplankton diversity

Phytoplankton communities control a variety of ecosystem functions such as nutrient cycling, structure and efficiency of food web, carbon fluxes etc. (Smith and Sakshaug, 1990). Mangrove waters serves as an ideal medium for phytoplankton growth, on the other hand they play a major role in food web of mangrove habitats exhibiting a symbiotic interaction between both. Upper layers of water body are most favourable for phytoplankton as sufficient light intensity for photosynthesis occurs in this layer. Taxonomically phytoplankton is diverse groups (~20000sps.) with ~10,000spp. of diatoms, 1200 spp. of dinoflagellates (Jeffrey and Hallegraeff, 1990) and other forms of chryptophytes, cyanophytes etc. The phytoplankton communities in mangroves are diverse and change within short period of time. The species composition of microphytoplankton in the present study revealed the presence of 85 species belonging to 60 genera under 40 families. Six major classes were identified: Bacillariophyceae, Myxophyceae, Chlorophyceae, Euglenophyceae, Charophyceae and Dinophyceae. Similar number of species was reported from Pichavaram mangroves; 82spp. by Kathiresan (2000), 94spp. by Rajkumar et al. (2009), 62 spp. by Silambarasan et al. (2016) and 95spp. by Varadharajan and Soundarapandian (2015) from Muthupett mangroves. Suman et al., 2010 recorded 49 spp. while Rahman et al., 2013 recorded 134 spp. from the Sundarban mangroves. Bignesh et al., 2015 recorded 78spp. from Gulf of Kutchh and while more numbers of species were identified from Andaman and Nicobar Islands (104spp.).

The class Bacillariophyceae was dominant throughout the study period, represented by 50 species under 33 genera and 22 families. The abundance of diatoms was followed by Chlorophyceae and Myxophyceae. Diatoms constituted more than 80% throughout the study period irrespective of stations or seasons. Various studies on Indian context also highlight the dominance of diatoms (Kathiresan, 2000; Rajkumar et al., 2009; Suman et al., 2010; Rahman et al., 2013;Varadharajan and Soundarapandian, 2015; Silambarasan, 2016). The dominance of diatoms and dinoflagellates in high concentrations of nutrients were recorded in studies by Murugan and Ayyakkannu, 1991(Cuddalore Uppanar backwaters); Ananthan, 1991 (Parangipettai and Cuddalore marine environs); Patterson and Ayyakkannu, 1991 (Kollidam estuary); Kannan et al., 1992 and Mani,1994 (Pichavaram mangroves); Govindasamy, 1992 (Coromandel coast); Sampathkumar,1992 (Tranquebar-Nagapattinam) and Santhosh and Perumal, 2012 (Ayyampattinam coast). The dominance of diatoms in mangrove waters was not only reported in Indian mangroves. More than 80% of diatom abundance were reported in Matang mangrove of Malaysia (Tanaka and Choo, 2000), Kuantan coast (Mohammad-Noor et al. 2013).

The diatoms mainly constituted the small sized, unicellular forms rather than chain forming ones and preferred lower nutrient requirements and lower sinking rates. The diatoms identified from all the six stations belonged to 22 families. The family Bacillariaceae represented 7genera (12sp.) with dominance of Nitzschia, Cylindrotheca, Pseudonitzschia, Ceratium, Bacillaria, Ankistrodesmus and Achnanthus species. The diatoms species identified in the study belonged to the families Bacillariaceae (12)>Coscinodiscaeae (5) > Fragilariaceae (3), Surirellaceae (3), Catenulaceae (3) > Pleurosigmataceae (2), Naviculaceae (2), Eunotiaceae (2), Amphipleuraceae (2), Diploneidaceae (2), Pinnulariaceae(2) > Rhizosoleniaceae (1), Cocconeidaceae (1), Cymbellaceae (1), Hemidiscaceae (1), Stephanodiscaceae (1), Thalassiosiraceae (1), Melosiraceae(1), Hemiaulaceae (1), Biddulphiaceae(1), Triceratiaceae(1), Chaetocerotaceae (1). The class Chlorophyceae formed the second group with 16 species (13 genera) followed by Myxophyceae (8 species, 7 genera) and Euglenophyceae (7 species, 3 genera). Other minor groups included Dinophyceae and Charophyceae. The class Dinophyceae had only three representatives (3 species, 3 genera) and only a single species was identified from class Charophyceae. Rahman et al., 2013 also identified dominance of diatoms (99spp.) along with other groups Pyrophyta (18 spp.); Chlorophyta (12sps.); Cyanobacteria (4sps.); and Ochrophyta (1sp.) along Sundarban mangroves. Suman et al., 2010 identified 46 genera of phytoplankton representing 6 groups along sundarbans, with diatoms dominatig the ecosystem (27 genera). Other classes included Chlorophyceae, Cyanophyceae, Pyrrophyceae and Chrysophyceae. However, representatives of Pyrophyceae, Chrysophyceae and Ochrophyceae were not encountered in mangrove waters of Ernakulam. In family Euglenaceae, 3 genera were identified (Euglena, Trachelomonas and Phacus) among which genus Euglena represented maximum diversity and abundance. Closterium was the only species identified from family Conjugatophyceae. The present study also strengthens the view of diatom dominance in mangrove habitats, which could be due to the broader tolerance range of the species. Most of the species are euryhaline and eurythermal exhibiting active growth than other forms.

The spatial variation in phytoplankton diversity was higher in station 6 (Valanthakad- Arkathadam) followed by Puthuvypin. All the stations recorded higher numbers of Bacillariophyceae> Chlorophyceae> Myxophyceae> Euglenophyceae> Dinophyceae >Charophyceae. Even though Malippuram station exhibited least species diversity during both years, highest biomass was recorded in this station. The charophycean species was observed only at station 6 during the second year (2011-12). During the present study 13 species were commonly distributed in all stations. *Nitzschia closterium, Cylindrotheca gracilis, Nitzschia sigma, Navicula* spp., *Pleurosigma* spp., *Diploneis* spp., *Coscinodiscus eccentricus, Melosira* spp. were the common species of class Bacillariophyceae. Other species were; *Oscillatoria limosa* (Myxophyceae); *Scenedesmus acuminatus, Pediastrum simplex* (Chlorophyceae) and *Euglena limnophila*, *Phacus* sp. (Euglenophyceae).

The species diversity was higher in second year (81sps.) than first year (79sps.). The present study did not portray a seasonal trend species composition during study period. During first year, the species diversity showed a declining trend from pre monsoon season >post monsoon > monsoon seasons. While the second year displayed higher diversity in pre monsoon season followed by monsoon and post monsoon seasons. Diatoms were dominant group in all season during both years and almost 30 species were commonly found in all seasons. Species of Myxophyceae and Chlorophyceae were dominant in monsoon season. Species of *Merismopoedia, Nostoc, Oscillatoria, Arthrospira* and *Spirulina* from Myxophyceae and *Ankistrodesmus* spp., *Spirogyra* spp., *Pediastrum simplex, Scenedesmus acuminatus* representing Chlorophyceae were common in all seasons. Euglenophyceae was also dominated in monsoon season, with *Euglena limnophila* prevailing in all seasons. Closterium species was rare in occurrence and was recorded only from St.3 (first monsoon) and St.6 (second pre monsoon). The spatial variation in species diversity portrayed higher number of species along the mangroves of Valanthakad followed by Puthuvypin, Aroor and Malippuram during the first year. However during second year station 5 recorded lower species diversity compared to St. 3, Puthuvypin.

The seasonal variation in biomass was recorded higher in monsoon season during both years (26.57ml/m^3, 23.56ml/m^3) and was proportional to the increase in species diversity (81 spp., 79 spp.) and cell density (100.399 $x10^3$, 108.916$x10^3$ cells/m^3) in the respective season during first and second year respectively. Spatial and seasonal variations in cell density were also reflected in the study area. The cell density of microphytoplankton ranged from 6.30×10^3 cell/m^3 to 218.19×10^3 cell/m^3

during the study period indicating rich phytoplankton growth in mangrove habitats. The cell density was higher in second year and showed a declining trend from monsoon >post monsoon > pre monsoon season. However in various other studies, the maximum cell density was recorded in summer period favoured by high temperature and salinity. Various other studies (Kouwenberg, 1994; Ramaiah and Nair, 1997; Chandramohan and Sreenivas, 1998; Balasubramanian and Kannan, 2005; Sridhar et al., 2006) also highlighted the influence of salinity in phytoplankton distribution. Such observations were also reported from Cochin back waters were maximum cell density 12000-322000 cells/l was recorded in summer period (Selvaraj et al., 2003). Rahman et al., 2013 also reported lowest abundance in monsoon (3.709×10^3 cells/l) and highest in summer (2.174×10^5 cells/l) along Sundarban mangroves.

7.5.2 Physico-chemical factor controlling microphytoplankton composition

In mangrove environment the seasonal as well as the daily changes in the surface currents drives the variation in temperature, nutrient concentrations and productivity patterns. The phytoplankton community responds to a large number of spatio- temporal variations in biological, physical and chemical factors. Pradhan and Shaikh (2011); Mohamad-Noor et al. (2012); and Rahman et al., 2013 had reported the influence of seasonal changes in hydrography controlling the phytoplankton abundance which in turn affects the productivity pattern. Usually in deeper water bodies, the stratification of water layer is evident which results in the vertical distribution of phytoplankton. Denman and Marra (1986) demonstrated the variations in phytoplankton distribution based on exposure to light field and nutrient availabilities. Such vertical distribution was absent in the mangrove ecosystems of Ernakulam district as all the study sites were shallow in nature and the light was available plentiful throughout the water column. Water temperature and transparency has significant role in distribution and seasonal variation of phytoplankton growth (Bouman et al., 2010).

In the present study the BIOENV analysis revealed a significance of $\rho=0.429$ with water temperature and phytoplankton abundance. This could be due to the cross interaction between the parameters. Even though the monsoon season reflects highly turbid water column, portraying reduction in phytoplankton density the present study sites recorded higher temperature irrespective of seasons due to shallow nature. The algal groups such as diatoms, dinoflagellates, blue green algae, green flagellates and silicoflagellates are the major forms that compete for light and nutrients and hence are found in most turbulent environments (Townsend, 2001). Besides light and temperature, salinity seems to be an important parameter influencing the phytoplankton species composition, density and primary production. The mangrove sites of Ernakulam are mixo-mesohaline in nature. The salinity was found to be higher in second year similar to the spatial variation in cell density. All the stations displayed a direct proportionality between two parameters except for St.3. The cell density was observed to be in declining order from St.1> St.6>St.2>St.5> St.3> St.4. The mean value of salinity increased from 11.42ppt (1year) to 16.57ppt (2year) at St.3 while the cell density exhibited a declining trend ($28.91x10^3$ to $23.83x10^3$cells/m^3). It was also observed that St.1, 2, 5 and 6 had lower salinity values compared to St.3 while higher cell density was recorded at St.1 and St.6. The BIOENV analysis could not draw a significant correlation with the parameter thus it can be inferred that the salinity did not play a major role phytoplankton distribution and abundance in the present study sites. Thirunavukkarasu et al. (2013) reported higher number of algal species in moderately saline soils mainly dominated by species of dinoflagellates like *Ceratium*, *Peridiniales* and *Prorocentrum* which preferred low salinity.

Fresh water inflow, sewage discharge and salt water intrusion are the major sources of nutrient input into the ecosystem. Nitrate, nitrite, ammonia, phosphate and silicate are the major inorganic nutrients influencing phytoplankton growth. The concentration of nutrients and phytoplankton population exhibit an inverse relation i.e., decrease in nutrients level with increase in phytoplankton population indicates the rapid utilization of nutrients by phytoplankton. The red field ratio indicated a nitrate and phosphate limited condition in the mangrove waters of Ernakulam. The BIOENV analysis did not display a significant role of nitrate; a rho value of 0.443 was exhibited for the combined role of water temperature and phosphate in the phytoplankton abundance. Similar observations were also reported in mangroves of Pichavaram, Ennore and Adyar mangroves (Purvaraj and Remesh, 1999). Mani and Krishnamurthy (1989) and Murugan and Ayyakkannu (1991) opined that high salinity could be a reason for reduced nitrite in pre monsoon and post monsoon periods. The lower concentration of phosphate during post and pre monsoon seasons could be due to decreased runoff and utilization by algae (Ramakrishnan et al., 1999).

The ammonia concentration is usually higher in mangrove environments due to higher rates of litter decomposition. The ammonia concentration in the water column along with water temperature and sulphide were also significant (ρ=0.425) in determining the phytoplankton abundance. Saifullah et al. (2014) reported a positive correlation between various hydrographic parameters (nitrates, phosphates, salinity, turbidity) and phytoplankton abundance and distribution in tropical ecosystems. The higher concentration of silicate than other nutrients all the stations were proportional to the maximum density of diatoms in all stations. Mishra et al., 1993 also reported higher silicate concentration than other nutrients in mangroves of Pichavaram. Reyes-Rodrguez (2001) reported the higher silicate concentration could be from the effluents from adjacent shrimp farms and harbors. It is also found that the reduction in silicate would reduce the diatom growth and often got replaced by dinoflagellates (Tilstone et al., 2000). Higher silicate concentration also displays the direct anthropogenic interactions and inputs in the study sites.

Dissolved oxygen content has a significant role in phytoplankton growth and productivity rate and a significant correlation was established in the present study. The combination of water temperature and DO displayed a rho value 0.571. The DO values ranged from 2.78-4.5mg/l (2010-11) and 3.7-5.8mg/l (2011-12). The frequent flushing of water usually enhances the oxygen supply in mangrove waters while the increase in temperature and salinity depletes the dissolved oxygen. It was also evident that St.1 and St.6 had higher DO content and displayed a linear relation with the higher cell densities in respective stations. Besides these factors, the dissolved oxygen is low in mangrove waters even during monsoon period due to increased load of organic matter. The continuous addition of effluents and organic litter load excretes greater oxygen demand in mangrove water column. Jayalakshmi et al.

(1986) identified temperature, salinity and dissolved oxygen as the major influencing factors in phytoplankton distribution in Cochin backwaters.

7.5.3 Productivity of mangroves

Chlorophyll concentration is most reliable index for phytoplankton biomass hence most of the studies on composition and density of phytoplankton are carried out simultaneously with chlorophyll estimation. Various studies highlight the significance of pigment analysis in determining the phytoplankton community structure. Chlorophyll-a and carotenoid pigments primarily helps in determining the community structure (Everitt et al., 1990) while the amount of photosynthetically inactive pigments can be quantified by analyzing phaeophytin pigments. In seawater the Chl-a concentration ranges from 0.05mg/l (oligotrophic areas) to 20mg/l (eutrophic areas) with exceptionally higher values in bloom conditions (Strickland, 1964). In the present study the mean monthly variation ranged from 9.34±12.27mg/m^3 to 75.83± 133.84 mg/m^{3}exhibiting an oligotrophic condition of study sites. Rahman et al. 2013 reported higher chl. ‘a’ values in mangrove waters than other nertic waters. Tripathy et al., 2005 reported a chl. ‘a’ concentration of 12.49µg/l (Sundarbans) and 0.2-105.6µg/l (Pichavaram). While much lower chl. ‘a’ concentration was reported by Rajkumar et al., 2009 (0.2-69.82µg/l) and Senthilkumar et al., 2008 (8.62-11.42µg/l) in Pichavaram. Meera and Bijoy Nandan (2010) reported 0.005-0.032 µg/l of chl. ‘a’ from mangroves of Valanthakad. Chl. ‘a’ did not show a particular trend in seasonal variation. During first year the chl. ‘a’ concentration decreased from pre monsoon> monsoon >post monsoon, while in the second year the values decreased from pre monsoon>post monsoon> monsoon. The higher chl. ‘a’ concentrations in monsoon season due to rich phytoplankton growth as a result of higher concentrations of nutrients brought into the system through surface runoff was reported by Subrahmanyan (1959, 1960). But the present study highlighted a different pattern with higher Chl-a concentration values prevailing in the pre monsoon season. Chl. ‘a’ was positively correlated with chl. ‘c’ and carotenoid concentrations but established a negative correlation with phaeophytin and active chlorophyll. The mean chl. ‘b’ values were lower than chl. ‘a’ values

(0.08 mg/m^3 to14.09 mg/m^3). Chl. 'b' values indicate the significant role of green algae in contributing to primary production in mangrove waters.

The productivity pattern did not exhibit a distinct seasonal pattern. The monthly variation in GPP recorded the highest in May 2012 (1.722±1.29mgC/L/day). Higher GPP values were observed in the monsoon season during first year and in the post monsoon season during second year. Both seasonal and spatial variation in GPP recorded higher values in the second year (2011-12). Station 6 and 5 marked higher productivity which was clearly reflected in the phytoplankton abundance in these stations. Lower GPP values were recorded by Purvaraj and Ramesh, 2000; 113gC/m^2/y (Pichavaram), 157gC/m^2/y (Ennore Creek) and 83gC/m^2/y (Adyar estuary). Comparatively higher GPP values were reported by Rajkumar et al., 2009 (16.54-826.8 mgC/m^3/h). GPP value of 0.24-3mgC/L/day was reported by Meera and Bijoy Nandan (2010) from Valanthakad mangroves.

Temperature is one of the major factors influencing the variation in primary production, as increase in temperature increases the rate of photosynthesis to a particular peak after which it drops. But in tropical regions there is not much seasonal variation in temperature and above all the shallow nature of mangrove study sites receives sufficient illumination throughout the water column. The primary productivity marked a positive correlation atmospheric temperature (r^2=0.198, $p<0.01$) and water temperature (r^2=0.273, $p<0.01$). The GPP also established a positive correlation with DO, salinity, chl. 'b' and chl. 'c' while a negative relation was displayed with hardness and phaeophytin concentration. The NPP values followed a similar trend that of GPP both seasonally and spatially. NPP exhibited a positive correlation with water temperature and dissolved oxygen. GPP and NPP displayed a positive correlation with 0.01 level of significance.

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Conclusions and Recommendations

Mangroves are pristine ecosystem inhabiting the inter tidal zone of tropical and subtropical countries. They provide a wide range of goods and services to the local community and are bestowed with rich species diversity. However, the mangroves are globally over exploited and are subjected to large scale degradation. These wanton destructions are even visible in the mangrove habitats of Kerala. Since there is a wide gap in the knowledge of mangrove species diversity and extend on mangrove cover in Kerala, the degree of destruction is unaccounted.

The present study was carried out to provide the present status of mangroves of Kerala. The mangroves in Kerala are spread across ten districts, inhabiting around 18 true mangrove species and 23 species of mangrove associates. Kollam district displayed the highest species diversity and accounted for the presence of rare species such as *Avicennia alba* and *Ceriops tagal.* Alappuzha, Ernakulam and Kannur also ranked the consecutive positions in terms of species diversity. Ayiramthengu region Kollam was identified as the most species rich zone along the entire study area. The study could provide a detailed taxonomic description of all the 18 spp. with suitable scientific diagrams and photographs. Even though many studies are reported on the mangrove species diversity from Kerala, most of them are restricted to the major mangrove stands of Kannur, Thrissur, Ernakulam and Kollam. Besides these, most of these reports also highlighted varying number of species over a course of time. In this context the present study would be helpful for future researchers in better identification of mangrove species along various mangrove habitats of Kerala. However, various morphometric characters of each species could not mark a significant district wise variation among species; it would be supportive in future taxonomic studies and in identification of new geographical varieties of species.

Zonation is a characteristic feature of mangrove habitats and is well documented along the global mangrove chunks. As most of the mangrove habitats of Kerala are fast disappearing and exist as narrow fringes and open stands, a distinct zonation pattern is not perceived. Thus studies on this context are lacking along the Kerala mangroves for decades. The study provides an elaborate picture of zonation pattern in various mangrove habitats along the ten districts of Kerala. As dense mangrove forest are lacking in the state, each mangrove habitat exhibited variations in zonation pattern. A general trend in zonation along the three mangrove zones were identified in the study with the dominance of *Rhizophora* spp.., *Acanthus ilicifolius, Kandelia candel, Sonneratia caseolaris, Aegiceras corniculatum* and *Avicennia marina* in the fringing zones. The intermediate zone was formed by mixed community of *Sonneratia* spp., *Excoecaria agallocha, Lumnitzera racemosa* and *Avicennia officinalis.* The landward zone is inhabited by the species of *Bruguiera* and *Acrostichum.* The zonation pattern also exhibited overlapping of these species along the fringing, intermediate and landward zones. The present study figured four types of mangrove forests throughout Kerala: Fringing mangrove forest (Kozhikode, Malappuram and Ernakulam), Overwash mangrove forest (Thrissur, Ernakulam and Alappuzha), Hammock mangrove forest and Dwarf forest type (Thiruvananthapuram). The fringe mangroves are most common in Kerala and almost all the larger and the rich stands of mangroves that exist today in Kerala, are of this type.

The extent of mangrove vegetation along various districts has under gone drastic changes due to anthropogenic interventions. But such localised losses are unaccountable, as most of the mangrove sites lack authentic information on the present mangrove cover. The study attempted to identify the district wise mangrove cover of Kerala and identified 1782ha of mangrove. The highest area under mangrove cover was noticed in Kannur district (900ha) followed by Ernakulam district (396ha). Better mangrove vegetation is spread along the North zone (1191ha) followed by central zone (440ha) and southern zone (151ha). Based on the SWOT analysis the study identified intense loss of mangroves in Ernakulam district. Most of the mangrove sites faced the threat of urbanisation, reclamation and unsustainable tourism operations.

Being the buffer zone between the land and water, mangroves are always subjected to frequently changing physico- chemical parameters. Besides this, the ecology of mangrove habitats is very much altered by various human activities. Since mangroves of Ernakulam exhibited the highest degree of mangrove destruction, the ecology of mangrove waters of Ernakulam district was studied in depth. The thesis provides detailed information on the various physico- chemical parameters prevailing in these mangrove zones. It was found that most of the physico- chemical parameters varied greatly along Puthuvypin, as the site was most seriously altered due to various activities of LNG terminal sites. The study identified comparatively productive and intact mangrove habitats along Valanthakad. The variations in these physico- chemical parameters also affected the phytoplankton composition and productivity pattern in various mangrove habitats of Ernakulam.

Based on the above observations, the study suggests few recommendations.

Recommendations

- Mangroves are ecologically fragile ecosystems and are categorised under CRZ I-A (Coastal Regulation Zone). Even though the norms of CRZ, 2011 does not permit any developmental activities within 100m from coast in CRZ-I areas, large extend of mangroves are already destructed by now. The amendment of CRZ, 2018 notification would result in further loss of mangrove cover as the protected area from the coast is further reduced from 100 metres to 50 metres. As mangroves are the only ecosystems flourishing within these limits, would be greatly subjected to destructional activities. Thus exclusive mangrove forest protection laws have to be framed and legislated with immediate effect to protect the existing mangrove patches along Kerala coast.
- Most of the mangrove habitats of Kerala are vulnerably affected by various reclammational activities resulting in great loss of ecologically important and sensitive species of flora and fauna. Thus regular monitoring of mangrove habitats of the state has to be initiated by the government for better preservation and conservation of germplasam.
- The high resolution maps of mangrove habitats at panchayath level have to be developed for Kerala mangroves to identify the localised loss of

mangrove patches. Existing policies and laws has to be strengthened even at panchayath level to improve the conservation of mangroves.

- Immediate conservation strategies have to be implemented by government in protecting the mangroves of Puthuvypin (Ernakulam), Ayiramthengu (Kollam), Pappinissery and Pazhayangadi (Kannur) which holds ecologically potential mangrove stands with rich biodiversity.
- It has been witnessed that many of the mangrove species are lost from Kerala coast during the course of time. Thus mangrove conservation authorities have to be formed for better monitoring of mangroves at regional level. A mangrove plant database for Kerala state is essential for categorisation of mangroves species at regional level, as the species categorisation by IUCN and other international data bases are not applicable to mangrove species at regional levels.
- Conservation and restoration activities have to be fortified through nursery management, micro propagation and sanctuaries to revamp the already lost mangrove species. Various programmes can be implemented by state government with collaboration with universities, research institutes, panchayath and local communities for better protection of these habitats.

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Glossary

Acuminate	-	tapering to a pointed apex, sides more or less pinched in before reaching the tip.
Acute	-	tapering to the apex with the sides straight or nearly so; usually less tapering than acuminate.
Adnate	-	the fusion of unlike parts
Anther-lobe	-	pollen containing sac of the stamen
Apical	-	at the terminal point of any structure
Apiculate	-	with a short , but not rigid point
Axillary	-	situated in the axil, usually in the axil of stem and leaf
Beaked	-	provided with a solid, narrow, tubular beak-like prolongation
Berry	-	a pulpy fruit with embedded seeds
Bifid	-	divided into two parts, bifurcated
Bisexual	-	containing both stamen and carpels
Bract	-	a modified reduced leaf on an inflorescence with a flower in its axil
Bracteolate	-	the condition of having bracteole (in flowers)
Bracteole	-	a small bract often on the petiole or immediately below the calyx
Buttress	-	downward sloping radial projection from lower trunk of tree
Caducous	-	falling of early
Calyx	-	the outermost series of parts of a flower
Campanulate	-	bell - shaped
Capitate	-	knob like
Capsule	-	dry dehiscent fruit, when ripe opens by two or more values
Carpel	-	a modified leaf forming an ovary bearing the ovules
Catkin	-	a type of inflorescence having usually of unisexual flowers without petals solitary or twin in the axils of bracts
Caudate	-	with a tail like ending

Cauline	-	belonging to the stem
Cilia	-	a marginal hair
Ciliate	-	hairy along margins
Clavate	-	club shaped
Compound	-	formed of similar parts grouped in a whole usually of leaves consisting more than one separate leaf lets
Connate	-	united to one another
Cordate	-	deeply notched at base, conventional heart-shaped
Coriaceous	-	leathery
Corolla	-	the interior series of the perianth
Corymb	-	a type of inflorescence with several flower stalks arising at different levels which reach the same level at the top
Cryptoviviparous	-	in which the seeds germinate but are covered with their pericarp (fruit skin) before detaching from the parent tree
Culm	-	the stem of a grass or bamboo
Cyme	-	a type of inflorescence in which the secondary or lateral branches continue to grow and may extend beyond the main axis
Cymose	-	sympodially branched
Deciduous	-	losing leaf seasonally / falling off
Decussate	-	with successive pairs of organs arranged at right angles to one another, causing them to appear
Dichotomous	-	forked
Didynamous	-	in an androecium for stamens in two pairs, one pair shorter than the other
Dioecious	-	male and female flowers segregated on different plants
Dorsal	-	relating to the back
Drupe	-	a fleshy fruit with 1- many celled stony seeds
Ebracteate	-	without bracts
Ellipsoid	-	an elliptical solid body
Elliptic	-	broader in the middle with narrowed ends
Entire	-	without any teeth at the margin
Epipetalous	-	placed on the petal or corolla
Erect	-	rigid, strong, and upright stem

Exstipulate	-	without stipules
Filament	-	the stalk of an anther; any thread like body
Frond	-	leaf of a fern
Glabrous	-	without any hair or smooth
Glume	-	the bracts and bracteoles on the spike-lets of grasses and sedges
Hermaphrodite	-	bisexual, flower having both androecium and gynoecium
Hypocotyl	-	the axis of an embryo below the cotyledons
Imbricate	-	overlapping; usually of arrangement of sepals and petals
Imparipinnate	-	a condition in a compound leaf with an odd terminal leaf-let
Inferior	-	position of a floral part at lower level (usually of ovary)
Inflorescence	-	a group of flowers as a whole
Lumina	-	leaf blade
Lanceolate	-	shaped like a lance-head
Leaflet	-	one of the blades of compound leaf
Midrib	-	the conspicuous central vein in the vascular system of an appendage
Monoecious	-	bearing male and female flowers separately on the same plant
Mucron	-	a short, small abrupt tooth-like tip; loosely used but not very sharp at the extreme apex
Mucronate	-	tipped with a short hard blunt point
Oblique	-	a shape with half more large than the other; usually of leaf
Oblong	-	longer than broad with sides nearly parallel
Obovate	-	reversed ovate shape
Obtuse	-	blunt ended
Ovate	-	egg shaped
Ovule	-	minute bodies from inside the ovary which after fertilization develop into seeds
Panicle	-	a repeatedly branched inflorescence
Papillose	-	with soft superficial protuberances or glands
Pedicel	-	stalk of a flower

Pedicellate	-	the flower with pedicel
Peduncle	-	a common stalk of more than two flowers
Pendulous	-	hanging
Pentamerous	-	five-merous, the parts in 5's or multiple of 5
Perianth	-	having the stipe attached the lower surface but not at the base or margin
Pericarp	-	outer wall of a fertilized ovary or fruit
Persistent	-	not falling off
Petal	-	a single member of the corolla
Petioled	-	like petals
Petiolate	-	leafs with stalks
Petiole	-	leaf stalk
Pinnae	-	the lobes of a bipinnate leaf
Pinnate	-	feather-formed with the leaflets of a compound leaf placed on either sides of the rachis
Pistil	-	the female sex organ consisting of ovary style and stigma
Pneumatophore	-	vertical outgrowths of roots which facilitates breathing in swamp plants
Raceme	-	a type of inflorescence with a continuously growing main axil and the oldest flowers at the base opening first
Reticulate	-	netted
Rhizomes	-	a modified horizontally running underground stem
Scaly	-	with scale
Sepal	-	a single member (lobe) of the calyx
Serrate	-	toothed, with the teeth inclined upwards
Sessile	-	without a stalk
Sheathing	-	the leaf having expanded base of the petiole encircling partially or completely the stem
Solitary	-	flowers borne singly, not in clusters
Spadix	-	a flower spike with a fleshy axis
Spathe	-	a more or less modified bract enclosing an inflorescence
Spathulate	-	structure has broad apex and long, narrow base
Spike	-	inflorescence with sessile flowers on elongate axis

Spikelet	-	an ultimate part of a spike with one or more sessile flowers
Spine	-	a rigid, sharp-pointed structure usually modified from a stem
Spinous	-	bearing many spines
Spore	-	reproductive body of flowers plants, usually single cell
Stalk	-	a short or elongated structure bearing or supporting another structure
Stamen	-	the floral organ bearing the anther and pollen
Staminode	-	an abortive stamen without anther and pollen
Stigma	-	the terminal part of pistil which receives the pollen
Stilt-root	-	looping aerial roots exposed to the air, arising from the trunk and lower branches and extending outward and downward into the soil
Stipule	-	a lateral appendage at the base of petiole
Succulent	-	juicy; fleshy; soft thickened in texture
Terminal	-	arising from the end of the stem
Trichotomous	-	an axis successively 3 forked
Trigonous	-	said of an achene or other structure which is 3-sided or triangular in cross section
Twisted	-	one margin of the petal overlaps that of the next one , and the next margin overlaps the third one
Umbel	-	an inflorescence in which a cluster of pedicels arise from the same point
Unipinnate	-	having leaflets on each side of the axis
Unisexual	-	in flowering plants, said of a plant or flower that either bears only stamens or only pistils, but not both
Venation	-	arrangement of veins
Ventral	-	relating to the front side
Vivipary	-	the process of germination of seeds while still attached to the parent plant
Whorled	-	occurring in a whorl
Zygomorphic	-	having the members of an whorl unlike irregular

ANNEXURE

Annexure 4.1 Distribution of Mangroves in various districts of Kerala

Mangrove Spp.	KSD	KNR	KKD	MLP	TSR	EKM	KTM	ALP	KLM	TVM
Acanthus ilicifolius	*	*	*	*	*	*	*	*	*	-
Avicennia officinalis	*	*	*	*	*	*	*	*	*	*
Avicennia marina	*	*	*	-	-	*	-	-	*	-
Avicennia alba	-	-	-	-	-	-	-	-	*	-
Ceriops tagal	-	-	-	-	-	-	-	-	*	-
Bruguiera sexangula	*	-	-	-	-	*	*	*	-	-
Bruguiera gymnorrhiza	-	-	-	*	-	*	*	*	*	-
Bruguiera cylindrica	*	*	*	-	*	*	-	*	*	-
Rhizophora apiculata	*	*	*	-	-	*	*	*	*	-
R.mucronata	*	*	*	-	*	*	-	*	*	-
Kandelia candel	*	*	*	*	*	*	*	*	*	-
Excoecaria agallocha	*	*	*	*	*	*	*	*	*	-
Excoecaria indica	-	-	-	-	-	-	*	*	-	-
Sonneratia alba	-	*	-	-	-	*	-	*	-	-
Sonneratia caseolaris	*	*	*	*	*	*	*	*	*	*
Aegiceras corniculatum	*	*	*	-	*	-	-	-	*	-
Lumnitzera racemosa	*	-	-	-	-	-	-	*	*	-
Acrostichum aureum	-	*	*	*	*	*	*	*	*	*

KSD- Kasaragod, KNR- Kannur, KKD- Kozhikode, MLPM- Malappuram, TSR- Thrissur, EKM- Ernakulam, KTM- Kottayam, ALP- Alappuzha, KLM-Kollam, TVM- Thiruvananthapuram; (* present, - absent)

Annexure 4.2 Major mangrove species and types of mangrove forest of Kasaragod

No	Station	Major species	Type
1	Manjeswaram	*R.mucronata, B.cylindrica, B. sexangula*	Coastal
2	Uppala - Muttom	*Aegiceras corniculatum, Excoecaria agallocha*	Estuarine
3	Kumbala North	*Acanthus ilicifolius, Avicennia officinalis*	Estuarine
4	Kumbala South	*A. officinalis, R. mucronata*	Estuarine
5	Mogral puthur	*A. officinalis, B. sexangula, Kandelia candel*	Estuarine
6	Chandragiri	*Sonneratia caseolaris, K. candel*	Estuarine
7	Neeleswaram	*K. candel, A. ilicifolius, Acrostichum aureum*	Estuarine
8	Achanthuruth	*K. candel, A. officinalis*	Estuarine
9	Kottapuram	*A. officinalis, E. agallocha*	Estuarine
10	Kariyamkodu	*K. candel, A. officinalis*	Estuarine
11	Edayilakadu	*A. marina, B. cylindrica, A. corniculatum*	Estuarine
12	Kavai	*A. marina, L. racemosa, A. corniculatum*	Estuarine

Annexure 4.3 Major mangrove species and types of mangrove forest of Kannur

No	Station	Major species	Type
1	Pazhayangadi	*R. mucronata, A. officinalis*	Estuarine
2	Pappinissery	*R. mucronata, A. officinalis*	Estuarine
3	Valapattanam	*A. officinalis, B. cylindrica, K. candel*	Estuarine
4	Ramapuram	*A. ilicifolius, E. agallocha*	Estuarine
5	Chempallikundu / Vialapra	*E. agallocha, R. mucronata, A. corniculatum, A. marina*	Estuarine
6	Ezhome	*R. mucronata, S. caseolaris* *A. ilicifolius, A. officinalis*	Estuarine
7	Kunjimangalam	*A. officinalis, A. marina* *B. cylindrica*	Landward
8	Edattu	*E. agallocha, R. mucronata , A. corniculatum*	Landward
9	Perumba	*R. mucronata, S. caseolaris, A. officinalis*	Estuarine
10	Kandankali	*E. agallocha, B. cylindrica, A. corniculatum*	Estuarine
11	Cherukunnu	*A. officinalis, A.marina, S. alba*	Estuarine
12	Madakara	*B. cylindrical, A. marina, A. corniculatum*	Estuarine
13	Thavam	*A. officinalis, B. cylindrica, A. corniculatum*	Estuarine
14	Edakkad	*A. officinalis, E. agallocha*	Landward
15	Dharmadam	*A. marina*	Coastal
16	Koduvalli	*A. officinalis, A. marina, R. mucronata*	Estuarine
17	Thalassery	*A. marina, S. caseolaris*	Estuarine
18	Korapuzha	*A. officinalis*	Estuarine

Annexure 4.4 Major mangrove species and types of mangrove forest of Kozhikode

No	Station	Major species	Type
1	Chemancheri	*E. agallocha, K. candel, A. officinalis*	Estuarine
2	Atholi	*A. officinalis, S. caseolaris*	Estuarine
3	Kallai	*A. officinalis, A. marina*	Estuarine
4	Kadalundi	*R. mucronata, A. officinalis*	Coastal
5	Koyilandi- Kanayamkodu	*A. officinalis, K. candel,* *S. caseolaris*	Estuarine
6	Koyilandi	*A. officinalis, A. corniculatum,* *K. candel, E. agallocha*	Estuarine
7	Kolavipalam	*A. officinalis, A.marina, B. cylindrica*	Coastal
8	Beypore	*A. officinalis, E. agallocha*	Estuarine

Annexure 4.5 Major mangrove species and types of mangrove forest of Malappuram

No	Station	Major species	Type
1	Alathyur-Pullunni	*A. officinalis*	Estuarine
2	Mangateripalam	*A. officinalis, S. caseolaris*	Estuarine
3	Thazhepalam	*K. candel, S. caseolaris*	Estuarine
4	Tanur	*A. officinalis, A. ilicifolius*	Estuarine
5	Ponnani	*A. officinalis, E. agallocha*	Estuarine

Annexure 4.6 Major mangrove species and types of mangrove forest of Thrissur

No	Station	Major species	Type
1	Chettuva	*R. mucronata, A. corniculatum, B. cylindrica*	Estuarine
2	Mullassery-Idiyanchira	*A. officinalis, R. mucronata*	Estuarine
3	Chapara	*A. officinalis, E. agallocha, S. caseolaris*	Landward
4	Pezhungadu-Vallivatttom	*A. officinalis, A. ilicifolius*	Landward
5	Narayanamangalam	*E. agallocha*	Landward
6	Koshavankunnu	*A. officinalis, E. agallocha, S. caseolaris*	Estuarine
7	Poyya	*A. officinalis, E. agallocha*	Estuarine
8	Anapuzha	*A. ilicifolius, A. officinalis*	Estuarine

Annexure 4.7 Major mangrove species and types of mangrove forest of Ernakulam

No	Station	Major species	Type
1	Kumbalangi	*B. gymnorrhiza, E.agallocha, A. officinalis*	Estuarine
2	Chellanam	*A. officinalis, B. gymnorrhiza, B. cylindrica*	Coastal
3	Kannamali	*A.officinalis, B. gymnorrhiza, R. mucronata*	Coastal
4	Panangad	*A. officinalis*	Estuarine
5	Aroor south	*R. mucronata, A.officinalis, R. apiculata*	Estuarine
6	Kumbalam	*R. mucronata, A.officinalis*	Estuarine
7	Thirunettur	*A. ilicifolius, A.officinalis*	Estuarine
8	Valanthakad	*A. officinalis, K. candel, E. agallocha*	Estuarine
9	Elankunnapuzha	*A.officinalis, R. mucronata, B. cylindrica*	Coastal
10	Fisheries Research Station Puthuvypin	*A.officinalis, B. gymnorrhiza, B.cylindrica*	Coastal
11	Cherai	*A. officinalis, E. agallocha*	Coastal
12	Pallipuram	*A. officinalis, E. agallocha*	Landward
13	Sattar Island	*A. officinalis, E. agallocha*	Estuarine
14	Valappu	*B. gymnorrhiza, B. cylindrica, E. agallocha*	Coastal
15	Mulavukad	*B. gymnorrhiza, E. agallocha, R. mucronata*	Estuarine
16	Vallarpadam	*B. gymnorrhiza, E. agallocha R. mucronata*	Estuarine
17	LNG Puthuvypin	*A. officinalis, B. cylindrica, S. alba*	Coastal
18	Edakochi	*B. gymnorrhiza, R. mucronata, A.officinalis*	Estuarine
19	Mangalavanam	*B. gymnorrhiza, R. mucronata A.officinalis, B. sexangula*	Estuarine
20	Bolgatty	*A.officinalis, E. agallocha*	Estuarine
21	Panambukad	*B. gymnorrhiza, B. cylindrica*	Estuarine

Annexure 4.8 Major mangrove species and types of mangrove forest of Kottayam

No	Station	Major species	Type
1	Pallichira	*B. sexangula*	Estuarine
2	Kumarakom Bird Sanctuary	*B. sexangula, E. indica*	Estuarine
3	Thalayazham-Vaikom	*B. gymnorrhiza, A. aureum*	Estuarine

Annexure 4.9 Major mangrove species and types of mangrove forest of Alappuzha

No	Station	Major species	Type
1	Nerekadavu	*A. aureum, A. ilicifolius, S. caseolaris*	Estuarine
2	Kizhake mattel	*A. ilicifolius, R. mucronata, E. indica*	Estuarine
3	Naduke mattel	*R. mucronata, K. candel*	Estuarine
4	Padinjare mattel	*R. mucronata, R. apiculata*	Estuarine
5	Aroor North	*R. mucronata, B. cylindrica, B. gymnorrhiza*	Estuarine
6	Vaduthala	*R. mucronata, S. caseolaris, E. agallocha*	Estuarine
7	Chandiroor	*S. caseolaris, A. officinalis, R. apiculata*	Estuarine
8	Kudapuram Jetty	*R. mucronata, A.ilicifolius, A. officinalis*	Estuarine
9	Poochakal	*E. indica, B. sexangula, A.ilicifolius*	Estuarine
10	Anjuthuruth	*R. apiculata, K. candel, E. indica*	Estuarine
11	Anjilithuruth	*E. agallocha, B. gymnorrhiza*	Estuarine
12	Pallipuram	*E. indica*	Estuarine
13	Vayalar	*E. indica, B. sexangula*	Estuarine
14	Aroor- Keltron	*B. gymnorrhiza, B.cylindrica, E.agallocha*	Estuarine
15	Chandiroor West	*S. caseolaris, E. agallocha, R.apiculata*	Estuarine
16	Eramalloor	*S. caseolaris, R. apiculata, E. indica*	Estuarine
17	Kakkathuruthu	*R. mucronata, E. indica, R. apiculata*	Estuarine
18	Ottathuruthu	*R. mucronata, A. officinalis*	Estuarine
19	Thotappally	*S. caseolaris, R. mucronata*	Estuarine
20	Thuravoor	*E. indica, K. candel, A. ilicifolius*	Estuarine
21	Azheekal	*E. agallocha, B. cylindrica*	Estuarine
22	Ottamassery	*E. agallocha*	Estuarine
23	Padinjare manakadom - Thuravoor	*L. racemosa, E. agallocha*	Estuarine
24	Pallithodu	*L. racemosa, A.officinalis*	Estuarine
25	Neendakara	*E. agallocha, A. officinalis*	Estuarine
26	Ezhupunna	*R. mucronata, B. cylindrica*	Estuarine
27	Valiyazheekal	*A. marina, L. racemosa*	Estuarine
28	Valiyazheekal jetty	*A.marina, L. racemosa A. ilicifolius*	Estuarine
29	Kochide jetty	*A.marina, B. cylindrica*	Estuarine

Annexure 4.10 Major mangrove species and types of mangrove forest of Kollam

No	Station	Major species	Type
1	Ayiramthengu	*A. marina, A.alba, B. cylindrica, L. racemosa*	Estuarine
2	Ayiramthengu fish farm	*A.marina, A. corniculatum, R. apiculata*	Estuarine
3	Munrothuruthu	*E. agallocha, A. aureum*	Estuarine
4	Koyivila	*A. officinalis*	Estuarine
5	St Sebastian island	*R. mucronata, Ceriops tagal, L. racemosa*	Estuarine
6	Poothuruthu	*A.marina, A.alba, R. mucronata*	Estuarine
7	Veluthuruthu	*A.marina, R. mucronata*	Estuarine
8	Bhavanithuruthu	*R. mucronata, E.agallocha*	Estuarine
9	Kadanmoola	*R. mucronata*	Estuarine
10	Puthenthuruthu	*R.mucronata, A. marina*	Estuarine
11	Asramam	*R. mucronata, R. apiculata, S. caseolaris*	Estuarine

Annexure 4.11 Major mangrove species and types of mangrove forest of Thiruvananthapuram

No	Station	Major species	Type
1	Akkulam	*A. aureum*	Estuarine
2	Veli	*S. caseolaris, A.officinalis*	Coastal

0Annexure 6.1 The Pearson correlation analysis of hydrographic parameters

	Atm. temp	Water temp	pH	Eh	Cond	TDS	Turb	Sal	Alk	Thd	Ca hd	Mg hd	DO	BOD	CO_2	NO_3	NO_2	NH_4	PO_4	SiO_2	H_2S	DIN
Atm. temp	1																					
Water temp	0.666**	1																				
pH	-0.078	0.016	1																			
Eh	0.180*	0.166*	-0.377**	1																		
Cond.	-0.122	-0.086	0.270**	-0.163	1																	
TDS	-0.153	-0.121	0.298**	-0.153	0.973**	1																
Turb.	0.167*	0.083	-0.092	0.203*	-0.023	-0.045	1															
Sal.	-0.024	0.075	0.307**	-0.111	0.777**	0.739**	-0.071	1														
Alk	-0.142	-0.136	-0.119	-0.091	-0.018	-0.020	-0.012	-0.040	1													
Thd	-0.100	-0.063	0.041	-0.330**	0.445**	0.401**	0.002	0.382**	0.217**	1												
Ca hd	-0.177*	-0.061	0.007	-0.302**	0.400**	0.365**	-0.028	0.399**	0.247**	0.795**	1											
Mg hd	-0.073	-0.059	0.047	-0.315**	0.427**	0.384**	0.010	0.352**	0.195*	0.987**	0.688**	1										
DO	0.225**	0.383**	0.229**	-0.027	-0.008	-0.013	0.118	0.066	-0.128	-0.170*	-0.197*	-0.151	1									
BOD	0.018	-0.022	-0.036	0.088	0.100	0.106	0.025	0.132	-0.004	-0.019	0.014	-0.026	-0.233**	1								
CO_2	-0.214*	-0.210*	-0.070	0.181*	-0.017	0.043	-0.038	0.021	-0.065	-0.038	0.031	-0.054	-0.083	0.085	1							
NO_3	0.056	0.018	-0.019	-0.031	-0.071	-0.089	0.110	-0.117	-0.095	-0.216**	-0.238*	-0.196*	0.135	-0.098	0.011	1						
NO_2	0.057	0.175*	0.008	0.074	0.136	0.120	0.327	0.105	0.146	0.248**	0.188*	0.248**	0.035	-0.024	-0.097	0.111	1					
NH_4	0.019	0.200*	0.153	0.008	-0.111	-0.111	0.075	-0.076	-0.114	0.018	0.072	0.003	0.011	0.010	0.003	-0.053	0.125	1				
PO_4	-0.098	0.090	-0.045	-0.074	0.184*	0.161	0.146	0.256**	-0.058	0.266**	0.343**	0.228**	-0.153	-0.019	0.112	0.057	0.329**	0.193*	1			
SiO_2	0.092	0.024	0.109	-0.332**	-0.223**	-0.222**	0.038	-0.246**	0.058	0.018	0.094	-0.003	0.016	-0.053	-0.275**	0.108	0.125	0.038	-0.071	1		
H_2S	0.015	0.147	0.204*	-0.042	-0.071	-0.068	-0.052	-0.043	-0.044	-0.053	-0.014	-0.060	0.040	-0.045	-0.053	-0.059	-0.086	0.709**	-0.033	0.156	1	
DIN	0.022	0.203*	0.152	0.008	-0.113	-0.114	0.084	-0.080	-0.117	0.012	0.063	-0.003	0.017	0.005	0.003	-0.009	0.141	0.999**	0.199*	0.044	0.706**	1

Significance ** (0.01 level), * (0.05 level)

Annexure 6.2 Results of Principal Component Analysis (PCA) of the hydrographic parameters

Eigen values	Water	
Components	Eigen Values	%Variation
1	12.14	55.2
2	3.35	15.2
3	2.89	13.1
4	2.12	9.6
5	1.47	6.7

Annexure 6.3 Factor loading values obtained for the PCA of the hydrographic parameters

Variable	PC1	PC2	PC3	PC4
Atm. temp	-0.212	-0.218	0.020	0.212
Wat. temp	-0.137	-0.043	0.445	-0.259
pH	0.241	-0.092	0.031	-0.339
Eh	-0.270	0.112	0.028	0.138
Cond	0.270	0.155	0.061	0.065
Turb	0.037	0.225	-0.438	0.344
TDS	0.272	0.150	0.048	-0.031
Sal	0.253	0.192	0.142	0.107
T. hard	0.272	0.100	0.056	-0.004
Ca hard	0.280	0.092	0.062	0.018
Mg hard	0.269	0.103	0.052	-0.021
CO_2	0.246	-0.138	-0.025	-0.181
Alk	0.266	0.160	0.087	-0.018
DO	-0.164	0.394	-0.182	-0.154
BOD	0.126	-0.094	-0.421	-0.167
SiO_3-Si	0.066	-0.381	0.243	0.291
PO_4-P	0.191	-0.226	0.048	0.350
NO_3-N	0.017	0.124	0.229	0.528
NO_2-N	0.246	0.175	-0.167	0.191
NH_4-N	0.159	-0.399	-0.229	-0.012
DIN	0.167	-0.391	-0.224	0.013
H_2S	0.187	0.001	0.326	-0.088

Annexure 7.1 List of Bacillariophyceae species identified from mangrove habitats of Ernakulam

Family	Species	Family	Species
Fragilariaceae	*Asterionella* spp.	Pleurosigmataceae	*Gyrosigma* spp.
	Lichmophora spp.		*Pleurosigma* spp..
	Fragillaria spp.	Diploneidaceae	*Diplonis* spp.
Eunotiaceae	*Eunotia major*		*Diplonis littoralis*
	Eunotia spp.	Pinnulariaceae	*Pinnularia* spp.
Bacillariaceae	*Nitzschia closterium*		*Pinnularia rectangulata*
	Cylindrotheca sigmoidia	Cymbellaceae	*Cymbella* spp.
	Cylindrotheca gracilis	Catenulaceae	*Amphora* spp.
	Nitzschia navicularis		*Amphora ovalis*
	Nitzschia sigma		*Amphora turgidis*
	Nitzschia palea	Rhizosoleniaceae	*Rhizosolenia* spp.
	Nitzschia spp.	Coscinodiscaceae	*Coscinodiscus eccentricus*
	Pseudonitzschia spp.		*Coscinodiscus marginatus*
	Cerataulina spp.		*Coscinodiscus nodulifera*
	Bacillaria paradoxa		*Coscinodiscus radiatus*
	Ankistrodesmus spp.		*Coscinodiscus* spp.
	Achnanthus spp.	Hemidiscaceae	*Hemidiscus* spp.
Cocconeidaceae	*Cocconeis* spp.	Stephanodiscaceae	*Cyclotella* spp.
Surirellaceae	*Campylodiscus* spp.	Thalassiosiraceae	*Thalassiosira* spp.
	Surirella straiatula	Melosiraceae	*Melosira* spp.
	Surirella spp.	Hemiaulaceae	*Eucampia* spp.
Naviculaceae	*Navicula* spp.	Triceratiaceae	*Triceratium* spp.
	Navicula carinifera	Biddulphiaceae	*Biddulphia* spp.
Amphipleuraceae	*Amphiphora* spp.	Chaetocerotaceae	*Chaetoceros* spp.
	Amphiphora angustata		

Annexure 7. 2 List of other microphytoplankton identified from mangrove habitats of Ernakulam

Class	Family	Species	Class	Family	Species
Myxophyceae	Merismopediaceae	*Merismopoedia* spp.	Chlorophyceae	Oedogoniaceae	*Oedogonium* spp.
	Nostocaceae	*Nostoc* spp.		Selenastraceae	*Ankistrodesmus* spp.
		Anabaena spp.		Chlorellaceae	*Chlorella* spp.
	Oscillatoriaceae	*Oscillatoria* spp.			*Actinastrum* spp.
		O. limosa		Chlamydomonaceae	*Chlamydomonas* spp.
	Phormidiaceae	*Arthrospira* spp.		Zygnemataceae	*Spirogyra* spp.
		Gleotricha spp.		Desmidiaceae	*Micrasterias* spp.
	Spirulinaceae	*Spirulina* spp.		Hydrodictyaceae	*Pediastrum duplex*
Euglenophyceae	Euglenaceae	*Euglene* spp.			*P. simplex*
		E. acus			*Tetraedron* spp.
		E. limnophila		Scenedesmaceae	*Scenedesmus spp.*
		E. proxima			*S. acuminatus*
		Trachelomonas spp.			*S. carinatus*
		Phacus spp.			*Tetrastrum* spp.
		P. curvicauda		Oocystaceae	*Oocystis* spp.
Dinophyceae	Ceratiaceae	*Ceratium spp.*	Charophyceae	Conjugatophycaeae	*Closterium* spp.
		Protoperidinium spp.			
		Peridinium spp.			

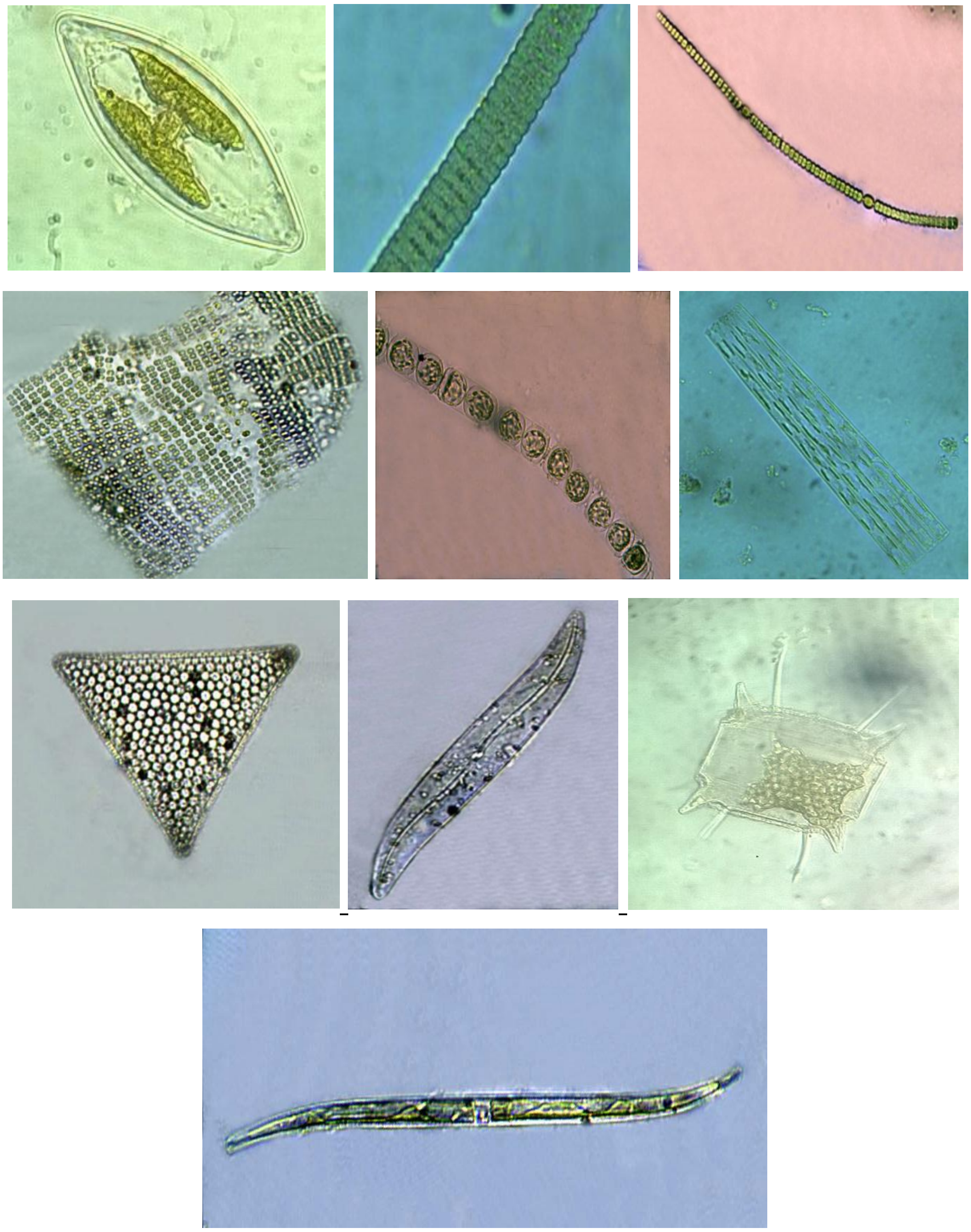

Plate 7.1 Microphytoplankton identified; (a) *Navicula* spp. (b)*Oscillatoria* spp.(c)*Anabeana* spp.(d) *Merismopedia* spp. (e) *Melosira* spp.(f) (g) *Triceratium* spp.(h) *Pleurosigma* spp.(i)*Biddulphia* spp.

Annexure 7.4 List of microphytoplankton species recurrently occurring in all seasons in the mangrove stations of Ernakulam during 2010-12 period

Class	Species	1MN	1Post MN	1Pre MN	2MN	2Post MN	2Pre MN
Bacillariophyceae	*Asterionella* spp.	+	+	+	+	+	+
	Lichmophora spp.	+	+	+	+	+	+
	Fragillaria spp.	-	-	+	-	-	+
	Eunotia spp.	+	+	+	+	+	+
	Eunotia major	+	-	+	-	-	+
	Nitzschia closterium	+	+	+	+	+	+
	Cylindrotheca sigmoidia	+	+	+	+	+	+
	Cylindrotheca gracilis	+	+	+	+	+	+
	Nitzschia navicularis	+	-	+	+	-	+
	Nitzschia sigma	+	+	+	+	+	+
	Nitzschia palea	+	+	+	+	+	-
	Nitzschia spp.	+	+	+	+	+	+
	Pseudonitzschia spp.	+	+	-	+	+	+
	Cerataulina spp.	+	+	+	+	-	+
	Bacillaria paradoxa	+	+	+	+	+	+
	Ankistrodesmus spp.	+	-	-	+	-	+
	Achnanthus spp.	+	+	-	+	-	+
	Cocconeis spp.	+	+	-	+	+	+
	Campylodiscus spp.	+	+	-	+	+	+
	Surirella straiatula	+	+	+	+	+	+
	Surirella spp.	+	+	+	+	+	+
	Navicula spp.	+	+	+	+	+	+
	Navicula carinifera	+	+	+	+	+	+
	Amphiphora spp.	+	+	+	+	+	+
	Amphiphora angustata	+	+	+	+	+	+
	Gyrosigma spp.	+	+	+	+	+	+
	Pleurosigma spp.	+	+	+	+	-	+
	Diploneis spp.	+	+	+	+	+	+
	Diplonis littoralis	+	+	+	+	-	+
	Pinnularia spp.	+	+	+	+	+	+
	Pinnularia rectangulata	+	-	-	+	-	+
	Cymbella spp.	+	+	+	+	+	+
	Amphora spp.	+	+	+	+	+	+
	Amphora ovalis	+	+	-	+	-	+
	Amphora turgidis	+	+	-	-		+
	Rhizosolenia spp.	+	-	-	+	-	+
	Coscinodiscus eccentricus	+	+	+	+	+	+
	C. marginatus	+	+	+	+	-	+
	C. nodulifera	+	+	+	+	-	+
	C. radiatus	+	+	+	+	+	+
	Coscinodiscus spp.	+	+	+	+	+	+
	Hemidiscus spp.	+	+	+	+	+	+
	Cyclotella spp.	+	+	+	+	+	+
	Thalassiosira spp.	+	+	+	+	+	+
	Melosira spp.	+	+	+	+	+	+

	Eucampia spp.	+	+	+	+	-	+
	Triceratium spp.	+	+	+	+	+	+
	Biddulphia spp.	+	+	+	+	+	+
	Chaetoceros spp.	+	-	-	+	-	+
	Eucampia spp.	+	+	+	+	+	+
Myxophyceae	*Merismopoedia* spp.	+	+	+	+	+	+
	Nostoc spp.	+	+	+	+	+	+
	Anabaena spp.	+	+	-	+	+	+
	Oscillatoria spp.	+	+	+	+	+	+
	Oscillatoria limosa	+	-	-	+	+	+
	Arthrospira spp.	+	+	+	+	+	+
	Gleotricha spp.	-	-	-	-	-	+
	Spirulina spp.	+	+	+	+	+	+
Chlorophyceae	*Oedogonium* spp.	+	-	+	+	+	+
	Ankistrodesmus spp.	+	+	+	+	-	+
	Chlorella spp.	+	-	-	+	-	-
	Actinastrum	+	+	-	+	-	+
	Chlamydomonas spp.	-	-	-	-	-	+
	Spirogyra spp.	+	+	+	+	+	+
	Micrasterias spp.	+	+	+	-	-	+
	Pediastrum duplex	+	+	-	+	-	+
	Pediastrum simplex	+	+	+	+	+	+
	Tetraedron spp.	-	+	-	-	+	+
	Scenedesmus acuminatus	+	+	+	+	+	+
	Scenedesmus carinatus	+	-	+	-	+	+
	Scenedesmus spp.	+	+	-	+	-	-
	Tetrastrum spp.	-	-	-	-	-	+
	Oocystis spp.	+	-	-	-	-	+
	Chodatella spp.	+	-	-	-	-	+
Euglenophyceae	*Euglena acus*	+	+	-	-	-	+
	Euglena limnophila	+	+	+	+	+	+
	Euglena proxima	+	-	-	-	+	+
	Euglene spp.	+	+	-	+	+	+
	Trachelomonas spp.	+	-	-	-	-	-
	Phacus spp.	+	-	-	+	+	+
	Phacus curvicauda	+	-	-	+	-	+
Charophyceae	*Closterium* spp.	+	-	-	-	-	+
Dinophyceae	*Ceratium* spp.	-	+	+	+	-	+
	Protoperidinium spp.	+	+	+	+	+	+
	Peridinium spp.	+	-	-	-	+	+
TOTAL		79	63	55	69	52	81

Table 7.5 The Pearson correlation analysis of Chlorophyll pigments during 2010-12 period

	W temp	Sal.	pH	Turb.	DO	BOD	NO_2	NO_3	NH_4	PO_4	SiO_2	H_2S	Chl. a	Chl.b	Chl.c	Carot.	Phaeo.	GPP	NPP
W temp	1																		
Sal.	-	1																	
pH	-	.307**	1																
Turb.	-	-	-	1															
DO	.383**	-	.229**	-	1														
BOD	-	-	-	-	.233**	1													
NO_2	.175*	-	-	.327**	-	-	1												
NO_3	-	-	-	-	-	-	-	1											
NH_4	.200*	-	-	-	-	-	-	-	1										
PO_4	-	.256**	-	-	-	-	.329**	-	.193*	1									
SiO_2	-	.246**	-	-	-	-	-	-	-	-	1								
H_2S	-	-	.204*	-	-	-	-	-	.709**	-	.192*	1							
Chl.a	-	-	-	-	-	-	-	-	-	-	-	-	1						
Chl.b	-	-	-	-	-	-	.259**	-	.200*	-	-	.192*	-	1					
Chl.c	-	-	-	.172*	-	-	.381**	-	-	-	-	-	-	.588**	1				
Carot.	-	-	-	-	-	-	.214**	-	-	-	-	-	.843**	-	.433**	1			
Phaeo.	-	-	-	-	-	-	.185*	-	-	.233**	-	-	.789**	.239**	.194*	.644**	1		
GPP	.273**	.179*	-	-	.480**	-	-	.187*	-	-	-	-	-	.196**	.189*	-	.185*	1	
NPP	.235**	-	-	-	.169*	-	-	-	-	-	-	-	-	-	-	-	-	.697**	1

Significance ** (0.01 level), * (0.05 level)

LIST OF PUBLICATIONS

Papers Published

Sreelekshmi S., **Preethy C.M.,** Varghese R., Joseph P., Asha C.V., Nandan S.B., Radhakrishnan C., 2018. Diversity, stand structure and zonation pattern of Mangroves in Southwest coast of India, Journal of Asia-Pacific Biodiversity, doi: 10.1016/j.japb.2018.08.001.

Sreelekshmi, S., Rani Varghese, Philomina Joseph, **Preethy, C. M.** and Bijoy Nandan, 2017.Structural Characteristics and Zonation Pattern of Mangroves from a Ramsar site, on the South west coast of India**.**Indian Forester, 143 (2):96-100.

Sreelekshmi, S., **Preethy, C. M.,** Philomina Joseph, Rani Varghese and Sivasankaran Bijoy Nandan, 2017. Mesozooplankton community structure in a degrading mangrove ecosystem of Cochin coast, India. Lakes and Reservoirs: Research and Management, 20:1-14.

Rani, V., Sreelekshmi, S., **Preethy, C. M.** and Bijoy Nandan, S., 2016. Phenology and Litterfall Dynamics Structuring Ecosystem Productivity in a Tropical Mangrove stand on South west coast of India. Regional studies in Marine Sciences, 8:400-407.

Book Published

Bijoy Nandan S., Sreelekshmi S., **Preethy C.M.,** Rani Varghese, Philomina Joseph (eds.). 2015. Manual on Mangroves. Directorate of Public Relations and Publications, CUSAT, Kochi, India.

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