ECOPHYSIOLOGY OF SOME SPECIES OF MANGROVES OF KERALA

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By

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CERTIFICATE

This is to certify that the thesis entitled **"Ecophysiology of Some Species of Mangroves of Kerala"** is an authentic record of the research work carried out by **Mrs. Sheela Francis K.,** under my supervision in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** in Botany, University of Calicut. This work or part thereof has not been presented before for the award of any other degree.

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DECLARATION

I hereby declare that the thesis entitled **"Ecophysiology of Some Species of Mangroves of Kerala"** submitted by me in the partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy** in Botany, University of Calicut, has not been submitted before any other degree.

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CONENTS

Dedicated to

My Beloved Father

INTRODUCTION

Mangroves are halophytes which grow in saline marshy places. The word mangrove is formed by two words – the Portuguese “Mangue” (meaning tree bush) and the English – “Grove”. Macnae (1968) coined a new name ‘mangal’ for mangrove community and retained the term‘mangrove’ for individual species.

The term mangrove refers to an ecological group of evergreen plant species belonging to different families, but possessing marked similarity in their physiological characteristics and structural adaptations. These are salt tolerant forest ecosystems of the inter-tidal regions along the coastal lines. Mangroves consist of a complex of plant communities, fringing sheltered tropical shores and estuaries. Such communities usually comprise of trees, mostly species of the family Rhizophoraceae (Aksornkoae, 1993).

Mangroves are distinguished by their peculiar morphology and physiology. Mangroves are a prominent component of coastal vegetation, occupying flood plains, margins of bays and tidal rivers and in the shores of all these. Uniqueness of mangrove ecosystem is that its biota is constantly under physiological stress caused by extreme environmental conditions. Despite the extreme conditions prevailing, mangroves have successfully colonized their habitats by developing morphological, reproductive and

physiological adaptations like pneumatophores, stilt roots, prop roots, knee roots and viviparous germination which facilitate their growth in aquatic environment (Tomlinson, 1986).

Mangrove forests are regarded as one of the most productive and biodiverse wetlands on earth, as an important natural reserve of biological diversity. The mangrove ecosystem represents a bridge between terrestrial and marine ecosystems. It constitutes an extremely delicate and unique ecosystem mainly found along the inter-tidal regions of the tropics and subtropics. In the mangroves, tides and coastal currents bring unremitting variations, and the plants and animals have to adapt themselves continuously to changing chemical, physical and biological characteristics of their environment. Within this ecosystem, individual plants, animals, soil microbial populations and the physical environment are linked by processes by which a continuous exchange and assimilation of energy occurs (Singh and Odaki, 2004).

The coastline in the tropical and sub tropical regions is fringed with a strip of swampland which is inundated by high tide with marine or brackish waters. They are well adapted to the salty conditions as they can prevent high concentrations of salt entering the roots and can secrete excess salt from their leaves. Mangrove swamps are influenced strongly by tides. Incoming tides

import nutrients to the system, and tides are also responsible for dispersing seeds (Chapman and Reiss, 1992).

In a coastal area, a natural mangrove belt exerts protection against encroachment of sea, destructive forces of tides and storms. Its ability to stabilize the coastal area against long-term climatic fluctuations and sea level rise is now globally accepted (Mohanan, 1999). The role of mangroves in soil conservation is very significant. The high nutrient status of mangrove areas resulted by the redistribution of nutrients through the incoming tidal waters and seasonal floods, make mangrove ecosystem a most fertile and productive ecosystem. As a habitat of a variety of organisms, mangrove shelters specialized group of plants and animals which cannot survive outside. Therefore, mangroves not only ensure maintenance of essential ecological process but also act as sanctuaries to protect the genetic diversity of various organisms. Many of the commercially important fishes and crustaceans adopt mangrove ecosystem as nursery, feeding and spawning place.

The mangroves are with multiple benefits to common people. It provides a variety of products directly extracted from mangroves like timber, construction poles, firewood, charcoal, tannin, etc. Mangroves are valued greatly as fodder. Seeds of some mangrove plants are edible (eg. *Avicennia*). Mangroves are also of recreational and educational values and are ideal spots for environmental education.

The mangroves are mostly restricted to the tropical and subtropical zones, on shelter shore lines covered with soft inter-tidal sediments. These complex ecosystems are found between the latitudes of 30^0 North and 38^0 South, along the tropical coast of Africa, Australia, Asia and America. Mangroves include approximately 16 to 24 families and 54 to 75 species. Mangroves are well distributed in Asia, North America, Africa, Australia and New Zealand. The greatest diversity of mangrove species exists in South-East Asia. A world wide, natural division of mangrove vegetation into two groups - the old world mangroves and the new world mangroves has been reported by Chapman (1976). The old world mangroves extend from East Africa across the Indian Ocean to Australia, thence northwards to the Philippines and Southern Japan and Southwards to New Zealand. The new world mangroves are restricted to American and West Indies shores. A greater variety of species exist in the Indian and Pacific Ocean regions, suggesting that the mangroves probably originated there.

In India, the total area of mangroves is estimated to be 6740sq.km (MoEF, 1987), which is about 7% of the world's mangrove area. The extent of mangroves along the East coast of India is larger than those along the West coast. Banerjee *et al.* (1989) and Naskar (2004) studied the mangroves in India and provided detailed manuals. West Bengal has the biggest mangrove formation and about 4200sq.km support mangroves (Chand Basa, 1992). The mangrove ecosystem of the Sundarbans (West Bengal) comprises about 65%

and the remaining 35% mangals are distributed in the bay islands (Andaman and Nicobar islands) and coast lines of eight states of India. A detailed account of mangroves in India was provided by Blasco (1975).

Mangroves in Kerala are highly fragmented and confined mostly to the estuaries of major rivers, lagoons, backwaters and creeks along the coastal belt. It is said that Kerala coasts once supported about 700sq.km of mangroves and at present the area has dwindled considerably. Mohanan (1999) estimated mangroves in Kerala coast to be less than 50sq.km, existing in discrete and isolated patches.

Present investigation involves the ecophysiological study of mangroves of Thrissur and Ernakulam districts of Kerala. In Thrissur district, Chettuwai estuary is the main area of mangroves. The rivers Chettuwaipuzha and Karanjirapuzha join to form the Chettuwai estuary which supports a good mangrove patch near Pattekkat and tidal flat further inside. The flora is rich in *Acanthus, Aegiceras, Avicennia, Bruguiera* and *Rhizophora.* In Ernakulam district mangroves occur in several places and the main developments are in the islands of Vypin, Panangad, Kumbalangy and Puthuvyppu. The mangrove formation of Puthuvyppu is the main area selected in the present study. It is very close to the sea front. Here the flora includes *Acanthus, Avicennia. Bruguiera, Excoecaria, Rhizophora* and *Sonneratia* .

The halophytic mode of life of mangroves is very interesting. The mechanism of salt tolerance in mangroves, its adaptations for surviving in a saline habitat, anatomical and physiological characteristics are peculiar. The substrate of mangrove ecosystem consists of soft mud. It is richly organic with peat made up of accumulated underground portions of mangrove root system, fallen branches, etc. The structure of mangrove ecosystem is determined by the physical and chemical factors of the habitat. The limit of tolerance of each species is determined by its specific environmental requirements such as salinity, temperature, soil feature, pH, electrical conductivity, etc. Thus at the sea front *Avicennia* and *Sonneratia* are the pioneers. There are various morphological and physiological adaptations which help the mangroves to adjust the changes in environment and stress due to salinity. The present investigation intends to analyze the morphological, anatomical, physiological, and biochemical characteristics of the mangroves.

Seasonal variations in Kerala due to monsoons - South West monsoon during June-September and North East monsoon during October-December are well marked. The seasonal variations affect the physiological and biochemical status of the mangroves. The environmental factors of mangrove ecosystem, mainly salinity cause ‘physiological drought’ in mangroves. As a result, they develop xerophytic adaptations like succulent leaf, thick cuticle, epidermal outgrowth, sunken stomata, etc. So a detailed anatomical study is included in this work.

Biochemical studies carried out in the present investigation include estimation of proline and other organic metabolites in the vegetative parts of the mangrove species. Stewart and Lee (1974) highlighted the importance of proline in halophytes. Accumulation of compatible solutes under salt stress was thought to be a basic process of adaptation (Singh and Odaki, 2004). Presence of tannin is another important characteristic of mangroves. So, seasonal variation in tannin content of mangroves is also being investigated. Similarly, variation in epicuticular wax content is examined to assess the impact of seasonal variations on plants. Seasonal changes in chlorophyll content, chlorophyll fluorescence, dry weight and moisture content percentage and similar aspects of mangrove flora are to be investigated in the present study.

The major threat to mangroves is the exploitation of it for timber, firewood, poles and cattle feed by human beings. This leads to a great loss of mangrove biodiversity. In Kerala the conversion of mangrove swamps into fish farm cause great ecological damage. Major portion of the vegetation has already been converted for alternate land use like agriculture and aquaculture. Loss of mangrove biodiversity may be due to anthropogenic mangrove destruction, land reclamation for settlement, solid waste disposal from industries which cause pollution in the mangrove ecosystem, development of ports and fishing harbours, etc. Retting of coconut husk is also causing degradation of mangroves. In Ernakulam district several mangrove sites are

being converted to aqua-farms for culturing prawns. All these human activities cause a great loss to mangrove areas in Kerala.

Therefore conservation of mangroves is highly essential. Priority should be given to biodiversity conservation and ecosystem restoration in mangrove area. Creating proper awareness among the public seems to be the most important aspect for the conservation of mangroves in Kerala. This can be achieved through education, media and through the activities of NGOs. Large scale afforestation, control on developmental activities in the mangrove areas, eco-tourism etc. give better results in the conservation of mangroves.

So the present study was conducted to get proper knowledge regarding the mangrove flora and fauna. Further, a complete study of morphological, anatomical, physiological and ecological and biochemical aspects will help us to know more about the nature of mangrove vegetation. This will help us to suggest the remedial measures needed for proper conservation of mangrove ecosystem in Kerala.

REVIEW OF LITERATURE

Plant ecophysiology is an experimental science that seeks to describe the physiological mechanisms that underlie ecological observations.

According to Waisel (1972) the pH of saline soils is usually close to neutrality (pH - 7.0 to 8.5), that of saline - sodic soils is close to pH 8.5, where as sodic soils have a high pH (>9.0). The pH of the growth medium affect the nutrition of plants in several ways: pH changes the ion species present in the growth medium. Low pH conditions tend to decrease dissociation of organic acids within plant cells.

Joshi (1982) in his work on 'Ecophysiological aspects of some salt marsh halophytes' included analysis of soil samples collected during different seasons and showed that pH of saturation extracts varies from 7.4 to 8.3. The salinity of the habitat was at a minimum during monsoon but increased during the dry period i.e., Summer through Winter. Exchangeable Sodium percentage and Sodium absorption ratio, important factors affecting swelling and dispersion of clay particles were found to be extremely high in all the cases. These observations suggest that the soils have saline - alkaline characteristics. The soils inhabited by halophytes have a wide range of texture. Indian halophytes occur on sandy loam to silty loam soils.

According to Aksornkoae (1993) mangrove soils are formed by the accumulation of sediment derived from coastal or river bank erosion or eroded soils from higher areas transported down along rivers and canals. The degradation of organic matter deposited through time is also part of mangrove soils. Results indicate that soil characteristics are major factor limiting growth and distribution of plants in mangroves. Species composition and distribution of mangroves are also related to soil characteristics.

Sengupta and Chaudurin (1993) in their study on Physico-Chemical properties of soils of Sundarban explained that levels of soil salinity based on pH, electrical conductivity and concentration of soluble anions and cations varied according to the eco-successional changes in direct relationship of salinity with the soil formation and saline water inundation. The organic carbon status of the soils also differed with the eco-successional stages. The formative mangrove swamp soil had a very low organic carbon status while soils from old formation mangrove soil had a higher value.

According to Aksornkoae (1993) moisture content of mangrove soil is between 43% and 196% by dry weight of the soil. Moisture content of deeper soil fluctuates between 29.5% and 98.2% by soil dry weight. The moisture content of the clay in the deeper soil layer underneath *Rhizophora* is more than that of the surface soil.

Light is vital for photosynthesis and growth process of green plants. In general mangrove plants are long-day plants and require high intensity of full sunlight. Light also affects the flowering and germination of mangrove species. Temperature is of importance to physiological processes such as photosynthesis and respiration. Periods of intense physiological stress may be experienced when high temperatures are combined with full sunlight and prevailing winds giving rise to high evapotranspiration and increased surface salinity due to capillary uptake (Aksornkoae, 1993).

According to Lugo (1980) a saline environment is required for stable mangrove ecosystems. Mangroves are facultative halophyte i.e., they can often survive though not necessarily thrive in non-saline habitats. It is reported that the growth of many halophytes is depressed without NaCl in the external environment (Flowers *et al.* 1977, Greenway and Munns, 1980). Limited amounts of NaCl is required in the external medium for the maximum growth of the mangroves.

Salinity and interstitial water salinity are important to growth rate, survival rate and zonation of mangrove species (Aksornkoae, 1993). Mangroves usually exist and thrive in estuaries with a range of salinity between 0 to 30 ppt and interstitial water salinity between 10 to 30 ppt. He also proved that several mangrove species can grow in very high salinity. In Australia *Avicennia marina* and *Excoecaria agallocha* can grow in areas

where salinity is as high as 85 ppt. *Avicennia officinalis* can grow in areas with a maximum salinity of 63 ppt. If the salinity is less than 28 ppt. the growth of mangrove plants will decline.

Chandrashekhar and Sandhyarani (1996) reported that higher salinity values were recorded for coastal soils in all the months compared to interior soils. The salinity was lowest in January and highest in March for both the soils. There was a gradual increase in salinity from January to March and then decrease in both the cases. According to those authors the salinity of the coastal soils was higher compared to interior soils. The increase in salinity level upto March may be due to decreased water content in both the soils. Decreased salinity from April onwards was because of leaching of salt ions as a result of precipitation.

Waisel (1972) proved that salinity at higher concentrations may have affected the turgidity of the leaf cells. The assimilation of certain essential nutrients such as N_2 and may have disturbed the hormonal balance of the plants so severely that salinity effects the time and rate of germination, the size of the plant, branching, leaf size and species zonation. Succulence is one of the most common features of halophytes, which is often considered to be an adaptation to reduce the internal salt concentration (Sen and Rajpurohit, 1982). Numerous structural changes ascribed to salinity are increase of succulence, changes in number and size of stomata, thickening of the cuticle,

inhibition of differentiation, extensive development of tyloses, earlier occurrence of lignification, changes in diameter and number of xylem vessels, (Waisel, 1972).

Salinity alters many biochemical reactions in plants as a result of which many intermediate products are formed. Free aminoacids represent a group of such compounds in the plants subjected to salinity. Proline always occurs in large quantities (Stewart and Lee, 1974).

According to Cherian *et al.* (1999) increase in salinity stimulated production of fresh biomass. However, drymass did not show significant enhancement. Water contributed to a large proportion of increase in fresh mass. *Avicennia marina* gave better growth in the presence of NaCl salinity. Considerable enhancement in freshmass was noticed with increase in salinity. In leaf and shoot both fresh and drymass increased with increase in salinity. The increase in fresh weight in leaf and shoot was mainly due to an increase in tissue water content.

Meloni *et al.* (2004) proved that salinity caused reduction on root and shoot dry biomass only at the higher NaCl concentration. NaCl concentration of 600 m mol L^{-1} decreased shoot and root biomass by 65% and 35% respectively. Increased root/shoot ratio appears to be an adaptation to salinity resulting in a more efficient water and nutrient uptake under saline stress.

Dissolved oxygen is extremely important for the existence of the plants and animals in mangroves, especially in the process of respiration and photosynthesis. A study conducted by Aksornkoae (1978) in mangroves at Amphoae Khlung, Chanthaburi, Thailand, indicated that the dissolved oxygen concentration outside mangroves (4.4 mg/l) was higher than that within the mangroves (1.7 to 3.4 mg/l). It also plays an essential part in the decomposition of litter in the mangrove ecosystem. Oxygen concentration varies over 24 hours, lowest at night and highest during the day. Mangrove plant with pneumatophores need dissolved oxygen for their respiration. In some areas where dissolved oxygen is only 1.0 to 2.0 mg/l, aquatic organisms can still survive because they can adapt themselves to low oxygen content. Dissolved oxygen concentrations in mangroves varies according to areas and zonation of plants.

It was found that areas outside and inside mangroves had $4.9mgl^{-1}$ and $2.4mgl^{-1}$ dissolved oxygen, respectively. The dissolved oxygen in the coastline, the mouth of bays and rivers and streams ranged between 3.8 mgl^{-1} to 7.3 mgl^{-1}. However, dissolved oxygen concentration varies according to time, season and richness of plants and aquatic organisms in mangroves (Aksornkoae, 1993).

According to Kar and Satpathy (1995) mangrove forests serves as a link between terrestrial and marine ecosystems. They receive a continuous

supply of inorganic nutrients from the adjacent land mass and release dead organic matters to the sea through rivers and estuary. Best development of the mangroves are found at locations with deep well aerated soils, rich in organic matter and low in sand, usually in estuaries. Most species of mangroves have special adaptations, such as vivipary, high salt tolerance, ability to withstand tidal submersion, pneumatophores, succulence and salt excreting glands.

The composition of mangrove forest encompasses a variety of plants including trees, epiphytes, lianas and algae. Almost all are evergreen, possess similar physiological and structural adaptations and are salt tolerant. Soil type is one of the main factors for mangrove zonation. *Rhizophora* grows on mud flats and *Avicennia marina* and *Bruguiera gymnorrhiza* on sandy soils (Singh and Odaki, 2004).

Adaptation of mangrove plants - Mangrove forests are constantly exposed to high salinity, strong winds and high light intensity. In order to survive under these harsh conditions mangroves have many adaptations. The external and internal structure of the stem, leaf, flower and fruit have undergone considerable changes to suit the environment. Leaves are succulent eg. *Rhizophora* and *Sonneratia*. This feature is to facilitate water storage in the mesophyll. Leaves of *Rhizophora* and *Bruguiera* are succulent and shiny white, those of *Avivennia* are thinner and covered with a number of hairs on

the abaxial side. Leaves are hypostomatic. *Rhizophora* and *Bruguiera* have sunken stomatas. In *Avicennia* stomatas are raised with tricellular peltate hairs. A thick cuticle develops on the leaves of all mangrove species. Leaves are dorsiventral with palisade parenchyma. Underneath the adaxial epidermis are hypodermal cells, the largest cells in *Rhizophora* and smallest in *Avicennia.* Sclereids common in spongy parenchyma (Das and Ghose, 1996).

Most species possess a specialised root system such as pneumatophores in *Avicennia* and *Sonneratia*, knee-root in *Bruguiera* and prop roots in *Rhizophora* and *Acanthus*. These root structures are adaptations for physical anchoring and aeration for the plant, since soil aeration is poor in mangroves (Aksornkoae, 1993).

According to Das and Ghose (1996), mangrove leaves possessed thick cuticle. Colourless, non-assimilatory water storage tissue is hypodermal in dorsiventral leaves but is deep seated in the mesophyll region of isobilateral leaves. Terminal tracheids at vein endings are commonly found in many species. Branched sclereids present in some species. Mucilage cells, tannin cells and laticifers occur in hypodermal zone in some species. Crystalliferous cells are common.

All the above characters may be interpreted as adaptation to climate and habitat. The presence of water storage tissue and terminal tracheids

causes leaf succulence with high water content. According to Zimmermann (1983) both sclereids and tracheids are involved in capillary water storage. Tomlinson (1986) suggested that in addition to water storage, sclereids might also provide mechanical support to leaves with diminished turgor or discourage herbivores. The coriaceous nature of many mangrove leaves is due to the presence of sclereids. Waisel (1972) assumed that thick cuticle of mangrove leaves is an adaptive feature.

Ecophysiology of Salt excretion

Salt excretion is a common phenomenon in various halophytic plant genera. It is found in the mangrove species *Acanthus, Aegiceras, Avicennia* and *Sonneratia* (Waisel, 1972). *Aegiceras* regulate its salt content by secreting salt through glands on their leaves. A gland consists of a large number of abutting secretory cells and a single, large basal cell. The secretory cells and basal cells are joined by well defined plasmodesmata (Cardale and Field, 1971).

Salt excretion by salt glands of halophytes is claimed to be the fastest ion transport system in plants. (Pollak and Waisel, 1979). These authors reported that Sodium excreted from *Aeluropus* leaves is more than any other cation. According to Waisel (1972) the ecological logic that stands beyond the selective properties of excretion out of leaves of *Aeluropus* is self evident and is common also to other excreting plants. In all the cases the salt glands have

been initiated an early stage in the development of the leaf and their differentiation was completed much earlier than the differentiation of various other leaf tissues. Cells of the salt glands differ in many respects from the surrounding epidermal or parenchymatous cells.

Salt secretion is an efficient mechanism which prevents accumulation of large quantities of Na^+ and Cl^- inside the tissues. It is an adaptive characteristic of non-succulent halophytes growing in saline habitats. Succulents release accumulated salts by shedding leaves or other fleshy tissues (Waisel, 1972). He also proved that regulation of salt content of shoots is by transpiration. Salts are continuously transported into plant shoots via the transpiration stream. Secretion of ions by special glands is the best known mechanism for regulating mineral content of the plant shoots. Salt secretion is a common phenomenon in various halophytic plant genera. Three fundamental features determine the effectiveness of salt glands in removing salt excesses a) their structure, location and abundance, b) their mechanism and c) their physiological and ecological significance.

Ecophysiological significance of salt recretion of *Avicennia* is explained by Waisel *et al.* (1986). The secretion mechanism is capable of removing only 40% of the absorbed salts. The quantitative contribution of the salt glands to the removal of excess salts is relatively small. The salt resistance of *Avicennia marina* is based upon three different mechanisms

1) Salt avoidance - where the roots have low permeability to salt. This is the most important mechanism 2) Salt tolerance - the capability to preserve normal metabolic activity even in the presence of high intracellular salt levels 3) Salt evasion-secretion of some of the penetrating ions, but retention of others. The magnitude of salt secretion in *A. marina* does not yield a quantitative solution to the problem of excess accumulation of salt. Salt secretion may contribute to the mineral balance of *Avicennia* leaves in a qualitative way, by changing the ratio between the nutrition ions and interfering ones (Waisel, 1972).

According to Aksornkoae (1993) the function of salt glands is to regulate the salt balance in the plant, through secretion. Salt glands control the salt balance in *Avicennia* by secreting excess salt from the leaves. The glands are sunken in the upper surface of the leaf because there is no trichome to protect them on this side. The abaxial salt glands are conspicuous because they are protected by dense hairs.

Most species of mangroves possess a specialised root system such as pneumatophores in *Avicennia* and *Sonneratia*, knee-roots in *Bruguiera* and prop roots in *Rhizophora*. These root structures are adaptations for physical anchoring and aeration for the plant since soil aeration is poor in mangroves. Mangrove root system contain a large amount of gas space (Chapman, 1976) which is reported to act as a pathway for molecular oxygen for respiring roots

(Curran, 1985). According to Hovendan and Allaway (1994) pneumatophore root caps are heavily suberized which are not close to aerenchymatous tissue. The edges of the root cap curl upwards away from the root and some of the cells which are sloughed from the root cap and adhere to the surface. Horizontal structures are present on all actively growing pneumatophores of *Avicennia marina*. Lenticels and horizontal structures are responsible for gaseous exchange.

Vivipary

Propagules of certain genera contain viviparous seeds which germinate while still attached to the parent tree. When the ripe propagules fall from the parent plant, the seedlings germinate rapidly. Air spaces in the propagules or germinating seedlings are modified to facilitate floating for dispersal by water. These can be found in *Rhizophora*, *Bruguiera, Avicennia* and *Aegiceras*. The propagules of all mangroves are buoyant and are able to disperse by water (Tomlinson, 1986; Aksornkoae, 1993).

Protein

High concentrations of soluble salts in the root medium influence plant metabolism in a variety of ways. Under water stress conditions, protein breakdown is accelerated. Salinity is also known to reduce the synthesis of protein. NaCl decreases protein synthesis and increases its hydrolysis in many crop plants.

Waisel (1972) proved the effect of salinity on metabolism of proteins. High ion content in plant cells is likely to induce changes in protein hydration, because ion effect the nature of the hydration shell which surrounds the protein molecules. Protein content of various plant tissues declined under drought or saline conditions, on account of increased proteolysis and decreased protein synthesis. Reduction in protein content under low water potential is mostly due to increased protein destruction.

According to Levitt (1980), NaCl decreases protein synthesis and increases hydrolysis in many crop plants. This hydrolysis was considered to be a primary effect of salt. The increase in hydrolysis of proteins in salinized glycophytes must, of course, lead to an increase in the products of hydrolysis - the amino acids.

According to Dungey and Davies (1982) protein synthesis was reduced by the stress but a greater effect of stress was seen on protein degradation. Drought stress commonly causes a loss of protein from tissues as a result of disruptions in the normal protein synthetic and degradative processes occurring in unstressed cells. It has been shown repeatedly that the rate of protein synthesis is reduced by stress (Hsiao, 1973; Bewley, 1981).

Stress caused a significant ($P<0.001$) increase in the rate of protein degradation. The loss of protein brought about by stress is the result of both reduced protein synthesis and enhanced protein degradation. Degradation

was apparently affected to a greater extent than synthesis. Under the stress conditions applied in the present investigation, protein synthesis continued and may have been concerned with the production of 'Stress Proteins' (Webster, 1980).

Reddy and Vora (1985) demonstrated that protein and RNA contents decreased by salinity. Salinity treatments decreased the leaf protein content. Salinity treatments either decreased or had no effect on soluble proteins content.

According to Joshi *et al.* (1993) the amounts of proteins showed seasonal changes in saline habitats. In *Salvadora persica* the amount of alkali soluble proteins in leaves and stems varied between 93 to 161 mgg^{-1} while that of alcohol and water soluble proteins fluctuated between 56 to 109 mgg^{-1}. These results showed that the protein content in leaves was usually one and half times more than in stems and that minimum concentrations of protein in leaves were recorded in Summer. Amounts of proteins in stems were not much affected by climatic changes.

De and Kar (1994) studied the effect of water stress induced by polyethylene glycol (PEG) on the changes in protein during germination of mungbean (*Vigna radiata*) seeds. Both the protein loss (degradation) in cotyledons and the increase in protein level in embryonic axis during germination was retarded by water stress.

Rani and Jesudas (1994) proved that in stressed leaves the protein contents were reduced when compared to controls.

According to Chandrasekar and Sandhyarani (1996) protein content was higher in *Crotalaria striata* plants of non-saline habitats compared to the plants of saline habitat. The mature leaves were found to have more protein than the young leaves. The soluble proteins and total nitrogen content were lower in the plants growing in saline habitat compared to plants of non-saline habitat.

A significant reduction in the protein content in the seeds of chickpea treated with NaCl was reported by Kumar *et al.* (1983). According to Krishnamurthy and Bhagwat (1989) the protein and total nitrogen content in the salt tolerant rice variety Co43 was higher compared to the salt sensitive variety.

Mondal and Mondal (Nee Parui) (2002) reported that the protein, carbohydrate and lipid content decreased in the xeric state but there was an increase in the free amino acid content. It is due to the higher temperature in the xeric condition.

Martino *et al.* (2003) proved that large protein degradation had taken place in salt stressed leaves, in agreement with the large loss of Rubisco. The salt stressed leaves turned yellow, appeared clearly aged and their physiological performance was much lower than the controls.

According to Ashraf and Harris (2004) several salt-induced proteins have been identified in plant species and have been classified into two distinct groups; salt stress proteins, which accumulate only due to salt stress, and stress associated proteins which also accumulate in response to heat, cold, drought, water-logging, and high and low mineral nutrients. Proteins that accumulate in plants grown under saline conditions may provide a storage form of nitrogen that is re-utilized when stress is over and may play a role in osmotic adjustment. Proteins may be synthesized *de novo* in response to salt stress or may be present constitutively at low concentration and increase when plants are exposed to salt stress.

Rao *et al.* (2005) proved that leaf protein content was found to be more in *Aelurops lagopoides* and *Eragrostis* sp. at all salinity treatments. With increase in salinity, a decrease in protein was noticed in both the grass species. There is a significant variation among the treatments in protein contents. There was an increase in protein with increase in salinity indicating the efficiency of nitrogen metabolism in these grasses.

Amino acids

Salinity alters many biochemical reactions in plants as a result of which many intermediate products are formed and free aminoacids represent a group of such compounds in the plants subjected to salinity (Strogonov, 1974). The investigations of free aminoacids in halophytes which occur in

extremely saline milius suggest that proline always occur in large quantities (Stewart and Lee, 1974). Proline accumulation was maximum during Winter in halophytes (Joshi, 1982) accompanied by maximum succulence of salt accumulating parts. According to Strogonov (1974) proline is one of the protective substances. Stewart and Lee (1974) suggested that proline functions as a source of solute for intracellular osmotic adjustment.

According to Dungey and Davies (1982) the soluble amino acid content of these segments was increased by stress and much of this enhancement was due to the accumulation of proline.

Reddy and Vora (1985) proved that amino acids contents showed fluctuating trend with growth stages and NaCl concentration. Salinity of 0.4% increased the amino acids content at first and second stages. Compared to total amino acids proline showed seven fold increase in 0.4% salinized plants.

Joshi *et al.* (1993) proved that seasonal variations showed maximum concentrations of alanine, γ-aminobutyric acid, leucine, phenyl-alanine, proline, serine and threonine in leaves in Summer. Maximum concentration of aspartic acid, glutamic acid and glycine in Winter, of that of methionine, valine and tyrosine in monsoon. Similar seasonal changes in accumulation of most of the amino acids were also noticed in stem. Seasonal changes

evidently showed that accumulation of most of the amino acids increase at the time of increased salinity in habitats.

De and Kar (1994) studied the effect of water stress on amino acids in mungbean (*Vigna radiata*) and proved that translocation of amino acids from cotyledons to embryonic axes during germination was also affected by water stress.

Martino *et al.* (2003) showed that a slight increase of amino acid content over the controls has been reported in spinach leaves exposed to salt stress, compared with those exposed to water stress (Sulpice *et al.* 1988).

According to Ashraf and Harris (2004) amino acids have been reported to accumulate in higher plants under salinity stress. Total free amino acid in leaves are reported to be higher in salt tolerant than in salt sensitive line of Sunflower, Safflower, *Eruca sativa* and *Lens culinasis*.

Proline

Bar-Nun and Poljakoff-Mayber (1977) showed that salinity stress induced an increase of proline content, mainly in the free aminoacid and of proline or hydroxyproline content. Proline very effectively counteracted the inhibitory effect of NaCl in pea seed germination and root growth. Further they reported the changes induced by salinity in the aminoacid composition of the free aminoacid pool and of protein, from the root of the halophytes

Tamarix tetragyna L. and the glycophyte *Pisum sativum* L. The incorporation of exogenously supplied proline and glutamic acid was also studied. In roots of both plants, the amount of free proline increased on exposure of the plants to salinity. The increase in proline content in pea roots was from approximately 1 to 3 percent of the total content of free aminoacids, while in *Tamarix* roots the increase was from 7 to 37 percent and 60 percent respectively. In the roots exposed to salinity the content of proline, or hydroxyproline or both increases. From the above it is obvious that proline is very effective in counteracting the effect of salinity on peas. It is suggested that tolerance of *Tamarix tetragyna* to salinity stress is at least partially due to the very large amount of free proline present in its roots.

According to Aspinall and Paleg (1981), proline accumulation in response to water deficit have been concerned with changes in concentration in the shoot or more specifically in the leaves. The progressive accumulation of proline has been accompanied by a fall in tissue water potential with time. Accumulation of proline during periods of stress has definite evolutionary advantage, in that it endows the cells with a measure of resistance, and is not merely a consequence of stress impaired metabolism. Proline is translocated freely within the plant during water stress and it get accumulated in younger leaves and shoots. The concentration falls rapidly, once stress is relieved.

According to Ungar (1982) an increase in salt stress has been associated with a rise in endogenous proline concentration in plants. In pea

and maize salinity caused an accumulation of free aminoacids, especially proline, which attained ten times the control value.

Reddy and Vora (1985), demonstrated that aminoacid content showed fluctuating trend with growth stage and with NaCl concentrations. Salinity of 0.4% increased the aminoacid content at first and second stages. Compared to total amino acids, proline showed sevenfold increase in 0.4% salinized plants. Accumulation of free proline in response to salinity was also reported by Weimberg *et al.* (1982). According to Chu *et al.* (1976) the accumulation of proline during stress is the consequence of reduction in cell osmotic potential and rapid accumulation of proline.

Kishore *et al.* (1986) conducted the work with the objective of determining the variation in proline content in salt affected perlette vine in a growing season and thereby ascertain its role in salt stress metabolism. The tested vines that survived had a high proline content when observed 60 days after treatment. The salt treatments reduced the proline content during the first 30 days of treatment, especially in the severely stressed vines. This could have been due to either 1) the mechanism for its synthesis being impaired or 2) there was an increased rate of its utilization in the active metabolism of the salt affected vines.

According to Ashraf (1993) addition of NaCl to the rooting medium increased the leaf proline content in both the cultivars. In this investigation,

however, both the cultivars accumulated greater proline in the leaves at high salinities than the control treatment. However, the results clearly show that proline levels in salt stressed plants were inversely correlated with ability to withstand salinity stress.

Singh and Sahay (1990) in their work showed that the moisture stress increased the leaf proline content in all the genotypes. Proline accumulation in leaf under stress condition showed positive association with biomass recovery and negative with reduction in yield. Significant reduction in yield under moisture stress in the susceptible genotypes may be attributed to low biomass recovery owing to less leaf proline accumulation in them. On the contrary, high leaf-proline accumulation under stress in the tolerant genotypes resulted in high biomass recovery and less reduction in seed-cotton yield. Singh and Singh (1986) proved this in their work on sugarcane.

Sarkar (1993) in his work revealed that proline levels in stressed plants were negatively related with capacity to withstand water stress. Nitrate reductase stability under stress showed significant negative association with proline accumulation during stress. Moftah and Michel (1987) reported more accumulation of proline in salt susceptible soybean. Proline accumulation is associated with changes in certain biochemical characters under conditions of water deficit signify susceptibility, injury rather than tolerance to water stress.

According to De and Kar (1994) proline content, an useful parameter for water stress studies, decreased to a minimum from the beginning in the cotyledons during germination and this decline was prevented by water stress, which might be due to inhibition of translocation. Embryonic axes accumulated proline, probably due to influx from cotyledons. Water stress although inhibited translocation of proline from cotyledons, augmented proline accumulation in embryonic axes. Such accumulation seems to be due to *de novo* synthesis of proline induced by water stress. This study revealed that water stress retarded mobilization of storage proteins in cotyledons during germination of mungbean and stress induced proline accumulation occurred only in embryonic axes.

Rani and Jesudas (1994) proved that the proline contents were more in stressed leaves than their controls. The diffusion of proline after rehydration of *Pennisetum* may be taken to indicate that proline serves as a storage compound during stress.

Pessarkali (1994) showed that plants subjected to most stressful environments show an increased level of total free amino acids. Proline seems to be the amino acid accumulated in the largest amounts in response to salinity, drought, temperature stress, etc. In most of the plants studied, salinity and water stresses caused substantial increases in the proline levels of the plant tissues. In salt stressed plants, proline accumulation results from

increased synthesis and decreased utilisation. As a result of water stress, free proline accumulated appreciably in leaves and other tissues. The functional role of proline accumulation appears to be as a cytoplasmic osmoticum to lower cell water potential, provide hydration to bipolymer and serve as an energy and nitrogen source under adverse environmental conditions.

Madan *et al.* (1995) in their work in *Brassica* proved that free proline content of whole seedlings as well as leaf tissue of plants at different stages of plant growth increased; though differently with the increasing salt stress. Proline protect plant tissues against stress by acting as a nitrogen storage compound, osmosolute and hydrophobic protectant for enzymes and cellular structures.

According to Zidan (1995), the fresh water green alga *Chlorella pyrenoidosa* synthesizes and degrades proline in response to increasing and decreasing NaCl concentrations, respectively. The proline content of the cell increases with increasing salinities of the medium. The major function of proline is to maintain osmotic balance. Reduction in salinity of the medium resulted in a decrease in proline content.

Chandrashekar and Sandhyarani (1996) proved that the salinity induced synthesis of proline and its accumulation associated with stress may serve as a compatible solute and thereby helps the plant to tolerate stress. The proline content was higher in the plants grown under saline conditions.

According to Lutts *et al.* (1999) proline accumulation was observed after 3 days of stress, exposure in two genotypes of rice. Proline concentration was higher in leaves than in roots. Proline accumulation is one of the most frequently reported modifications induced by water and salt stress in plants and is often considered to be involved in stress resistance mechanisms. Cytoplasmic accumulation of this amino acid is thought to be involved in osmotic adjustment of stressed tissue (Delauney and Verma, 1993).

Lacerda *et al.* (2001) showed that the proline contents in the control plants were quite low compared to other organic solutes in both *Sorghum* genotypes. After salt treatment, proline contents increased in all plant parts especially in the older leaves of both genotypes. The salt induced increase in proline content was always higher in the sensitive genotype than in the tolerant one.

It is interesting to observe that the highest proline content was found in the oldest leaves, which also exhibited the highest levels of leaf salt injury and the lowest fresh/dry matter ratios. Proline accumulation and level of leaf injury was also found in barley and cotton plants under water stress (Hansan *et al.* 1977) and in soybean plants under salt stress (Moftah and Michel, 1987).

Sahoo *et al.* (2001) studied accumulation of proline under NaCl stress of a salt-sensitive and a salt-tolerant rice cultivars during dark-induced senescence. Salinity significantly enhanced the rate of proline accumulation in the senescing leaves of both the cultivars, especially in the tolerant cultivars.

According to Mondal and Mondal (Nee Parui) (2002) individual amino acid analysis showed an increase in the level of proline in the xerophytic sporocarps of *Marsilea* sp. Proline is not only involved in several fundamental metabolic reactions associated with the sexual process but the concentration of proline often increase under physiological stress and in such conditions other amino acids seen to be converted into proline to act as a reservoir of amino acids (Singh and Chauhan, 1996). Under physiologically stressed conditions, the concentration of the amino acids other than proline also decreased.

According to Munns (2002) the compounds that accumulate most commonly are proline and glycine betaine, although other molecules can accumulate to high concentrations in certain species. All these compounds accumulate under water stress as well as salt stress, and are found at high concentrations in plants adapted to dry or saline soils.

Martino *et al.* (2003) proved that proline increased 30-fold compared with the controls and accounted for > 17% of the overall free amino acid content after 20 days of treatment.

Shubhra *et al.* (2003) proved through their work in cluster bean that there was many fold increase in proline content of leaf under water-stress condition. Water deficit increase accumulation of large amount of proline in leaf. Similar results were reported in pigeonpea (Scotti *et.al.*, 1999) and wheat (Hamada, 2000). From this work it is clear that proline accumulation was maximum at flowering stage and minimum at vegetative stage. Increase in proline content is effective in increasing osmotic status of the plant. The accumulation of proline decreased the osmotic potential of leaf and it again increased when water stress was relieved followed by simultaneous increase in leaf water potential in chickpea (Gupta *et al.* 2000).

Aziz and Khan (2003) found that accumulation of proline as an osmolyte occurred to varying extends in all species. Proline levels in both young and old leaves substantially increased during the dry period. In general higher proline content was observed in young leaves than old one. In rainy season the level of proline dropped dramatically in all species. Higher levels of proline during the dry period in *Senna holoserica*, was a feature of decreased water potential. *Calotropis procera* also had a higher proline content during the dry period even though it is a most succulent species.

According to Ashraf and Harris (2004) proline play an adaptive role in mediating osmotic adjustment and protecting the subcellular structures in stressed plants. Proline, which occurs widely in higher plants, accumulates in larger amounts than other aminoacids in salt stressed plants. Proline accumulation is one of the common characteristics in many monocotyledons under saline conditions. However, proline accumulation occurs in response to water deficit as well as to salt.

According to Meloni *et al.* (2004) proline accumulation was not significantly affected by salinity. Contrary to its generally accepted role in many other species, proline does not seem to play an important role in the mechanism of salt tolerance in *Prosopis alba*. The significance of proline accumulation in osmotic adjustment is still debated and varies according to the species.

Desingh and Reddy (2005) proved that proline and glycine betaine are known to serve as nitrogen and carbon sources, which can be used during water limited conditions as well as during recovery from the stress. These compatible solutes are also involved in cell osmoregulation and protection of proteins during dehydration (Rontein *et al.* 2002; Claussen, 2005).

From the account it seems that proline accumulation is a common metabolic response of higher plants to water deficits, and salinity stress. This highly water soluble amino acid is accumulated by leaves of many halophytic

higher plant species grown in saline environments. Proline protects membranes and proteins against the adverse effects of high concentrations of inorganic ions and temperature extremes.

Tannin

Tannins are water-soluble phenolic natural products that are protein precipitants (Mole and Waterman, 1987). Tannins constitute a very heterogenous group of phenolic secondary metabolites and hence are not so easily definable on the structural view-points (Martin and Martin, 1983). High levels of phenolic substances are often linked to unfavourable conditions of mineral nutrition of plants in general and, in particular, with reference to the availability of nitrogen and phosphorous (Chapin, 1980; Gershenzon, 1984).

Epicuticular Wax

Environmental conditions may strongly influence the quantity, composition and morphology of the waxy coverings of leaf surfaces. Rao and Reddy (1980) found that the composition and quantity of epicuticular waxes of shrubs growing in a semiarid environment varied with seasonal differences in temperature and rainfall, and both cuticular and total tanspiration appeared to be associated with changes in wax composition.

According to Mayeux and Jordan (1984) leaf characteristics and epicuticular wax amounts of leaves removed from branches facing the four cardinal directions were uniform within a tree. Leaf characteristics and wax amounts of honey mesquite tree (*Prosopis glandulosa* Torr.) growing at the same locations were also uniform. Amounts of epiculticular wax of fully expanded leaves were least in May at all locations.Quantity of wax increased significantly at each location by the second sampling date in July. However, irrespective of leaf area or weight, significantly more wax was extracted in October. An increase in amounts of epicuticular wax on leaves during the Spring and Summer is typical. The wax weight per unit leaf weight reached a maximum in July and August and then tended to decrease through October.

Chandrashekar and Sandhyarani (1994) proved that the observation of higher epicuticular wax (ECW) deposition in plants of *Crotalaria striata* under saline habitat corroborates with the results of Rao *et al.* (1981). The accumulation of ECW may be one of the adaptation for the survival of plants in the saline habitat which may result in reduced transpiration. In their study, there was gradual and significant decrease in ECW content from March to May in both plants grown under saline and non-saline conditions. This decrease may be due to the onset of rains, decreased temperature and light intensity.

Chlorophyll

Boucaud and Ungar (1976) have shown that in the halophyte, *Suaeda* the chlorophyll content tends to decline as salt concentration increase. Similarly in *Thespesia populnea*, the plants from the saline habitat have a lower chlorophyll content than the same species occurring in non-saline environment. Comparatively the loss of chlorophyll a is much greater than the loss of chloropyll b in *Thespesia populnea.*

According to Joshi (1982) the chlorophyll contents in the mangroves are higher during the Winter and lower during the Summer and monsoon. This may be due to light and temperature fluctuations. In Summer there is bright light and high temperatures while in monsoon the light is poor and temperatures are high. In Summer salinity of seawater is high. These factors may inhibit chlorophyll synthesis while moderate light and temperatures will promote chlorophyll synthesis.

According to Ashraf (1993), the chlorophyll contents were reduced significantly as a result of increasing salinity. Loss of chlorophyll due to NaCl stress was accompanied by rapid accumulation of proline.

According to Shubhra *et al.* (2003) total chlorophyll content of the leaf declined under water stress condition. Similar results have been reported in *Brassica* by Ashraf and Mahmood (1990). It may be due to decreased

synthesis and increased degradation of chlorophyll in leaves under water stress (Dekov *et al.* 2000).

Chlorophyll Fluorescence

Chlorophyll fluorescence has become one of the most powerful and widely used techniques available to plant physiologists and ecophysiologists. It is a tool that monitors the function of the photosynthetic apparatus, which has been shown to change in response to water stress and salinity. Chlorophyll fluorescence measurements have a wide range of applications from basic understanding of photosynthesis functioning to plant environmental stress responses and direct assessments of plant health.

According to Long and Baker (1986), salinity causes a decrease both in growth and in the net photosynthesis of higher plants. This may open the possibility of using photosynthetic parameters in salt-tolerance screening. Belkhodja *et al.* (1994) showed that changes in fluorescence occur in excised barley leaves exposed to saline solutions only in the presence of high light. They also showed that a significant correlation exists between some fluorescence parameters and independent measurements of salinity tolerance. These results suggested that chlorophyll fluorescence could be used as a tool for the screening of cultivars for salinity tolerance.

Maxwell and Johnson (2000) proved that when a leaf is transferred from darkness into light, PSII reaction centres are progressively closed. This

give rise to an increase in the yield of chlorophyll fluorescence. Chlorophyll fluorescence appear to give a measure of photosynthesis. Fluorescence can be used to measure the efficiency of PSII photochemistry. Fluorescence can give insights into the ability of a plant to tolerate environmental stresses and into the extent to which those stresses have damaged the photosynthetic apparatus.

According to Strasser *et al.* (2004) chlorophyll a fluorescence, though corresponding to a very small fraction of the dissipated energy from the photosynthetic apparatus, is widely accepted to provide as access to the understanding of its structure and function.

Mineral composition of mangroves

Waisel (1972) proved that sodium accumulation in *Suaeda nudiflora* and *Salicornia brachiata* was found to be higher than other cation. Accumulation of chloride ions decreases water absorption and transpiration and gives rise to succulence.

Divate and Pandey (1979) noted that sodium content of leaves increased with increase in the concentration of salts in the soils. Chloride also increases with salt concentration in the foliage of all the tree cultivars. Magnesium content of leaves decreased with increased salt concentration in all the cultivars. With increase in the salt concentration there was a proportional decrease in the Calcium content of leaves. High salt levels in the soil resulted in a corresponding decrease in the mean Potassium content of

leaves in all the cultivars. Various salinity treatments increased Nitrogen, Phosphorous, Sodium and chloride in leaves and decreased Potassium, Magnesium and Calcium. The increase or decrease was proportional to the concentration of salts applied. Among the various chloride salts $CaCl_2$ appears to promote more chloride accumulation in the grape leaves.

According to Pollak and Waisel (1979) salt excretion exhibited an optimum type of curve when measured against external salt concentration, while sodium content of the leaves increased linearly. Salt excretian by salt glands of halophytes is claimed to be among the fastest ion transport systems in plants. The efficiency of salt excretion system, the relative excretion values, were shown to be negatively correlated with the salt concentration of the habitat. The tendency of leaves to retain high Potassium levels is common in monocotyledonous halophytes (Albert and Kinzel, 1973).

The process of osmotic adjustment in the halophytes subjected to saline conditions is mainly achieved by uptake and accumulation of inorganic ions such as Na^+ and Cl^- in their shoots (Flowers *et al.* 1977; Greenway and Munns, 1980). Sodium and chloride concentration increased in plants grown at different salinities. In general chloride concentrations were slightly lower than Sodium.

Joshi (1982) proved that halophytes are able to survive in high concentration of salts. The salts are accumulated either in the plant until it

dies or in the deciduous leaves which fall from the plants. The excessive salts are excreted through the glands. The changing salinity of habitats have direct effects on mineral uptake and their accumulation in the plants. Salt contents increase during Winter and Summer when salinity of the habitat increased and the leaves become succulent. Sodium and chloride ions were found to be the main constituents of the ash and demonstrated a direct relationship with increased salt concentration. Potassium content showed an inverse relation with that of Sodium. Magnesium accumulation was always more than Calcium.

According to Joshi and Bhosale (1982) the estuaries in India are subjected to distinct seasonal variations. This is reflected in the composition of the water inundating the estuaries, as well as the elements in the leaves of the estuarine plants. The dominance of Na^{+} and Cl^{-} ions was obvious in the results. This was accompanied by lesser amounts of Mg. The capacity of the saline plants to develop salt tolerance is due to their capacity to increase uptake of Ca and K ions in spite of richness of Na and Cl ions in the soil. The accumulation as well as the excreting type have higher Na and Cl ions.

In all the plants studied, lowest values for Na^{+}, K^{+}, Ca^{++} and Cl^{-} were recorded in monsoon and the highest in the Summer months. The increase in K and Ca contents in the mangroves in Summer may be for the development

of salt tolerance. In *Acanthus*, high Ca values were recorded in Winter and not in Summer (Joshi and Bhosale, 1982).

According to Waisel *et al.* (1986) salts are continuously absorbed by plant roots and transported in to the shoots. Salt concentration in the xylem sap varied during day. All the three ions measured (Na^+, K^+, and Cl^-) had showed higher concentrations in the morning and in the evening. The concentrations of K^+ was lower than that of Na^+ or the Cl^-. The salt content of mature leaves of *Avicennia* was rather constant.

In his work, Gill (1992) proved that Na content increased with salinity at tillering stage of barley and was highest in varieties Karan 4 (huskless) and CS 80-2 (husked). Potassium content decreased with salinity and lowest K^+ was present in CS 37 (husked) and Karan 4 (huskless) resulting into higher Na^+/K^+ ratio.

Joshi *et al.* (1993) proved that Na^+, Cl^-, K^+, Ca^{2+} and Mg^{2+} were the principal inorganic constituents of leaves and stems in *Salvadora persica* with reference to saline habitats. The ash content in the leaves varied from 21 to 31% of dry weight. Amongst the cations, Na^+ and Ca^{2+} contributed to the major fractions of the ash followed by Mg^{2+} and K^+ where as Cl^- balanced about half of the cationic content. These results further showed steady increase in accumulation of salts and minerals from minimum amounts in monsoon to maximum in Summer through Winter. But K^+ content indicate

the reverse trend. Salt accumulation in stems was less than leaves and varied in narrow range of 13 to 17%. The K^+ content in stems was not only greater than in leaves but it did increase progressively along with other ions from monsoon to summer.

According to Ungar (1996) *Atriplex patula* accumulates Na^+ and Cl^- ions in stems and leaves with increase in media salinity, which is similar to the response of other halophytes in the family Chenopodiaceae.

Al-Zahrani and Hajor (1998) reported that Na^+ and Cl^- concentrations decreased with plant age in the plants grown in culture solution alone (control). The Na^+ and Cl^- concentrations in the root were much lower than in the shoot, the highest values were in the root of the plants grown in 510mM NaCl, and values decreased with the increase in salinity concentrations. The highest K^+ concentration was in the plants grown in culture solution and then decreased in the presence of salinity in the external solution, in both shoot and root. Ca concentration in the shoots decreased with increasing salinity in the external solutions. The Mg^{++} concentration was lower in the plants grown in the culture solution. The concentration of Mg^{++} and Ca^{++} in the roots were decreased with increasing salinity. K^+ concentrations in the roots was higher than Mg^{++} and Ca^{++} concentration.

According to Dua (1998), Na^+ concentration, as dry weight basis, was more in root than in shoot of sensitive genotype, where as in the tolerant

genotype the concentration and rate of increase of Na^+ in shoot and root were almost the same. On dry weight basis root as well as shoot components of the tolerant genotype had more Cl^- than the sensitive genotype. The concentration of Cl^- in the leaves of the sensitive genotype was almost four times the concentration in leaves of the tolerant genotype. K^+ content, on dry weight basis, remained almost constant in shoots of both the genotypes, where as in the roots it decreased on salinization. The concentration of Ca^{++} and Mg^{++} on dry weight basis, was similar in the sensitive and the tolerant genotypes on 18^{th} day of salinization. The concentration of Na^+ and Cl^- was far more in the salinized plants than in the non-salinized plants. In most of the species it is well established that the pattern of ion uptake is a useful measure of salinity tolerance. The greater the degree of ion exclusion, the greater the tolerance to salts. According to him on dry weight basis most of the ions were in almost equal concentrations in shoot components of the tolerant and the sensitive genotype. This indicates a halophytic mechanism of shoot tolerance in chickpea.

Cherian *et al.* (1999) proved that the increase in NaCl concentration steadily increased Na^+ and Cl^+ in all plant parts and the accumulation was significantly higher in leaf than in shoot or root. Cl^- concentration increased with external salinity in all plants parts. The salinity induced decrease in K^+ concentration. In parallel with the Na^+ accumulation and decline in K^+ content, the Na^+/K^+ ratio increased at all levels of external salinity.

Accumulation of Na^+ and Cl^- contributed substantially to the osmotic adjustment.

According to Lacerda *et al.* (2001) the Na^+ and Cl^- contents, which were low in control plants, greatly increased after salt treatment in both genotypes. The highest contents of these ions were found by order in stems plus sheaths, roots, young leaves and old leaves. The K^+ contents in control plants, as expected were much higher than that of Na^+ and Cl^- and drastically reduced after NaCl treatment. The salt induced reductions in K^+ contents were intense in the sensitive genotypes, except in the oldest leaves. The application of salt stress, resulted in a strong reduction of Ca^{2+} contents twice as much than the tolerant genotype. The Ca^{2+} contents in the roots did not differ between genotypes and salt stress reduced them only in the tolerant genotype.

They also proved that the salt stress caused reduction in Mg^{2+} contents in the stem plus sheaths in both genotypes, specially in the sensitive one. On the contrary, in the leaf blades Mg^{2+} contents increased in salt stressed plants of both genotypes. The Na^+/K^+ ratio, which was very small in the control plants, increased a lot after the plants were exposed to high levels of NaCl in the two genotypes, particularly in the sensitive one.

Martino *et al.* (2003) reported that the Na^+ accumulation was seen after 10 days of treatment with saline water (10 DOT) in spinach leaf and increased

linearly until the end of the experiment. Na^+ concentration in the salt stressed leaves was six fold higher than in controls and severely inhibited cell metabolism. The concentration of K^+, instead, did not significantly decrease in leaves of salt treated plants compared with controls or change during the experiment.

According to Ramos *et al.* (2004), when NaCl was used to induce salt stress, the Na^+ and Cl^- content in roots, stems and leaves increased with salinity. At the same time the K^+ content was low at 100 mM NaCl a relevant decrease in K^+ was observed in stems and leaves. On the other hand, increasing concentrations of KCl in the growth medium induced an important increase in the accumulation of K^+ and Cl^- with respect to control plants. It has been proposed that both K^+ and Na^+ are involved in the osmotic adjustment of plants in response to high soil salinity. Na^+ ions contribute more efficiently than K^+ ions to perform this function.

Rao *et al.* (2005) reported that the leaf and stem ions i.e., Na^+ and Cl^+ increased with increase in salinity in *Eragrostis* sp. and *Aeluropus lagopoides*. . In stem the Na^+ and Cl^- contents were higher when compared to the leaves indicating stem as a potential sink. The total Na^+ uptake showed a decreasing trend with increase in salinity of irrigation water in both the grasses. The total Na^+ content is less in shoot than in the root in both the grasses irrespective of salinity and age of the plant. Cl^- uptake is relatively more in shoot than in

root. The rate of flux of Na^+ and Cl^- to the whole plant increased with salinity and age of the plant. Their studies clearly indicate that *Aeluropus* has the ability to extract more salt than *Eragrostis*, thus indicating its higher salt tolerance.

According to Hossain (2006), in seedlings of *Bruguiera parviflora*, higher K^+ content was observed in leaves followed by roots and stem. Comparatively higher content of potassium was found in leaves, buds, branches and roots during the intermediate seasons (March), but similar content of K^+ was found in stem and bark in different seasons.

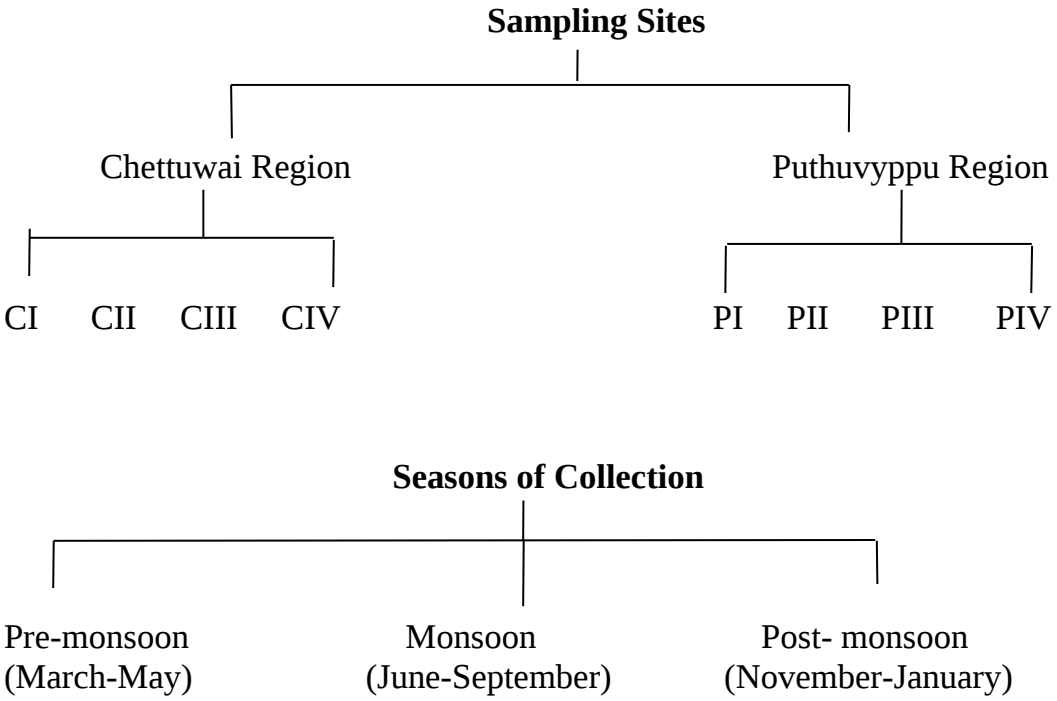
MATERIALS AND METHODS

Study Areas

For the present study, two specific areas were identified namely Chettuwai estuary of Thrissur District and Puthuvyppu of Ernakulam District in Kerala. Chettuwai is an estuary-backwater complex, coming under Orumanayur Grama Panchayat of Chavakkad Taluk in Thrissur District. The estuary is situated in the latitude 10^0 32'N and longitude 76^0 02' E. This area is a significant mangrove zone of Kerala. The rivers Chettuwaipuzha and Karanjirapuzha join to form the Chettuwai estuary which supports a fairly good mangrove patch near Pattekkat and tidal flats further inside (Mohanan, 1999). The flora is rich in species of *Acanthus, Aegiceras, Avicennia, Bruguiera* and *Rhizophora.* Puthuvyppu is situated along the Malabar coast under Elangunnapuzha Panchayath of Cochin Taluk in Ernakulam District. The area of mangrove in this region is approximately 101 ha. Species such as those of *Acanthus, Avicennia, Bruguiera, Excoecaria, Rhizophora* and *Sonneratia* are abundant here.

In each of these two study areas, four sampling sites were identified. Sampling sites of Chettuwai were named as CI, CII, CIII and CIV. Similarly sampling sites of Puthuvyppu were named as PI, PII, PIII and PIV. Sampling

was carried out in specific seasons *viz*. the pre-monsoon (March to May), the monsoon (June to September) and the post-monsoon (November to January), during the years 2004-2005 and 2005-2006 from each of the sampling sites. Water and soil samples were collected during the high tide.



Water qualify analysis

Temperature of water was measured directly at the sampling sites itself. For further analyses, water samples were collected in sterilized airtight bottles and brought to the laboratory. Electrical conductivity of water was measured using conductivity meter (Elico 180) and expressed in mhos cm^{-1}. Salinity of water was measured using salinity meter (YSI 85).

Dissolved Oxygen (DO) was calculated using Winkler's Azide Modification (APHA, 1995) using the formula-

$$\text{DO mgl}^{-1} = \frac{\text{Volume in ml of thio} \times \text{Normality of thio}}{\text{Volume of sample taken in ml}} \times 8 \times 1000$$

Biological oxygen demand (BOD) was estimated using Winkler's Azide modification (APHA, 1995).

Soil Analysis

Soil samples were collected from the identified sampling sites, air dried and stored for further analyses such as determination of pH, electrical conductivity, salinity, organic carbon content etc.

Determination of soil pH

Twenty gram of soil was dissolved in 100 ml. distilled water (1:5) and stirred with a glass rod for one hour at regular intervals. The pH was determined with a pH meter (Systronic 335) and expressed directly in pH units.

Determination of soil electrical conductivity

For the determination of electrical conductivity 1:5 soil suspension was prepared as mentioned above and electrical conductivity was measured using a conductivity meter (Elico 180).

Estimation of soil salinity

For measuring salinity of soil 1:5 soil suspension was prepared. The salinity was measured by dipping the electrode of salinity meter into the suspension. The salinity was expressed in ppt.

Analysis of soil organic carbon

For the analysis of organic carbon, which is a measure of nitrogen and minerals present in the soil, air dried samples of soil were used. Such samples were dissolved in distilled water and Na, K, Ca and Mg were estimated using Flame Photometer (Systronics 125). Chloride analysis was done using the method of Argentometry (Vogel, 1984). In this case, 50 ml of the sample was taken in a conical flask and 2ml. of potassium chromate solution was added. The contents were titrated against 0.028N $AgNO_3$ solution until a persistent reddish brown tinge marked the end point.

Calculation:

$$Cl^{-}\ mg\ l^{-1} = \frac{\text{Volume in ml of } AgNO_3 \times \text{Normality of } AgNO_3}{\text{Volume of sample taken in ml}} \times 1000 \times 35.5$$

Mangrove flora

Distribution of mangroves was studied in the two pre-identified areas. Specimens were collected and identified according to 'Flora of The Presidency of Madras' (Gamble, 1919) and compared with the specimens in

Calicut University Herbarium. The species collected from Chettuwai were *Acanthus ilicifolius, Aegiceras corniculatum, Avicennia officinalis, Bruguiera cylindrica and Rhizophora mucronata*. The species collected from Puthuvyppu include *Acanthus ilicifolius, Avicennia officinalis, Bruguiera cylindrica, B. gymnorrhiza, B. sexangula, Excoecaria agallocha, Kandelia candel, Rhizophora mucronata, Rhizophora apiculata*, and *Sonneratia caseolaris*.

Anatomical studies were made in all the mangrove species mentioned above. But physiological and biochemical studies were carried out only in seven species of the two study areas viz. *Acanthus ilicifolius, Aegiceras corniculatum, Avicennia officinalis, Bruguiera cylindrica, Rhizophora mucronata, Excoecaria agallocha* and *Sonneratia caseolaris*.

Anatomical Studies

For anatomical studies, plant parts like leaf, stem and roots (both stilt root and pneumatophores) of 7 genera of mangroves belonging to 5 families were collected from the study areas and fixed in FAA. Thin transverse hand sections were taken and stained with safranin. Observations were made and microphotographs were taken using Nikon Trinocular Image Analyser Model E100.

Structure of salt glands and its frequency were studied using leaf peelings. Transverse sections of leaves of *Acanthus*, *Aegiceras*, *Avicennia* and *Sonneratia* were used for the detailed study of salt glands.

Leaf thickness, thickness of epidermis, hypodermis and mesophyll were measured using micrometer. Length and breadth of salt glands was also measured using micrometer.

Stomatal Studies

Stomatal density on the adaxial and abaxial sides of the leaf was computed under a light microscope using leaf peelings stained with safranin. Stomatal index was calculated according to the formula of Meidner and Mansfield (1968).

$$\text{Stomatal Index} = \frac{\text{Number of Stomata per unit area}}{\text{Number of Stomata per unit area} + \text{number of epidermal cells per unit area}} \times 100$$

Dry Weight determination of tissues

A known quantity of fresh tissue was taken and was kept in hot air oven at 100^0C for 1 hour and then at 60^0C until constant weight was obtained.

The percentage of dry weight was calculated as explained by International Seed Testing Association (ISTA) (1985).

$$\text{The percentage of dry weight} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

The percentage of moisture content (MC) was calculated as per Copeland and Mc Donald (1995).

$$MC\% = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Dry weight}} \times 100$$

Separate samples were taken for biochemical estimation of total protein, total aminoacids, proline and tannin content.

Biochemical Studies

Mangrove leaf and stem samples were collected for biochemical analysis from the specific areas of study during different seasons *viz.* pre-monsoon, monsoon and post-monsoon. The leaves were chopped into small pieces and 0.5 gm of the material was weighed in triplicate and stored in a refrigerator for biochemical analysis. Similarly stem was also made into small pieces and 0.5 gm was weighed in triplicate and stored.

Estimation of Protein

Protein content of leaf and stem was estimated using Folin-Ciocalteau reagent according to the method of Lowry *et al.* (1951).

Five hundred milligram of fresh tissue was homogenized in distilled water using pre-chilled glass mortar and pestle kept in ice trays. Volume of

the homogenate was measured. One millilitre of the homogenate was taken in clean dry test tubes in duplicate and an equal volume of 10% (w/v) trichloroacetic acid (TCA) was added. The tubes were then kept in a refrigerator for one hour for flocculation. The protein precipitate was collected after centrifugation for 10 minutes. The supernatant was decanted off. The residue was washed twice with 2% (w/v) cold TCA followed by washing with anhydrous acetone and 80% acetone. The supernatant was decanted off in each step. The final residue was digested in 5.0 ml of 0.1 N Sodium hydroxide by heating in a boiling water bath for 5 minutes. The supernatant was clarified by centrifugation and was collected in test tubes. 0.2 ml aliquots were taken in triplicate and the volume was made up to 1.0 ml with double distilled water. To these aliquots, 5.0 ml of alkaline copper reagent was added and shaken well. After 10 minutes, 0.5 ml of Folin-Ciocalteau reagent was added, shaken well immediately. The tubes were kept 30 minutes for colour development. The optical density of the solution was read at 700 nm using a Genesis-20 Spectrophotometer. Bovine Serum Albumin (BSA) fraction V was used as standard.

Estimation of Total Free Amino Acids

Total free amino acids of leaves and stem of mangroves were estimated according to the method of Lee and Takahashi (1966).

Extraction

Five hundred milligram of fresh tissue was homogenised in 80% (v/v) alcohol using a clean glass mortar and pestle. The homogenate was transferred to a round bottomed flask fitted with vertical condenser and refluxed on boiling water bath for 2 hours. After cooling, the suspension was centrifuged and the supernatant was collected. The residue was re-extracted with 80% alcohol and after each centrifugation the supernatant was combined with original extract. The combined supernatant was then evaporated to dryness over a boiling water bath in china dish. The dried matter thus obtained was eluted using 4 ml of 10% iso-propanol and was used for the determination of total free amino acids.

To 0.2 ml of the sample, 3.8 ml of ninhydrin-citrate-glycerol mixture (reaction mixture), [prepared by mixing 1 ml of 1% ninhydrin solution in 0.5 M citrate buffer (pH 5.5), 2.4 ml of glycerol and 0.4 ml of 0.5 M citrate buffer] was added. After shaking well, the mixture was heated in a boiling water bath for 12 minutes and cooled to room temperature in tap water. The optical density of the resultant solution was measured at 570 nm using Genesis 20 Spectrophotometer. The reagent blank was prepared by mixing 0.2 ml distilled water and 3.8 ml ninhydrin-citrate-glycerol mixture. Glycine was used as the standard.

Estimation of Proline

Proline content of young and mature leaves and stem was estimated as per the method described by Bates *et al.* (1973).

Five hundred milligram of fresh tissue of leaf and stem homogenised in 10 ml of 3% (w/v) aqueous sulphosalicylic acid in a clean and dry glass mortar using a pestle. The homogenate was centrifuged for 10 minutes and the supernatant was collected. From the supernatant 2.0 ml of the aliquot was taken in triplicate in test tubes and 2.0 ml of glacial acetic acid and 2.0 ml of acid ninhydrin were added to it. Acid ninhydrin was prepared by dissolving 1.25 gm of ninhydrin in a mixture of 30 ml of glacial acetic acid and 20 ml of 6M orthophosphoric acid. The tubes were then heated in a bath of boiling water for one hour and then the reaction was terminated by placing the tubes in an ice bath. 4.0 ml of toluene was added to the reaction mixture and stirred well for 20-30 seconds. Then the tubes were brought to room temperature. The toluene layer was aspirated and the colour intensity was measured at a wave length of 520 nm using Photochem colorimeter. L-Proline was used as the standard.

Estimation of Tannin

Extraction

Tannin in mangroves was estimated according to the method of Folin and Denis (1915). For the estimation of tannin, dried samples were used. Leaves and stem were kept in an oven at 80°C for 4 days and the dried materials were powdered using a clean and dry mortar and pestle. 0.5 gm of the dried and powdered sample was boiled in 75 ml of distilled water in a conical flask for 30 minutes. After cooling, the extract was centrifuged for 20 minutes at 2000 rpm. The supernatant was collected and was made up to 100 ml using distilled water.

Preparation of Folin-Denis Reagent

One hundred gram sodium tungstate and 20 gm phosphomolybdic acid were dissolved in 750 ml distilled water in a suitable flask and 50 ml orthophosphoric acid was added. The mixture was refluxed for 2 hrs and was then made up to one litre with distilled water. The reagent was titrated against standard alkali to determine the normality. One Normal sodium carbonate solution was prepared by dissolving 350 gm Na_2CO_3 in one litre of distilled water at 70 – 80^{0}C. The mixture was filtered through glass-wool after allowing it to stand overnight.

Estimation

Aliquots of 0.5 ml of tannin extracts were pipetted out in triplicate and 0.5 ml of Folin-Denis reagent was added. The contents were thoroughly mixed and 1 ml of 1N sodium carbonate was added after 3 minutes. The mixture was then made up to 10 ml by adding 8.0 ml of distilled water, vortexed thoroughly and kept for 30 minutes. The absorbance was measured at 700 nm using a Genesis 20 spectrophotometer. Tannic acid was used as standard.

Estimation of Epicuticular Wax

For the determination of epicuticular wax, leaves of all the mangrove species was collected. Initial weight of the leaves was noted. These leaves were dipped in chloroform for two hours in closed containers. After two hours, the leaves were taken out and the solvent was allowed to evaporate to dryness at room temperature. The leaves were weighed several times till constant weight was obtained and the final weight was noted. Amount of epicuticular wax is obtained from the difference in the initial weight and final weight of the leaves.

Estimation of Minerals in mangroves

Samples of all species were collected during the three seasons. Leaf and stem samples were dried in an oven at 60^0C for four days. The dried

samples were powdered in a dry mortar using a pestle. For the analysis of minerals, one gram each of the dry powder from leaf and stem samples were used. These samples were digested in a mixture of concentrated nitric acid. and perchloric acid in the ratio 9:4. The digest was made up to 100 ml using distilled water. Minerals in the digest were estimated using Atomic Absorption Spectrometer (AAS) Varian Spectra AA-20 and Flame Photometer. (Jenway PFP, England).

Estimation of Chlorophyll

Chlorophyll estimation was done according to the method of Arnon (1949). Two hundred milligram of fresh leaf tissue was homogenised using chilled 80% acetone in a pre-chilled clear glass mortar and pestle. The homogenate was centrifuged for 10 minutes and the supernatant was collected in a test tube. The residue was again extracted with 80% acetone and centrifuged. The supernatant was pooled together and volume of the combined supernatant was noted. The absorbance of the solution was measured at 645 nm and 663 nm against the solvent (80% acetone) as blank using a Genesis 20 Spectrophotometer.

The amount of chlorophyll present in the leaf extract was calculated in mg chlorophyll per gram tissue according to the following equation.

$$\text{mg chlorophyll } {}^{a}\!/_{\text{gm tissue}} = 12.7(A_{663}) - 2.69(A_{645}) \times \frac{V}{1000 \times W}$$

$$\text{mg chlorophyll } b/\text{gm tissue} = 22.9(A_{645}) - 4.68(A_{663}) \times \frac{V}{1000 \times W}$$

$$\text{mg total chlorophyll}/\text{gm tissue} = 20.2(A_{645}) + 8.02(A_{663}) \times \frac{V}{1000 \times W}$$

where A = Absorbance at specific wavelengths

V = Final volume of chlorophyll extract in 80% acetone

and W=Fresh weight of tissue extracted. From the above values chlorophyll a/ chlorophyll b was also calculated.

Chlorophyll fluorescence measurements

Chlorophyll fluorescence was measured using Fluorescence Meter (Hansatech, Kings Lynn, UK). Measurement was conducted during early morning (6-7 AM) and noon (1-2 PM). For the measurement of chlorophyll fluorescence about eight leaves of each species was selected for getting eight values for a species. A leaf area of 0.18cm^2 was delimited by a leaf clip (Hansatech, Kings Lynn, U.K.). Blue light was passed through a copal photographic shutter (opening time 2 minutes). Fluorescence was detected through a 3-mm Schott RG-665 filter and a 680 nm interference filter with a photodiode (Hansatech) and the signal was fed to a digital storage oscilloscope.

Chlorophyll fluorescence was recorded as Fv/Fm using Fluorescence Meter,

where F_v = Variable fluorescence

F_m = Maximum fluorescence

$F_v = F_m - F_0$ (F_0 = minimum fluorescence) (Hall and Rao, 1999)

For evaluating the fluorescence induction transients, the Biolyzer software (Maldonado-Rodriquez, 2000) is used. The data obtained in the Fluorescence Meter were transferred to a computer where all calculations were performed using this computer programme. By using this software, a number of parameters were obtained. In the present investigation only four parameters like Fv/Fm, ETo/RC [Electron transport flux per Reaction Centre (RC) at t=0], Dlo/RC (dissipated energy flux per reaction centre at t=0) and Pl(abs) - performance index on absorption basis, were included.

RESULTS

The values presented in the Table as well as the histogram represent the average arrived by taking 10 replicate samples during the years 2004 - 2006.

Physico-chemical Parameters

The sampling and analysis of soil, water and plant materials were conducted in three seasons during the period from 2004-2006. As there was seasonal as well as year wise variations the average values have been computed for all the parameters. A number of parameters were employed for both physical and chemical analysis in the case of water as well as soil.

I. Water quality analysis

1. Physical parameters

1.1 Temperature

Temperature of water bodies generally varies with sites and seasons.

High temperature was recorded during post-monsoon season in Chettuwai and pre-monsoon season in Puthuvyppu. Low temperature was recorded during monsoon season in both study sites (Table 1, Fig. 1).

2. Chemical Parameters

2.1 Hydrogen ion concentration (pH)

High pH value was noticed during monsoon and pre-monsoon and low pH was observed during post-monsoon seasons in Chettuwai. But in Puthuvyppu high pH value was noticed during pre-monsoon and low during monsoon (Table 2, Fig. 2).

2.2 Electrical Conductivity (EC)

Electrical conductivity was maximum during pre-monsoon followed by post-monsoon seasons in both study sites which showed higher concentration of dissolved salts in water. Low value of EC during monsoon showed that the water was almost pure with lesser amount of dissolved salts (Table 3, Fig. 3).

2.3 Salinity

Highest salinity was recorded in pre-monsoon followed by post-monsoon in both study sites. Lowest salinity, was noted during monsoon season (Table 4, Fig. 4).

2.4 Dissolved Oxygen (DO)

Dissolved oxygen was high during monsoon season. DO values were less during pre-monsoon and post-monsoon seasons. Among the two sites, water collected from Puthuvyppu composed of high DO during all the seasons (Table 5, Fig. 5).

2.5 Biological Oxygen Demand (BOD)

BOD value was highest in post-monsoon season in both the study sites. In mangrove area high BOD was noticed. During monsoon season BOD was minimum in water collected from Chettuwai (Table 6, Fig. 6).

2.6 Chloride

Among the seasons studied, the pre-monsoon recorded high chloride concentration in Chettuwai and Puthuvyppu. Minimum concentration of chloride was recorded during monsoon season. When mangrove and non-mangrove areas were compared, non-mangrove areas showed higher chloride concentration than the mangrove sites (Table 7, Fig. 7).

2.7 Sodium

Well marked variations in Sodium concentration was recorded in all seasons. Maximum concentration was recorded during the post-monsoon season followed by the pre-monsoon one. During monsoon season, low values of Na were recorded which was attributed to dilution by rain water in both study sites (Table 8, Fig. 8).

2.8 Potassium

Higher concentration of K was recorded during pre-monsoon followed by post-monsoon season in both study sites. Lowest value of K was recorded in the monsoon season (Table 9, Fig. 9).

2.9 Calcium

Maximum concentration of calcium was recorded during pre-monsoon followed by post-monsoon season. Low value of Ca was recorded during monsoon season in both the study sites (Table 10, Fig. 10).

2.10 Magnesium

Maximum concentration of Mg was recorded during the pre-monsoon followed by post-monsoon season. Minimum value was recorded during monsoon season in both study sites. Higher concentration of Mg in the mangrove site was due to the contribution of Mg by the decomposed mangrove litter (Table 11, Fig. 11).

II. SOIL ANALYSIS

1. Physical parameters

1.1 Moisture content of the soil

Among the various seasons studied, the monsoon season recorded higher moisture content than the pre and post-monsoon seasons. The mangrove sites recorded high moisture content than the non-mangrove sites. This is due to the sandy-loam texture of the soil of these sites. It has high moisture holding capacity. Mangrove sites contained high organic matter, leading to high moisture content (Table 12, Fig. 12).

1.2 Soil Texture

The soil of mangrove sites was made up of silt and clay particles. This type of soil shows high water holding capacity, soil aeration and supply of available nutrients. Abundance of sand, silt and clay was noticed in the mangrove substratum of Chettuwai. In Puthuvyppu silt and clay was abundant in the substratum. At the estuary, sand was the main constituent of the sediment.

2. Chemical Parameters

2.1 Hydrogen ion concentration (pH)

pH was found to be low during the monsoon season than the pre and post-monsoon seasons in Puthuvyppu. Low pH was observed in Chettuwai during pre and post-monsoon seasons indicating the acidity of the soil. Puthuvyppu soil recorded a higher pH than the estuarine soil. This alkaline pH was due to the dominance of sea water (Table 13, Fig. 13).

2.2 Electrical Conductivity (EC)

High electrical conductivity (EC) values were recorded during pre and post-monsoon seasons in both study sites. The monsoon season recorded the lowest EC values which may be due to dilution by rain water. High EC values were observed in mangrove sites when compared to non-mangrove sites. The sediments of mangrove sites containing high organic matter and acidic pH attain specific conductivity values (Table 14, Fig. 14).

2.3 Salinity

The monsoon season recorded the lowest salinity. Post-monsoon recorded highest salinity followed by pre-monsoon season in both study sites (Table 15, Fig. 15).

2.4 Organic Carbon

The mangrove sites recorded higher values of organic carbon. It is due to plant and animal debris deposited in the soil. Increased organic carbon in the mangrove soil is due to microbial degradation of mangrove litter. Pre-monsoon and post-monsoon seasons recorded higher values for organic percentage than monsoon season in both study sites (Table 16, Fig. 16).

2.5 Chloride

Post-monsoon season recorded the highest concentration of Cl^- followed by pre-monsoon season. Higher concentration of Cl^- was noticed at the mangrove sites. Monsoon season recorded lowest Cl^- value because of the influx of rainwater (Table 17, Fig. 17).

2.6 Sodium

Higher concentration of Sodium during pre-monsoon followed by post-monsoon season in both study sites. Lowest concentration of Na during monsoon season may be because of dilution by rainwater. In the mangrove sites, higher concentration of Na was recorded (Table 18, Fig. 18).

2.7 Potassium

Potassium concentration was maximum during pre and post-monsoon seasons. Decay of mangrove leaves liberates K, contributing to high values of K in the sediment. low value of K was recorded during the monsoon season. It may be due to dilution by rain water (Table 19, Fig. 19).

2.8 Calcium

Higher concentration of Calcium during the pre and post-monsoon seasons. Lower value of Ca was recorded during monsoon season in both study sites (Table 20, Fig. 20).

2.9 Magnesium

Higher value of magnesium was recorded during pre and post-monsoon seasons. Lower concentration of Mg during monsoon season in both study sites (Table 21, Fig. 21).

III. FLORAL STUDIES

From the Table 22 it is clear that *Acanthus ilicifolius, Avicennia officinalis, Bruguiera cylindrica, Excoecaria agallocha* and *Rhizophora mucronata* are common in both study sites - Chettuwai of Thrissur District and Puthuvyppu of Ernakulam District. *Aegiceras corniculatum* is seen only in Chettuwai and absent in Puthuvyppu. Three species of *Bruguiera* present in Ernakulam district but only one (*B. cylindrica*) is present in Chettuwai [Plate I(a) and I(b)].

Vivipary

In *Rhizophora* and *Bruguiera* the seed germinates while it is still attached to the mother plant. Further, the seedlings grow, emerges from the fruit and is dispersed. But in *Avicennia* and *Aegiceras*, the seedling does not emerge from the fruit prior to dispersal and it is called cryptovivipary. In *Avicennia* sp. the fruit coat splits shortly after the time of dispersal, releasing an embryo with two thick and fleshy cotyledons folded in opposite directions. In *Aegiceras*, the radicle and hypocotyl elongate in the fruit and at dispersal the torpedo-shaped propagules are released (Plate II & III).

ANATOMICAL STUDIES

Acanthus ilicifolius L.

Leaf is dorsiventral and petiolate with thick cuticle. Epidermis is single layered both in upper and lower layers. Salt glands are present in both surfaces of the lamina. Each salt gland was one celled, surrounded by 5-6 jacket cells. Stomata are not sunken and confined to the lower epidermis. In the lower epidermis, both salt glands and stomata were intermingled. Hypodermis or water storage tissue was two layered thick below the upper epidermis. This aqueous tissue maintains succulence of the leaf. Mesophyll with upper two-layered palisade and lower spongy tissue consists of loosely arranged cells. Veins are embedded in the mesophyll surrounded by sclerenchyma.

Stem

Epidermis is two layers thick. Cortex is multilayered with compactly arranged parenchymatous cells. Stem shows secondary growth. Secondary xylem is with lesser number of xylem vessels and more tracheids. Sclereids occur external to secondary phloem. Pith was very large and with compactly arranged parenchymatous cells (Plate IV).

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

Leaf is dorsiventral and petiolate with thick cuticle. Epidermis single layered in both surfaces. Salt glands were present in both upper and lower surfaces. Each gland was composed of a large number of excretory cells (16-celled) and a single large basal cell. Stomata are confined to the lower epidermis and are sunken. In the lower epidermis, both salt glands and stomata were intermingled. Hypodermis is two layered thick below the upper epidermis. Mesophyll tissue consisted of upper two-layered thick palisade and lower spongy tissue with loosely arranged cells. Vascular bundles are collateral and closed with sclerenchyma on the outer side.

Stem is with multilayered and thick cork, covered with wax. Cortex is multilayered and is made up of parenchyma. Solitary sclereids are scattered in the cortex. Stelar region consists of inner circular cylinder of secondary xylem, cambium and outer secondary phloem. Secondary xylem is with small xylem vessels arranged in uniseriate manner. Pith consists of parenchymatous

tissue. Sclereids and a few secretary cells containing tannin are also seen in the pith. Tannin cells are abundant in *Aegiceras* (Plate V).

Avicennia officinalis L.

Leaf is dorsiventral and petiolate. Cuticle is waxy on the upper surface. Epidermis is one layer thick in the upper and lower region. Upper epidermis possesses a large number of salt glands. The salt glands are seen in shallow pits on the upper surface. Each salt gland consists of 2-4 highly vacuolated basal cells, a cutinised stalk cell and terminal cells that are covered by a thin cuticle. This thin cuticle is minutely perforated. Salt is deposited in the subcuticular cavity of the gland and then ultimately reaches the leaf surface through the cuticular pores. Salt glands excrete salt as crystals on the leaf surface in bright day time and as solution of salt in the evening.

Lower epidermis of leaf is with non-glandular uniseriate hairs with short stalk and pear-shaped terminal cells attached on it, providing white velvet appearance to the lower surface. The salt glands and hairs on the leaf surface are for removing salt from the underlying mesophyll cells. Stomata are deeply sunken in the lower epidermis. Due to the thick growth of non-glandular hairs in the lower epidermis, stomata are not clearly visible as in the case of other mangrove leaves.

Hypodermis is 4-layered thick beneath the upper epidermis with compactly arranged parenchymatous cells. Mesophyll consists of more than

one layer of upper palisade tissue and 3-4 layered thick lower spongy tissue. In the midrib region the vascular bundle was surrounded by sclerenchymatous cells. Vascular bundles are collateral and closed. Veins are seen embedded in the mesophyll tissue. Tannin cells are abundant in *Avicennia*.

Stem shows anomalous secondary growth with successive rings of cambia. Cambial ring produces secondary xylem in the inner region and secondary phloem in the outer region and ceases its growth. Second cambial ring developed in the cortex and produced secondary phloem in the outer region and secondary xylem in the inner region. Interxylary phloem is noticed in *Avicennia* stem as a result of anomalous secondary growth. The outer region of the stem is with multilayered cork. Cortex is with outer collenchymatous and inner parenchymatous cells. Pith consisted of compactly arranged parenchymatous cells. Tannin cells are present in the cortex and pith.

Pneumatophores are aerial roots developing from the lateral roots. Outer region of pneumatophore is with a multilayered cork which is thick. It is ruptured at the outer surface to form lenticles. Cortex is broad and parenchymatous having numerous air cavities. Secondary growth is seen in pneumatophores. Vascular cylinder is with inner secondary xylem and outer, secondary phloem. Secondary xylem contains small xylem vessels, xylem tracheids and fibres. Pith consists of parenclymatous cells which were loosely arranged (Plate VI).

***Bruguiera cylindrica* (L.) Blume**

Leaf epidermis is single layered with thick waxy cuticle. Stomata are confined to the lower epidermis. Hypodermis is one layer thick below the upper epidermis and above the lower epidermis. Crystals occur in the hypodermal cells. Mesophyll tissue is with an upper palisade consisting of three layers of elongated cells. Spongy tissue is multilayered with intercellular spaces. Stomata are deeply sunken and are confined to the lower epidermis. In the midrib region, large vascular bundles are present which are collateral and closed. Large air cavities are seen in the midrib region and mesophyll.

Stem is with multilayered cork in the outer region. Cortex is thick and multilayered with compactly arranged parenchymatous cells. Sphaeraphides occur in the cortical cells. Secondary xylem is with small xylem vessels. Xylem is traversed by fibres. Multiseriate rays are present. Pith is large and parenchymatous. Large number of tannin cells occurs in both cortex and pith. Sclereids are also present in the cortex and pith.

Stilt root - Aerial roots are modified into knee roots (*B. gymnorrhiza*), stilt roots (*B. cylindrica*) and root buttress (*B. sexangula*).

Outer region of these roots is protected by cork consisting of suberized cells and ordinary parenchymatous cells. Cortex is thick containing abundant, large intercellular spaces, arranged radiately around the stele.

Sclerenchymatous idioblasts occur in the cortical parenchyma.

B. gymnorrhiza and B. sexangula showed variations in leaf thickness, number of palisade layers, hypodermis, etc. *B. gymnorrhiza* shows grerater leaf thickness than *B. cylindrica* and *B. sexangula* [Plate VII(a) and VII(b)].

***Excoecaria agallocha* L.**

Leaf is dorsiventral and petiolate. Two glands are present on the base of lamina. Cuticle is thick. Epidermis is one layer thick on both surfaces. Hypodermis is single layered below the upper epidermis. Stomata are confined to the lower epidermis and are not sunken. Mesophyll is with an upper two-layered palisade and a lower spongy tissue. Upper layer of palisade consists of large cells and lower layer with smaller cells. Spongy tissue is multilayered with large air cavities. Veins are embedded in the mesophyll tissue. In the midrib region, large, collateral, closed vascular bundles are observed. Sclerenchyma is present external to phloem.

Stem is with cork layers in the outer region. Cortex is multilayered and parenchymatous. Stele is with circular cylinder of outer secondary phloem, cambium and inner secondary xylem. Pith consists of parenchymatous tissue. Leaf and stem are with latex cells. Tannin cells are also present (Plate VIII).

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

Leaf is isobilateral and petiolate. Epidermis is two layered in the upper and one layered in the lower surface. Cuticle is thick and waxy. Hypodermis is two layered below the upper epidermis and single layered in the lower region. Stomata are deeply sunken and are confined to the lower epidermis. Mesophyll is with upper single layered palisade. Lower region is occupied by multilayered spongy tissue with loosely arranged cells.

Mature stem consists of outer multilayered cork. Cortex is with two types of cells-outer small cells and inner medium cells, with sphaeraphides. Vascular region is with outer secondary phloem and inner secondary xylem. Pith consists of loosely arranged parenchymatous cells (Plate IX).

***Rhizophora mucronata* Lamk.**

Leaf is dorsiventral and petiolate. Lamina is with black circular spots in the lower surface known as corkwarts. Cuticle is thick and waxy. Epidermis is two layered in the upper and single layered in the lower surfaces. Hypodermis is three layered below the upper epidermis and single layered in the lower region. Stomata are sunken and are present in the lower epidermis. Mesophyll is with upper palisade of single layer of elongated cells. Lower spongy tissue is multilayered with large intercellular spaces. In the midrib region, large vascular bundles are seen. Around the vascular bundles air cavities are present. Sphaeraphides are present in the hypodermis and also in

the ground tissue of midrib region.

But in *R. apiculata* epidermis is single layered. Hypodermis is two layered below the upper epidermis. All other characters are similar to *R. mucronata*.

Stilt roots

Outer region is protected by cork which is ruptured by lenticels. Hypodermis consists of compactly arranged parenchymatous cells. Cortex is multilayered, parenchymatous and with solitary sclereids. Tannins cells are also present in the cortex. Vascular strand amphicribral in which central xylem is surrounded by phloem. Pith consists of compactly arranged parenchymatous cells (Plate X).

***Sonneratia caseolaris* (L.) Engl.**

Leaf is isobilateral and petiolate with thick cuticle. Epidermis is one layer thick in both upper and lower surfaces. Stomata are deeply sunken and confined to both epidermal layers. Salt glands are numerous and scattered in both abaxial and adaxial surfaces of leaf. Each salt gland is multicellular and surrounded by several jacket cells. Mesophyll consists of upper and lower palisade tissue below the upper epidermis and above the lower epidermis. In between these, about six layered thick colourless water storage tissue is present. It consists of compactly arranged parenchymatous cells. Idioblasts are scattered in the mesophyll tissue as well as colourless water storage tissue.

Mature stem is with an outer multilayered cork. Cortex is broad and parenchymatous. Stele shows outer secondary phloem and inner secondary xylem. Pith consists of parenchymatous cells.

Pneumatophores are aerial breathing roots with spongy outer surface. Lenticels or pores are formed by the rupture of epidermal layer. Outer layer of pneumatophore consists of multilayered thick cork. Cortex consists of air cavities surrounded by ovoid cells. Numerous branched sclereids are scattered in the cortex. Pneumatophore show secondary growth. Vascular cylinder is with outer secondary phloem and inner secondary xylem. Secondary phloem in the outer region is associated with groups of brachy sclereids. Pith consists of compactly arranged parenchymatous cells, associated with sclereids (Plate XI and XII).

A comparative account of leaf anatomy of all the above species is shown in the Table 23. Table 24 shows the stomatal study including stomatal frequency and stomatal index in all the above species except *Avicennia*. A comparison of the structure and size of salt glands of *Acanthus*, *Aegiceras*, *Avicennia* and *Sonneratia* was shown in the Table 25.

BIOCHEMICAL STUDIES

Seasonal variations in Dry weight percentage

(a) Leaf

Dry weight percentage of leaf tissue of all species shows seasonal variations. In *Acanthus* pre-monsoon season showed maximum value for dry weight percentage and minimum during post-monsoon season. *Aegiceras* leaf showed maximum value during pre-monsoon and minimum during monsoon season. *Avicennia* showed maximum value for dry weight percentage during pre-monsoon and low value during post-monsoon season. *Bruguiera* also showed maximum value during pre-monsoon season. But *Excoecaria* showed maximum value in post-monsoon season and minimum value during monsoon season. *Rhizophora* showed maximum value for dry weight percentage during pre-monsoon season and minimum value during post-monsoon season. *Sonneratia* showed maximum value during pre-monsoon season and minimum value during monsoon season. In almost all species maximum value for dry weight percentage was recorded during pre-monsoon season except *Excoecaria* leaf (Table 26).

(b) Stem

Mangrove stem also showed seasonal variations in dry weight percentage. Stem of all species showed maximum value for dry weight percentage during pre-monsoon season followed by post-monsoon season.

But *Avicennia* showed maximum value during pre-monsoon and minimum during post-monsoon season (Table 27). In this case, monsoon season showed greater value than post-monsoon season.

Seasonal variations in Moisture content percentage (MC%) in mangroves.

(a) Leaf

All species of mangroves investigated showed seasonal variations in moisture content. *Acanthus* showed maximum MC % during post-monsoon and minimum during pre-monsoon season. But *Aegiceras* showed maximum MC% during monsoon and minimum during pre-monsoon season. In *Avicennia* maximum value for MC% recorded in post-monsoon and minimum in pre-monsoon season. *Bruguiera* showed maximum value during post-monsoon and minimum value during pre-monsoon season. But in the case of *Excoecaria,* higher value for MC% was recorded during monsoon season and lower value during post-monsoon season. *Rhizophora* recorded maximum value during post-monsoon and minimum value during pre-monsoon season. In *Sonneratia* maximum value for MC% recorded in monsoon season and minimum value in pre-monsoon season (Table 28).

(b) Stem

Seasonal variations were found to be significant in moisture content percentage (MC%) in mangrove stem. *Acanthus* stem recorded maximum

MC% during monsoon season and minimum during pre-monsoon season. In *Aegiceras* also the same trend was noted. But in *Avicennia* maximum MC% was observed during post-monsoon and minimum during pre-monsoon season. In all other species, maximum MC% was seen during monsoon season and minimum during pre-monsoon season (Table 29).

Seasonal variations in total protein content of mangroves

(a) Leaf

Total protein content of mangrove leaves varied with seasons. In monsoon season the habitat of mangroves with low salinity and minimum salt stress, the investigated taxa showed maximum protein content. During post-monsoon season the protein content in the leaves of mangroves decreased when compared to monsoon season. During pre-monsoon season less amount of protein was recorded compared to monsoon season. In some species pre-monsoon season showed less amount of protein than post-monsoon season. Eg. *Acanthus*, *Aegiceras* and *Rhizophora*. But in all other species studied, pre-monsoon season showed high amount of protein than post-monsoon season. Maximum protein content recorded in *Rhizophora* during monsoon season. *Sonneratia* recorded next to *Rhizophora*. Low value was recorded in *Aegiceras*. Maximum protein content varied between 114 mgg^{-1} to 410 mgg^{-1} during monsoon season in mangrove leaves. Pre-monsoon season recorded 76 mg g^{-1} to 263 mg g^{-1} protein content. Post-monsoon recorded 85 mg g^{-1} to

310 mg g^{-1} protein content in mangrove leaves. In some species the variation in protein content between three seasons was less when compared to other species (Table 30, Fig. 22).

(b) Stem

Mangrove stem also showed seasonal variations in protein content. The protein content was highest in the monsoon season than in the other two seasons. In some species, pre-monsoon season with less amount of protein than the other two seasons eg. *Acanthus* and *Bruguiera*. In all other species post-monsoon season with less protein content than the other two seasons. In pre-monsoon season the protein content varied between 93 mg g^{-1} and 207.4 mg g^{-1}. In monsoon season the range of protein content was 134 mg g^{-1} to 324 mg g^{-1}. In post-monsoon season the range of protein content was 80 mg g^{-1} to 198 mg g^{-1}. Among the seven species studied the stem of *Rhizophora* showed maximum value for protein content during monsoon season and *Sonneratia* stem with minimum value for protein content. In *Rhizophora* stem a wide range of variation in protein content was recorded in three seasons (Table 31, Fig. 23).

Seasonal variations in Total Amino acid content of mangroves

(a) Leaf

Total amino acid content of mangrove leaves showed variations in three seasons. The monsoon season is with less amino acid content when

compared to pre-monsoon and post-monsoon seasons. *Sonneratia* leaves are found to possess very low amino acid content during monsoon when compared to other species. *Bruguiera* leaf with high amino acid content than the other species. The range of total amino acid in mangrove leaves was 0.33 mg g^{-1} to 1.76 mg g^{-1}. Pre-monsoon season showed an increase in the total amino acid content than the monsoon season. The range of amino acid content in the pre-monsoon season was 2.24 mg g^{-1} to 4.69 mg g^{-1}. Maximum value for amino acid content was recorded in *Rhizophora* and minimum in *Avicennia*.

Post-monsoon season showed a further increase in amino acid content than the pre-monsoon season. Maximum value was recorded by *Sonneratia* leaf and minimum by *Acanthus* leaf. The amino acid content varied between 3.37 mg g^{-1} and 11.25 mg g^{-1}. In *Sonneratia*, *Rhizophora* and *Avicennia* a wide range of increase in amino acid content was noticed between monsoon and post-monsoon seasons (Table 32, Fig. 24).

(b) Stem

Mangrove stem showed very low amino acid content during monsoon season. It ranged between 0.66 mg g^{-1} and 2.34 mg g^{-1}. The stem of *Excoecaria* showed maximum value for the total amino acid content during the monsoon season and *Avicennia* stem showed the minimum value. The pre-monsoon recorded an increase in the amino acid content in all the species

studied. The range of amino acid content was 2.03 mg g^{-1} to 5.43 mg g^{-1}. *Excoecaria* stem recorded maximum value and *Sonneratia* stem minimum value for the amino acid content. The post-monsoon season recorded maximum increase in the amino acid content than the other two seasons. The amino acid content varied between 3.25 mg g^{-1} and 8.59 mg g^{-1}. *Excoecaria* showed the maximum increase in amino acid content than the other species. The order of increase in amino acid content among the three seasons was monsoon, pre-monsoon and post-monsoon. Post-monsoon season showed maximum increase in amino acid content in all the species studied (Table 33, Fig. 25).

Seasonal Variations in Proline Content of Mangroves

(a) Leaf

Mangroves showed seasonal variations in proline content. During monsoon season minimum amount of proline was recorded in mangrove leaves. It was the normal value for proline in mangroves. The value ranged between 0.112 mg g^{-1} and 0.180 mg g^{-1}. During pre-monsoon and post-monsoon seasons the value of proline content increased considerably. Pre-monsoon season recorded higher values for proline content. The value ranged between 0.241 mg g^{-1} and 0.402 mg g^{-1}. Among the species studied *Aegiceras* showed maximum value for proline content and *Excoecaria* showed minimum value during pre-monsoon season. Post-monsoon season showed

further increase in proline content. The value ranged between 0.270 mg g^{-1} and 0.491 mg g^{-1}. Maximum increase recorded in the leaf of *Excoecaria*. Among the seasons studied post-monsoon recorded maximum increase in proline content followed by pre-monsoon (Table 34, Fig. 26).

(b) Stem

Seasonal variations in proline content was recorded in mangrove stem. Minimum value for proline content was noticed in the stems of all species in monsoon season. It ranged between 0.115 mg g^{-1} and 0.209 mg g^{-1}. *Sonneratia* stem with lower value for proline content and *Aegiceras* stem with higher value. Pre-monsoon season recorded an increase in the proline content. It ranged between 0.207 mg g^{-1} and 0.346 mg g^{-1}. High value for proline content was noticed in *Excoecaria* stem and low value in *Sonneratia* stem during the pre-monsoon season. Post-monsoon season recorded maximum increase in proline content in all species except *Rhizophora* and *Excoecaria* in which proline content is maximum in pre-monsoon season. The value of proline ranged between 0.241 mg g^{-1} and 0.423 mg g^{-1} in the post-monsoon season. Higher value for proline was noticed in the stem of *Acanthus* and lower value in the stem of *Excoecaria* during the post-monsoon season. The amount of proline increased from monsoon through pre-monsoon and reached maximum in the post-monsoon seasons (Table 35, Fig. 27).

Seasonal variations in Tannin Content in Mangroves

(a) Leaf

Mangroves showed seasonal variations in tannin content. The monsoon season recorded minimum value for tannin content when compared to pre-monsoon and post-monsoon seasons. The range of tannin content varied between 130 μg g^{-1} and 361 μg g^{-1}. Maximum amount of tannin recorded in the leaf of *Sonneratia* and minimum in the leaf of *Avicennia*. The pre-monsoon season recorded an increase in tannin content. The value ranged between 208 μg g^{-1} and 459 μg g-1. Maximum value recorded in the leaf of *Sonneratia* and minimum in *Bruguiera* leaf. But maximum increase in tannin content recorded in *Excoecaria* leaf. The post-monsoon season recorded a further increase in tannin content in all the species. The value ranged between 294 μg g^{-1} and 557 μg g^{-1}. *Sonneratia* leaf with higher value for tannin content and *Acanthus* with minimum value. *Excoecaria* leaf showed maximum increase in tannin content during post-monsoon when compared to that of the monsoon season (Table 36, Fig. 28).

(b) Stem

Mangrove stems showed seasonal variations in tannin content. The mangrove stem showed less amount of tannin in the monsoon season. The value ranged between 112 μg g^{-1} and 527 μg g^{-1}. Minimum value recorded in the stem of *Acanthus* and maximum in the stem of *Sonneratia*. Pre-monsoon

season recorded an increase in the tannin content than the monsoon season. The value of tannin content ranged between 192 μg g^{-1} and 246 μg g^{-1}. Maximum increase in tannin content was noticed in *Aegiceras* than the other species. Minimum increase was recorded in *Acanthus*. The post-monsoon season showed further increase in tannin content than the pre-monsoon season. The range of value varied between 228 μg g^{-1} and 691 μg g^{-1}. Maximum increase in tannin content was noticed in *Excoecaria* and minimum increase in *Acanthus*. Gradual increase in tannin content was noticed in pre-monsoon and post-monsoon seasons (Table 37, Fig. 29).

Seasonal variations in Mineral composition of mangroves

(a) Leaf

Mangrove leaves showed seasonal variations in mineral composition. In all the seasons Na^+ and Cl^+ ions were dominant than K^+, Ca^{++} and Mg^{++} ions. Lesser amount of all mineral ions was recorded during monsoon season. Highest values for these mineral ions were recorded in pre-monsoon season. Post-monsoon season with the values for mineral ions in between monsoon and pre-monsoon seasons. In *Acanthus* maximum values for Na^+ and Cl^- during pre-monsoon. But K^+, Ca^{++} and Mg^{++} showed maximum values during post-monsoon season. Minimum values for all ions recorded during monsoon season. Similar trend was noticed in *Aegiceras*. But in *Avicennia*, Potassium ion content was maximum during pre-monsoon season. In *Bruguiera* all

mineral ions showed maximum values during pre-monsoon seasons. But in *Excoeccaria* higher values for Na^{+} and Mg^{++} were recorded during post-monsoon season. In *Rhizophora* only Mg^{++} showed higher value during post-monsoon season and all other ions with maximum values during pre-monsoon season. In *Sonneratia* K^{+} and Mg^{++} ions showed higher values during post-monsoon season and all other ions with maximum values during pre-monsoon seasons (Table 38, Fig. 30).

(b) Stem

Mangrove stem showed seasonal variations in the mineral composition. *Acanthus* stem showed maximum values for all minerals during the pre-monsoon season. Monsoon season with minimum values for all minerals and post-monsoon season with mineral content greater than monsoon season and less than pre-monsoon season. The same trend was noticed in *Aegiceras, Avicennia, Bruguiera, Excoecaria, Rhizophora and Sonneratia*. The mineral contents showed only slight variation in pre-monsoon and post-monsoon seasons (Table 39, Fig. 31). Salt accumulation in stems was less than leaves and varied in narrow range.

Seasonal variations in the amount of Epicuticular wax (ECW) in mangroves

Environmental conditions influence the quantity, composition and morphology of the waxy coverings of leaf surfaces. Mangroves showed

seasonal variations in the amount of epicuticular wax (ECW). Maximum amount of epicuticular wax were recorded in most of the species during monsoon season. Gradual decrease in the amount of wax was noticed in both pre-monsoon and post-monsoon seasons.

In *Acanthus* maximum amount of wax was recorded during post-monsoon season than monsoon season and lowest value in pre-monsoon season.

In *Aegiceras*, *Avicennia*, *Bruguiera*, *Excoecaria*, *Rhizophora* and *Sonneratia*, the maximum value for epicuticular wax was recorded during monsoon season and lesser amounts in post-monsoon and pre-monsoon seasons (Table 40, Fig. 32).

PHYSIOLOGICAL STUDIES

Seasonal Variations in Chlorophyll Content of Mangroves

The chlorophyll content of mangroves varied with seasons. Less amount of chlorophyll was noticed in the pre-monsoon season than the other two seasons. The monsoon season recorded greater values of chlorophyll content than the pre-monsoon season. The post-monsoon season recorded an increase in the chlorophyll content than the monsoon season. A great variation in the chlorophyll content was noticed among the three seasons. In *Acanthus* there was five times increase in chlorophyll a in the post-monsoon season than the pre-monsoon season. Chlorophyll b showed three times

increase and total chlorophyll showed four times increase. In *Aegiceras* pre-monsoon season showed a decrease in chlorophyll content than the monsoon season. In monsoon and post-monsoon seasons the amount of chlorophyll b was greater than chlorophyll a. The post-monsoon season showed a greater increase in chlorophyll content. Chlorophyll a with five times increase and total chlorophyll showed four times increase.

In *Avicennia* the post-monsoon season recorded highest value for chlorophyll content. In the post-monsoon season there was about two times increase in chlorophyll content than the pre-monsoon season. In *Bruguiera* also there was decrease in chlorophyll content in the pre-monsoon and increase in post-monsoon season than the monsoon season. Chlorophyll a showed four times increase in the post-monsoon than the pre-monsoon season and chlorophyll b and total chlorophyll showed three times increase. In *Excoecaria* also the similar pattern of increase in chlorophyll content was noticed. Chlorophyll a recorded about 3 times increase in the post-monsoon season than the pre-monsoon and chlorophyll b and total chlorophyll showed double increase in chlorophyll content.

In *Rhizophora* there was slight increase in the chlorophyll content. The post-monsoon recorded maximum increase than the monsoon season and the pre-monsoon showed a decrease in the chlorophyll content than the monsoon season. *Sonneratia* also showed an increase in chlorophyll content in the post-monsoon season and decrease in the pre-monsoon season than the

monsoon season. Chlorophyll a, chlorophyll b and total chlorophyll showed about three times increase in the chlorophyll content in the post-monsoon season than the pre-monsoon season. Thus the leaf tissue of mangroves showed a decrease in chlorophyll content in the pre-monsoon season and an increase in chlorophyll content during post-monsoon season (Table 41, Fig. 33).

The ratio of chlorophyll a and chlorophyll b showed seasonal variations. In *Acanthus* chlorophyll a/chlorophyll b showed maximum value in the post-monsoon season. But in *Aegiceras* higher value for chlorophyll a/chlorophyll b was recorded in the pre-monsoon than the monsoon and post-monsoon seasons. In *Avicennia* higher value for chlorophyll a/chlorophyll b was recorded in the post-monsoon season. *Bruguiera*, *Excoecaria* and *Sonneratia* also recorded higher value for chlorophyll a/chlorophyll b in the post-monsoon season. But in *Rhizophora* the monsoon season recorded higher value for chlorophyll a/chlorophyll b (Table 42, Fig. 34).

Chlorophyll fluorescence

In *Acanthus ilicifoluis* Fv/Fm values ranges between 0.658 and 0.768. Lower values for Fv/Fm is in the afternoon and higher values in the morning. It showed maximum stress in the afternoon. This stress caused photosynthetic inhibition. The higher values of Fv/Fm in the morning showed recovery of photosynthetic inhibition in *Acanthus*. Electron transport pre reaction centre

(ET_0/RC) increased upto 1.00. When ET_0/RC increases dissipation of energy (DI_0/RC) decreases. Photosynthetic performance Index (PI) values varied between 22.71 and 93.77. The higher value for Fv/Fm (0.768) showed maximum photosynthetic performance index (93.77). This showed when stress is lowered, performance index increases (Table 43).

In *Aegiceras corniculatum* Fv/Fm varied between 0.618 and 0.802. Corresponding ET_0/RC also showed an increase. But some values for ET_0/RC showed a decrease, DI_0/RC showed decrease except two cases. Photosynthetic performance index varied between 8.746 and 93.18. The Fv/Fm value around 0.83 showed maximum photosynthetic performance index (Table 44).

In *Avicennia officinalis* the Fv/Fm values ranged between 0.648 and 0.790. ET_0/RC values and DI_0/RC values showed regular pattern ie. When ET_0/RC value is higher DI_0/RC value is lower. Only one value showed a slight increase (0.4398). Photosynthetic performance index varied between 16.055 and 118.304. Here also Fv/Fm value close to 0.83 showed maximum performance index (Table 45).

In *Bruguiera cylindrica* Fv/Fm values ranged between 0.663 and 0.818. The higher values were recorded in the forenoon (between 7.00 AM and 8.00 AM). The maximum values like 0.786, 0.817 and 0.818 were close

to 0.83 and it showed less stress in the morning because of recovery of photosynthetic inhibition. Lower Fv/Fm values with higher ET_0/RC value and lower dissipation of energy showed changes occured in the photosystem II (PSII). Photosynthetic performance index is maximum in the cases where Fv/Fm values were maximum (Table 46).

In *Rhizophora mucronata* Fv/Fm values varied between 0.651 and 0.791. ETo/RC also showed a gradual increase from 0.498 to 0.638. Correspondingly DI_0/RC showed a gradual decrease from 0.640 to 0.269. Photosynthetic performance index is maximum in the case where Fv/Fm value was higher (0.79). It showed leaf with less stress and maximum photosynthetic performance index (Table 47).

DISCUSSION

Ecological study included analysis of water and soil of two study areas - Chettuwai and Puthuvyppu. Both physical and chemical parameters were analysed.

Water Quality Analysis

Physical parameters of water includes mainly temperature. Water temperature is crucial to aquatic life. Temperature is of importance to physiological processes such as photosynthesis and respiration. Physiological stress may be experienced when high temperatures are combined with full sunlight. Pre-monsoon and post-monsoon seasons recorded high values for temperatures in both study sites, evidently exerting maximum stress on mangrove flora.

High pH values during monsoon and pre-monsoon seasons in Chettuwai indicates that water is alkaline. It may be due to mixing of fresh and brackish waters during tides in the estuary. But in Puthuvyppu high pH value during post-monsoon season indicates that water is alkaline. It may be due to decomposition of mangrove litter.

Electrical Conductivity (EC) of water is a measure of ability of the water sample to conduct electric current, which is the reciprocal of resistance.

It provides a very rapid means of obtaining a good estimate of the total dissolved solid concentration and salinity of water samples. Most of the dissolved inorganic substances in water are in an ionised state which contributes to conductance. A number of salts are found dissolved in natural water, the common ones being carbonates, chlorides, sulphates, phosphates and nitrates of Ca, Mg, Na, K, etc. which contribute to electrical conductivity in water samples analysed (Lakshmy, 2002). Maximum value for EC during pre and post-monsoon seasons is due to higher concentration of dissolved salts in water. During monsoon, the water is almost pure with lesser amount of dissolved salts.

Salinity was considered the most significant parameter controlling the distribution of mangroves. Salinity of mangrove areas was greatly affected by seasonal rainfall and evaporation (Aksornkoae, 1993). The salinity of water may be mainly due to the presence of NaCl. A very high salinity was observed in pre-monsoon when compared to monsoon season. Very low salinity during monsoon may be due to high flushing during the monsoon season. The high values during the pre-monsoon season were found to be related to the lean Summer flows and increase in evaporation (Lakshmi, 2002).

Dissolved oxygen (DO) is an important parameter of water quality, which is an index of physical and biological processes taking place in water.

Dissolved oxygen in water maintains the higher form of life and keep the proper balance of various populations, thus making the water body healthy. Dissolved oxygen concentrations in mangroves varies according to areas and zonation of plants (Aksornkoae, 1993). The results indicate that dissolved oxygen is maximum in monsoon season - 6.69 mgl^{-1} and 7.89 mgl^{-1} in Chettuwai estuary and Puthuvyppu respectively. Lowest values are recorded in post-monsoon season with values 3.52 mgl^{-1} and 4.56 mgl^{-1} in Chettuwai and Puthuvyppu respectively. This showed that dissolved oxygen concentration varies according to season, richness of plants and aquatic organisms in mangroves. The higher values in the monsoon period may be due to the intrusion of fresh DO rich water into the study sites. Mangrove rich sites CI, CII and CIII recorded high DO values which are an indication of productive water body. In Puthuvyppu PII, PIII and PIV are mangrove rich site with higher values of DO.

The rate of removal of oxygen by microorganisms through the anaerobic degradation of dissolved organic matter is reflected as Biological Oxygen Demand (BOD). It is an index of organic pollution in water. The BOD of tidal waters and estuaries is affected by salinity and only low values was obtained. The BOD values for Chettuwai estuary during pre-monsoon ranges from 2.80 to 3.42 mgl^{-1} and 0.43 to 1.12 mgl^{-1} during monsoon. In Puthuvyppu, the value for BOD was 2.65 to 3.68 mgl^{-1} and 0.45 to 1.4 mgl^{-1} in pre-monsoon and monsoon seasons respectively.

Chloride is the common anion found in water. Its concentration in natural waters varies from a few milligrams to several thousand milligrams per litre. In coastal region and estuary, seawater intrusion may contribute to the chloride content of inland water. Chloride is a major constituent in seawater. High chloride content was noted during pre-monsoon in Chettuwai and Puthuvyppu. During pre-monsoon high electrical conductivity (EC) was also noted. It is due to high chloride content during pre-monsoon. Low chloride concentration in mangrove sites may be due to special tolerance mechanism shown by mangroves. They have the unique capacity for salt accumulation, which may reduce the chloride content in water. The fine grained sediments in the mangrove sites may bind chloride from the overlying water.

Sodium is one of the important, naturally occuring alkali metals whose concentration is remarkably high in saline and brackish waters. Sodium limits biological diversity due to osmotic stress (Lakshmi, 2002). In both study sites, high concentration of Sodium is reported during post-monsoon season. Sodium concentration in Chettuwai was in a range of 414mgl^{-1} and 1081mgl^{-1} during monsoon and pre-monsoon respectively. In Puthuvyppu Sodium concentration was in a range of 356 mgl^{-1} and 1822 mgl^{-1} during monsoon and pre-monsoon respectively. Very low concentration during monsoon season may be due to dilution by rain water.

Potassium is a naturally occurring element whose concentration remains quite lower than Sodium. Higher concentration of Potassium was recorded during pre-monsoon season - 812 mgl^{-1} and 921 mgl^{-1} in Chettuwai and Puthuvyppu respectively. Monsoon season recorded lowest value for Potassium, 146 mgl^{-1} and 101 mgl^{-1} in Chettuwai and Puthuvyppu respectively. The lowest value in monsoon season may be due to influx of freshwater.

Calcium is an important macronutrient in the aquatic environment and it is the fifth element in the order of abundance. It is a predominant cation in river water. High concentration of Calcium is recorded during the pre-monsoon season in both study areas - 1445 mgl^{-1} and 515 mgl^{-1} in Chettuwai and Puthuvyppu respectively. Monsoon season recorded lowest value for Calcium concentration. It may be due to dilution by rainwater and influx of freshwater.

Magnesium is an important constituent of seawater and estuarine water. It is an essential constituent of chlorophyll molecule without which no ecosystem could operate. High values of Magnesium concentration were recorded during pre-monsoon in both Chettuwai and Puthuvyppu -16.90 mgl^{-1} and 24.51 mgl^{-1} respectively. Lower value for Magnesium during monsoon season may be due to dilution of water by rain. Mangrove sites with high

concentration of Magnesium is due to the contribution by decomposed mangrove litter.

Soil analysis

Soil is a natural medium for plant growth and it supplies the required nutrients to growing plants. Water in the soil is an important solvent and transporting agent. It maintains the texture and compactness of soil and makes it habitable for microbes, plants and animals. The moisture content in soil is mainly from infiltration of precipitated water. Its content in soil depend upon the water holding capacity of soil, evaporation, soil texture, porosity, etc. (Lakshmi, 2002). The percentage of moisture content in Chettuwai and Puthuvyppu was maximum during monsoon season. It is due to the soil texture. Chettuwai estuary soil is rich in sand, silt and clay and hence has maximum water holding capacity. In Puthuvyppu, silt and clay was abundant in the substratum. Chettuwai soil is with higher moisture content percentage than Puthuvyppu soil. In Chettuwai the estuarine soil is permanently water satuarated whereas in Puthuvyppu the soil is only moist.

pH of the soil is a good measure of the indication of acidity or alkalinity of soil. Chettuwai estuary soil showed pH value close to neutral value - 6.5 to 6.9 during monsoon season and low pH during pre-monsoon and post-monsoon seasons. This indicates acidity of the soil. In Puthuvyppu higher values for pH were recorded during pre-monsoon and post-monsoon

seasons, indicating alkalinity of the soil. The mangrove sediments were found to be acidic. Mangroves prefer low pH ie. the sediments may become acidic due to the reduction of sulphides to sulphate with consequent formation of sulphuric acid in annoxic conditions (Lakshmi, 2002).

Electrical conductivity (EC) gives a clear idea of the soluble salts present in the soil. Conductivity of soil is usually lower than that of water. In both study areas, the monsoon season recorded the lowest EC values which may be due to dilution of soil water by rain water. The increase in salt content in mangrove sites may be due to estuarine water and the decaying mangrove litter. Decreased salinity in the monsoon season may be due to the leaching of salt ions as a result of precipitation (Chandrashekhar and Sandhyarani, 1996). The increase in salinity level during pre and post monsoon seasons may be due to decreased water contents in both soils of the study sites.

The salinity of the habitat is at a minimum during monsoon but increased during the dry period ie. pre-monsoon and post-monsoon seasons. Lowest salinity was recorded in the monsoon season in both study areas and it ranged between 0.5 ppt to 1.1 ppt in Chettuwai and 0.8 ppt to 1.7 ppt in Puthuvyppu. Salinity observed in the pre-monsoon season was 0.9 ppt to 2.9 ppt and 1.8 ppt to 6.2 ppt in Chettuwai and Puthuvyppu respectively. In the

post-monsoon, the values were 1.8 ppt to 3.1 ppt and 0.9 ppt to 3.6 ppt in Chettuwai and Puthuvyppu respectively.

The high salinity values were recorded for coastal soils in all the months compared to interior soils. The salinity was lowest in January and highest in March for both the soils. There was a gradual increase in salinity from January to March and a subsequent decrease in both the cases. The increase in salinity level upto March may be due to decreased water content in the soil of both the study areas. Decreased salinity from April onwards was because of leaching of salt ions as a result of precipitation (Chandrashekhar and Sandhyarani, 1996).

Mangrove soils showed high values for organic carbon. It is due to the microbial degradation of mangrove litter. The organic carbon percentage in Chettuwai and Puthuvyppu soil varied from 0.38% to 0.65% and 0.55% to 1.85% respectively during monsoon season. But pre-monsoon and post-monsoon seasons recorded higher values for organic carbon percentage. During pre-monsoon season, organic carbon percentage varies between 0.59% to 2.92% in Chettuwai and 0.41% to 2.12% in Puthuvyppu. Post-monsoon values for organic carbon percentage are 0.55% to 1.15% and 0.38% to 2.21% in Chettuwai and Puthuvyppu respectively. This shows that the estuarine soil in Chettuwai is rich in organic carbon than Puthuvyppu soil.

The chloride content in Chettuwai and Puthuvyppu during monsoon ranged between 150 mg/100 gm to 205 mg/100 gm and 122 mg/100 gm to 205 mg/100 gm respectively. Higher values were recorded during pre-monsoon and post-monsoon seasons. This may be due to the decomposition of mangrove litter in both the study areas. Lowest value in the monsoon may be due to the influx of freshwater. The Sodium content was maximum during the pre-monsoon season in both the study areas. The values ranged between 10.9 mg/100gm and 17.5gm/100gm in Chettuwai and 9.5gm/100gm and 22.4gm/100gm in Puthuvyppu. Lowest value was recorded during the monsoon season because of the influx of rainwater.

The pre-monsoon period recorded higher values for Potassium content in both the study areas. The values ranged between 2.70 mg/100gm and 9.61mg/100gm and 3.81 mg/100gm to 9.31 mg/100gm in Chettuwai and Puthuvyppu respectively. Lesser value in post-monsoon season was recorded in both study sites. Lowest value was recorded during the monsoon season. It may be due to dilution by rainwater. Higher values during pre-monsoon and post-monsoon seasons is due to decay of mangrove leaves, liberating Potassium.

Both the study areas recorded high values for Calcium content during pre-monsoon season. The values ranged between 2.8 mg/100gm to 6.2 mg/100gm and 3.8 mg/100gm to 6.2 mg/100gm in Chettuwai and Puthuvyppu

respectively. Monsoon season recorded minimum values in both the study areas. This may be due to influx of freshwater. Higher values may be due to the degradation of mangrove leaves. Magnesium content was maximum during the pre-monsoon season in both the study areas. The value ranged between 2.9mg/100gm and 8.9mg/100gm in Chettuwai and 2.5mg/100gm and 4.1mg/100gm in Puthuvyppu. The monsoon season recorded lowest value due to the influx of freshwater. The increase in Magnesium contents during the pre-monsoon may be due to the decay of mangrove litter.

Anatomical Studies

The way in which the plants function is determined by their physiology and the internal structural organization and arrangement. Anatomical data are capable of predicting many of the most important physiological and ecological features of species.

The important anatomical features of mangrove leaves are the presence of colourless water storage tissue at different levels of mesophyll and at hypodermal layers, short tracheids at the vein endings, sclereids of various shapes, etc. These features may be interpreted as an adaptation to climate and habitat. The presence of water-storage tissue and terminal tracheids cause leaf succulence with high water content (Das and Ghose, 1996). According to Zimmermann (1983) both sclereids and tracheids are involved in capillary water storage. Tomlinson (1986) suggested that in addition to water storage,

sclerids might provide mechanical support to leaves with diminished turgor or discourage herbivores. The coriaceous nature of many mangrove leaves is probably due to the presence of these sclereids.

The significance of succulence in the physiology of halophytes has been discussed at length in botanical literature. One effect is to reduce the rate of water loss relative to the volume of the shoot and another is to reduce the concentration of salt in the cells through the absorption of water. In some plants, it has been observed that, despite the continued accumulation of salt in the leaves during growth, salt concentration does not rise appreciably because of increased succulence.

The cuticle is thick in many mangroves. It is generally smooth but is uneven in *Sonneratia*. Waisel (1972) assumed that the cuticle of mangrove leaves is an adaptive feature.

Mangrove leaves contain some isolated specialized cells such as sclereids (*Rhizophora*), oil cells (*Bruguiera*), crystalliferous cells or sphaeraphides (*Bruguiera*, *Kandelia* and *Rhizophora*), tannin cells (*Rhizophora, Kandelia, Bruguiera*, etc). and laticiferous cells (*Excoecaria*). Each palisade cell of *Bruguiera* and *Avicennia* has large oil globules.

Among the mangrove leaves studied, there are different structural types. *Rhizophora mucronata* and *R. apiculata* have dorsiventral leaf with hypodermal water storage tissue. In *Bruguiera,* the dorsiventral leaf possess

hypodermal and internal water storage tissue. *Excoecaria agallocha* has dorsiventral leaf and single layered hypodermal water storage tissue. *Kandelia candel* with isobilateral leaf, has no stomata on the upper surface, whereas *Sonneratia* with isobilateral leaf, has stomata on both surfaces. In *Sonneratia* middle part of the mesophyll is occupied by water storage tissue.

The water storage tissue is a characteristic feature of mangrove leaves. The thickness of water storage tissue causes leaf succulence with increased water content. About six-layer thick water storage tissue is present in *Sonneratia.* So *Sonneratia* leaf shows maximum succulence. Succulence is one of the most common features of halophyte, which is often considered to be an adaptation to reduce the internal salt concentration (Sen and Rajpurohit, 1982).

The occurence of salt glands is inherent in many plant species adapted for marshy habitat, because salt cannot accumulate in plant tissues beyond a limit. Excretion of ions by special glands is a well known mechanism for regulating the mineral content of many halophytic plants. Salt glands are found most abundantly on leaves, though their number is lesser than that of stomata in the lower epidermis. The morphology of salt glands varies from the simple to multicellular structures. The walls of the cells of the salt gland, which are exposed to the external air are covered by a cuticle, which has pores through which the salt solution is excreted. Gland cells differ from

normal mesophyll cells in shape and arrangement. Cells are without chloroplasts. The salt gland in *Aegiceras* is large and composed of more cells than *Acanthus*, *Avicennia* and *Sonneratia*. Irrespective of the environmental conditions and the species studied, salt glands are present in the seedling and mature plants, but the excretion of salt is limited to the plants growing in the saline habitat. This reveals that eventhough salt glands are present in the seedlings growing in non-saline habitat, its function is restricted in mature plants growing in saline environment. The salt glands are meant for excreting excess salts accumulated in the mangroves, thus maintaining a salt balance in the plants.

In the leaf of *Avicennia*, the lower epidermis possesses thick growth of non-glandular, uniseriate hairs with short stalk. These hairs give a white velvety appearance to the lower surface of *Avicennia* and protect sunken stomata, thereby reducing transpiration.

The stem of mangroves showed secondary growth. But definite annual growth rings are absent. In *Avicennia* stem, anomalous growth rings are observed. The absence of growth ring is due to the variation in cambial activity (Tomlinson, 1986). All the species investigated showed the abundance of tannin cells in the cortex and pith. So the stem of mangroves possess significant tannin content. High frequency of narrow vessel elements occur in all mangroves (Tomlinson, 1986). He also concluded that a slight

decrease in diameter of vessel elements brings about a proportionally much greater increase in resistance to flow. Wood anatomical features of the true mangroves do not show any uniformity, although all of them belong to the same ecological environment. Their anatomical affinities are more towards their respective families than the special ecological community and distinct variability exists in the morphological features and density of the vessel elements, fibres, ray and axial parenchyma (Das and Ghose, 2000).

Pneumatophore in *Avicennia* show a large number of lenticels on the surface. In young pneumatophores, the lenticles are not functional in gas exchange. As the pneumatophores grow, the complementary tissue ruptures, the periderm and the lenticel becomes functional (Hovenden and Allaway, 1994). They also proved that the periderm of pneumatophores is both water-air-tight resulting in gases kept in the root system and water out. The greater the cross sectional area of the internal gas space, the greater the maximum oxygen conductance of the pneumatophore.

In *Sonneratia*, the roots have much longer period of development and undergo secondary thickening and they become quite tall up to 1 m. The pneumatophores usually remain unbranched. The surface of pneumatophore in *Sonneratia* is with flaky bark in younger roots and smooth bark in older roots. The cortex in both *Avicennia* and *Sonneratia* pneumatophore is with parenchymatous tissue enclosing wide air spaces or aerenchyma.

In *Rhizophora* stilt roots arise from the trunk and lowest branches and anchor the tree into muddy substrate. In the cortex of stilt roots in *Rhizophora*, branched cells joined together by round tannin cells and scattered trichosclereid are observed. Large pith of the stilt root contains prismatic crystals. In *Bruguiera* the aerial roots are represented by knee-roots. The cortex of knee-roots contains chains of lignified, thick-walled aerenchymatous cells alternating with thin-walled cells, enclosing large air spaces. The outer cortex contain large number of tannin cells.

The aerial roots in mangroves are adapted for aeration with numerous lenticels in the periderm and aerenchyma which has air spaces that act as reservoirs. Root hairs are absent in all subterranean roots of mangroves. Fibres and sclereids found in prop roots and stilt roots supporting the main stem.

Biochemical Studies

Salinity alters many biochemical reactions in plants. The monsoon season recorded maximum protein content in the vegetative tissues in all the species investigated. Reduction in protein content is observed in both pre-monsoon and post-monsoon seasons. In stressed leaves, the protein content was reduced. Leaves of *Acanthus, Aegiceras, Avicennia* and *Rhizophora* showed maximum reduction in protein content during pre-monsoon season while those of *Bruguiera, Excoecaria* and *Sonneratia* showed maximum

reduction in protein content during post-monsoon season. But in stem, *Acanthus* and *Bruguiera* showed maximum reduction in protein content during pre-monsoon season and in others during the post-monsoon season.

Maximum protein content was shown by *Rhizophora* leaf and stem. Present investigation in protein content gives an idea about the nutritive value of mangrove species in terms of protein content. The leaves of mangroves are used as fodder.

The reduction in protein content during pre-monsoon and post-monsoon seasons is due to salinity or water stress which caused proteolysis or inhibition of protein synthesis (De and Kar, 1994).

Protein synthesis was reduced by the stress, but a greater effect of stress was seen on protein degradation. The loss of protein brought about by stress is the result of both reduced protein synthesis and enhanced protein degradation. Degradation was apparently affected to a greater extent than synthesis (Dungey and Davies, 1982). Present investigation also showed that stress caused a significant increase in protein degradation. Under stress conditions 'stress proteins' are synthesized (Webster, 1980). NaCl decreases protein synthesis and increases its hydrolysis in many crop plants. This increase in hydrolysis of proteins in salinized glycophytes, must lead to an increase in the products of hydrolysis - the amino acids (Levitt, 1980).

Increase in free aminoacid content and simultaneous enhancement in protease activity and decrease in protein content were found in bajra leaf under saline conditions. It explains that the accumulation of free amino acids may be partially due to hydrolysis of protein by the enzyme protease (Reddy and Vora, 1985).

Aminoacids have been reported to accumulate in higher plants under salinity stress. Total free aminoacids in leaves are reported to be higher in salt tolerant than in salt sensitive lines of sunflower (Ashraf and Tufail, 1995). In the present investigation, lesser amino acid content was recorded in both leaf and stem of all species in the monsoon season. In the pre-monsoon season an increase in total aminoacid content was noticed. A greater increase in aminoacid content was recorded in post-monsoon season in all the species. This increase in aminoacid content is due to the degradation of protein by salinity stress in plants. Seasonal changes evidently show that accumulation of aminoacids increase at the time of increased salinity in habitats (Joshi *et al*., 1993).

Considerable increase in free aminoacid content and simultaneous enhancement in protease activity and decrease in protein content were found in bajra leaf under saline conditions, explaining that the accumulation of free aminoacids may be partially due to hydrolysis of protein by the enzyme protease (Reddy and Vora, 1985). Under physiological stress there was an

increase in the total free amino acid content and the concentration of individual aminoacids in the free and bound state also varied (Mondal and Mondal (Nee Parui), 2002).

The investigations on free aminoacids in halophytes which occur in extremely saline milieus suggest that proline always occurs in large quantities (Stewart and Lee, 1974). Proline accumulation was maximum during Winter in halophytes accompanied by maximum succulence of salt accumulating parts (Joshi, 1982). Stewart and Lee (1974) suggested that proline functions as a source of solute for intracellular osmotic adjustment.

In the present investigation proline content showed an increase from monsoon, pre-monsoon and to post-monsoon seasons. Monsoon season with normal proline content in leaf with values ranged between 0.112 mgg^{-1} dry wt. and 0.180 mgg^{-1} dry wt. The pre-monsoon season showed an increase from 0.241 mgg^{-1} dry wt. to 0.402 mgg^{-1} dry wt. Maximum proline content was noticed in the post-monsoon season - 0.270 mgg^{-1} dry wt. and 0.491mgg^{-1} dry wt. Similarly mangrove stem also showed minimum value for proline content in monsoon season. The values ranged between 0.115 mgg^{-1} dry wt. and 0.209 mgg^{-1} dry wt. Increase in proline content was noticed in pre-monsoon and post-monsoon seasons. Maximum proline content was noticed in post-monsoon season in both leaf and stem of mangroves.

Stewart and Lee (1974) investigated different halophytic species and found that most of them are able to accumulate free proline. In some of them free proline comprises about 70 percent of the free amino acids. Bar-Nun and Poljakoff-Mayber (1977) showed that the amount of free proline increased in the roots of *Tamarix tetragyna* and *Pisum sativum* on exposure of the plants to salinity. This accumulation of proline may be linked with a better survival under stress. Proline accumulation was maximum during Winter in the halophytes accompanied by maximum succulence of salt accumulating parts (Joshi, 1982). In his work high accumulation of proline accounting for 20% to 83% of the total aminoacids was noticed.

Increase in proline content occurs in response to water deficit as well as to salt accumulation. Seasonal changes evidently show that accumulation of most of the amino acids increase at the time of increased salinity in habitats (Joshi *et al*., 1993). Proline accumulation is a common metabolic response of higher plants to water deficits and salinity stress. Proline protects membranes and proteins against the adverse effects of high concentrations of inorganic ions and temperature extremes (Pollard and Wyn Jones, 1979). The accumulation of proline or some other organic solutes associated with stress may be serving as a compatible solute in order to maintain the osmotic balance between the cytoplasm and vacuole (Flowers *et al*., 1977). It has been suggested that proline accumulation may be due to *de novo* synthesis (Barnett and Naylor, 1966) or decrease in proline utilization by decreasing

protein synthesis (Stewart, 1973). The diffusion of proline after rehydration of *Pennisetum* may be taken to indicate that proline serves as a storage compound during stress (Rani and Jesudas, 1994).

In the study on germinating mungbean seeds, De and Kar (1994) proved that water stress retarded mobilization of storage proteins in cotyledons during germination and stress induced proline accumulation occured only in embryonic axes. Ashraf (1989) in his study on salt tolerance of *Vigna* cultivars proved that both cultivars accumulated significantly greater proline in the leaves at high salinities than the control. Increased proline content in the plants may be an adaptation to overcome the stress conditions and proline accumulated under saline conditions supplies energy for growth and survival and thereby induces salinity resistance in rice varieties (Bal, 1975). The study by Chandrasekhar and Sandhyarani (1996) on salinity induced changes in *Crotalaria* indicated that salinity induced synthesis of proline and its accumulation associated with stress may serve as a compatible solute and thereby helps the plant to tolerate stress. The major function of proline is to maintain osmotic balance (Zidan, 1995). Proline act as a cytoplasmic osmotium as it accumulates to a higher degree under stress conditions which play an adaptive role for salt tolerance (Greenway and Munns, 1980). Sahoo *et al*. (2001) proved proline accumulation at a higher rate under NaCl stress in the tolerant cultivar of rice.

Accumulation of compatible solutes under salt stress was thought to be a basic process of adaptation. Proline accumulates consistently in numerous plant species and under a wide range of environmental conditions.

Tannins are organic substances present in the water soluble extracts of certain plants. These are water-soluble phenolic natural products that are protein precipitants (Waterman and Mole, 1994). In the present study, seasonal variation in tannin content was noticed. Lesser amount of tannin content is recorded during monsoon season in the leaf and stem of all the species investigated. Mangrove stem is with more tannin content than the leaves. Anatomical study also revealed this. Cortex and pith of stem with more tannin cells than the leaf. A gradual increase of tannin content was noticed during pre-monsoon and post-monsoon seasons. Maximum value was recorded in the post-monsoon season. *Sonneratia* leaf and stem showed a higher tannin content than the other species.

Recent evidence indicates that high levels of phenolic substances are often linked to unfavourable conditions of mineral nutrition of plants in general and in particular with reference to the availability of nitrogen and phosphorous (Chapin, 1980; Gershenzon, 1984). From the present investigation, it is clear that variation in tannin content is an adaptation to salinity stress.

Environmental conditions may strongly influence the quantity, composition and morphology of waxy coverings of leaf surfaces (Mayeux and Jordan, 1984). Mangroves also showed seasonal variations in the amount of epicuticular wax (ECW). All the species except *Acanthus* recorded higher values for epicuticular wax during the monsoon season. *Acanthus* recorded maximum amount of wax content during the post-monsoon season.

Chandrashekhar and Sandhyarani (1996) observed higher ECW deposition in plants of *Crotalaria striata* grown under saline habitat. The accumulation of ECW may be one of the adaptations for the survival of plants in the saline habitat which may result in reduced rate of transpiration. The authors also noticed a gradual and significant decrease in ECW content from March to May in both the plants grown under saline and non-saline conditions. The decrease may be at the onset of rains, decreased temperature and light intensity.

The waxes of plants in the mangrove areas of the Sundarban contain a number of unusual components which may be due to the plants' habitat (Prabal Sil *et al*., 1983). The seasonal pattern of wax deposition on honey mesquite leaves (*Prosopis glandulosa*) was characterized by relatively rapid accumulation during Spring when leaves were expanding. Little additional deposition occured after July at most locations. Heavy epicuticular wax deposits are fully formed in Summer (Mayeux and Jordan, 1984).

The estuaries are subjected to distinct seasonal variations. This is reflected in the composition of the water inundating the estuaries, as well as the elements in the leaves of the estuarine plants (Joshi and Bhosale, 1982). In the present investigation, all the mangrove species showed seasonal variations in mineral composition in both the leaf and stem. Mineral content is very low in the monsoon season in all the mangrove species. Highest values for mineral ions were recorded in the pre-monsoon season. In most of the species Sodium and chloride accumulation is maximum in pre-monsoon season. But accumulation of Potassium, Calcium and Magnesium is maximum in the post-monsoon season. *Acanthus ilicifolius* shows maximum accumulation of mineral ions during pre-monsoon season in the case of both leaf and stem. In all the species Sodium and chloride ions are dominant.

The increase in Potassium and Calcium contents in the mangroves in Summer may be for the development of salt tolerance (Joshi, 1982). Halophytes are able to survive considerably high concentration of salts in the habitats. So the salts are accumulated either in the plant until it dies or in the deciduous leaves which fall from the plants. The excess salts are even excreted through the glands. The changing salinity of habitats have direct effects on mineral uptake and their accumulation in plants (Joshi, 1982). He also noted that salt content in *Suaeda nudiflora* increases during Winter and Summer, when the salinity of the habitat is also increased and the leaves become succulent. Sodium and chloride were found to be the main

constituents of the ash and demonstrated a direct relationship with increased salt accumulation.

Joshi *et al*. (1993) noted in his work on *Salvadora persica* that Sodium and Calcium contributed to the major fraction of the ash followed by Magnesium and Potassium. Chloride balanced about half of the cationic content. The results showed a steady increase in the accumulation of salts and minerals from minimum amounts in monsoon to maximum in Summer through Winter. Salt accumulation in stems was lesser in extent than in leaves and varied in narrow range.

Rao *et al*, (2005) noted in his study on effect of salinity on halophytic grasses that Sodium and chloride increased in the leaf and stem with increase in salinity. In stem the Sodium and chloride contents were higher when compared to the leaves indicating stem as a potential sink. The total Sodium content is less in shoot than in the root. The rate of flux of Sodium and chloride to the whole plant increased with salinity and age of the plant.

Physiological Studies

Seasonal variations in dry weight percentage of leaf and stem were noted in the present investigation. All species except *Excoecaria* showed maximum dry weight percentage during pre-monsoon season. The dry weight : fresh weight ratio was highest in the shoots of plants grown in

170mμ NaCl and it decreased with both increasing and decreasing salinity. But the dry weight : fresh weight for the root was higher than that for the shoot. This may be due to the immigration of the carbohydrates from the shoots to the roots and the consequent increase of the dry matter at the expense of the water content. This may help the plant to tolerate the high salinity stress (Al-Zahrani and Hajar, 1998).

Shubhra *et al*. (2003) noted in their study that the dry weights of leaf, stem and root declined by approximately 20 to 25% under water deficit conditions as compared to the control. This decrease in weight of leaf, stem and root under water stress in clusterbean is due to reduced water supply from the rooting medium leading to the loss of turgor and inhibition of assimilatory processes. Decline in the leaf weight may be due to abscission of leaves induced by stress.

At higher salinity *Aeluropus lagopoides* showed distinguishing variation in fresh and dry plant biomass indicating its higher tolerance. The root biomass was found to be more at higher salinity in both *Eragrostis* and *Aeluropus*. This showed that roots have more tolerance than shoots. This is also clearly evident from the shoot/root biomass ratios of both the grasses (Rao *et al*., 2005).

Thus mangrove species with maximum dry weight percentage at higher salinity are more tolerant. The moisture content percentage (MC %)

show a reverse trend than dry weight percentage. *Acanthus* with maximum MC% during post-monsoon season indicate that it became more succulent to resist salinity. Similar case is noted in *Rhizophora* also.

Seasonal variations in the chlorophylls was noted in the present investigation. Higher values for chlorophyll content were recorded during the monsoon season and lesser values during pre-monsoon season. A great variation in chlorophyll contents was noticed in the three different seasons. Different mangrove species show variation in chlorophyll contents in different seasons.

Joshi and Bhosale (1982) showed that in the mangroves the chlorophyll contents are higher during Winter and lower during Summer and monsoon. This may be due to light and temperature fluctuations. In Summer there is bright light and high temperature while in monsoon the light is poor and temperatures are high. In Summer salinity of sea water is high. These factors may inhibit chlorophyll synthesis, while moderate light and temperature will promote chlorophyll synthesis.

Salinity resulted decrease in chl-a, chl-b and total chlorophyll contents. The decrease in total chlorophyll is mainly attributed to the destruction of chl-a, which is considered to be more sensitive to salinity than chl-b. Salinity conditions lead to destruction of the fine structure of chloroplast and instability of the pigment-protein complex. It may be a cause of decrease in

total chlorophyll content. The increase in chlorophyllase activity due to salinity results lowering of chlorophyll content (Reddy and Vora, 1986).

Ashraf (1989) observed that chlorophyll contents were reduced in two cultivars of black gram as a result of increasing salinity in the soil. But variation between cultivars was apparent only for chlorophyll b. The total chlorophyll and the proportion of its components depend on the biological processes and developmental stages of the plant and also on the type and concentration of the salts.

Total chlorophyll content decreased with increase in salinity at both the stages-tillering stage and grain filling stage of barley (Gill, 1992). The highest concentration of both chl-a and chl-b was noticed in the plants grown in the culture solution and then decreased with increasing NaCl concentration. The decrease in chlorophyll content may be due to salinity (Al-Zahrani and Hajar, 1998). Total chlorophyll content of the leaf declined under water stress condition at all the three sampling stages in clusterbean. It may be due to decreased synthesis and increased degradation of chlorophyll in leaves under water stress (Shubhra *et al*. 2003).

Chlorophyll fluorescence is one of the few physiological parameter that have been shown to correlate with salinity tolerance. A part of the light absorbed by chlorophyll molecules in a leaf is re-emitted as light ie. chlorophyll fluorescence. By measuring the yield of chlorophyll fluorescence,

information about changes in the efficiency of photochemistry and heat dissipation can be gained. The total amount of chlorophyll fluorescence is very small. When a leaf is transferred from darkness into light, photosystem II (PSII) reaction centres are progressively closed. This gives rise to an increase in the yield of chlorophyll fluorescence (Maxwell and Johnson, 2000).

In the present investigation, the data indicate that lower values for Fv/Fm in the afternoon and higher values in the morning. This indicates that maximum stress was in the afternoon. The higher values for Fv/Fm in the morning showed recovery of photosynthetic inhibition that has occurred during night. Lower Fv/Fm values with higher energy flux for electron transport showed changes occurred in Photosystem II (PSII). Photosynthetic performance index (PI) is maximum in the cases where Fv/Fm values were maximum. In the five mangrove species investigated, all are with lower values for Fv/Fm in the afternoon and higher values in the morning. This is because of the recovery from photosynthetic inhibition.

Chlorophyll fluorescence measurements provide a useful measure of photosynthetic performance of plants. Chlorophyll fluorescence can give insights into the ability of a plant to tolerate environmental stresses and into the extent to which those stresses have damaged the photosynthetic apparatus (Maxwell and Johnson, 2000). Photoinhibition was more recognisable as a

sustained increase in dissipation and a sustained decrease in electron transport probability than by reduction in trapping probability ie., the Fv/Fm ratio (Force *et al*., 2003).

SUMMARY AND CONCLUSIONS

Plant ecophysiology is an experimental science that seeks to describe the physiological mechanisms that underlie ecological observations. It is the study of physiological responses of plants to environment, aiming to provide causal mechanistic explanations for ecological questions that relate to survival, distribution, abundance and interactions of plants with other organisms. Ecophysiology of mangroves includes ecological, physiological and biochemical studies.

Mangroves are specialised salt tolerant plant groups which grow in the intertidal areas of tropical regions. These forest ecosystems are dominated by halophytic seed plants and belongs to different families. Uniqueness of mangrove ecosystem is that the biota is constantly under physiological stress caused by extreme environmental conditions. Mangroves have been successfully colonised by developing morphological, reproductive and physiological adaptations like pneumatophores, stilt roots, knee roots and viviparous germination.

For the present investigation, two study areas were identified - the Chettuwai estuary of Thrissur district and Puthuvyppu of Ernakulam district. The ecophysiological study of mangrove species of both the areas was conducted, encompassing ecological, physiological and biochemical aspects.

Ecological study includes the study of both abiotic and biotic components of mangrove ecosystem. Abiotic components include mainly water and soil which support the mangroves.

Water quality analysis involved both physical and chemical parameters. Physical parameter is mainly temperature of water. Chemical parameters assayed are pH, electrical conductivity (EC), salinity, dissolved oxygen (DO), biological oxygen demand (BOD) and mineral composition - Sodium, Potassium, Calcium, Magnesium and chloride.

Soil analysis comprises physical parameters like moisture content of the soil and soil texture. Chemical parameters studied are pH, EC, salinity, organic carbon and minerals like Sodium, Potassium, Calcium, Magnesium and chloride. All the studies were conducted in three seasons - monsoon, pre-monsoon and post-monsoon.

Biotic components of the mangrove ecosystem included in the present study comprises five species of mangroves in Chettuwai estuary - *Acanthus*, *Aegiceras*, *Avicennia*, *Bruguiera* and *Rhizophora*. Of the flora of Puthuvyppu, species of *Acanthus*, *Avicennia*, *Bruguiera*, *Excoecaria*, *Kandelia*, *Rhizophora* and *Sonneratia* were studied. Ecological study includes the floral study of the above mentioned species and their anatomical studies.

The floral studies reveal the morphological adaptations of mangroves in the saline habitat. *Avicennia* and *Sonneratia* with pneumatophores,

Bruguiera with knee roots and *Rhizophora* with stilt roots. Anatomical study includes the anatomy of leaf, stem and pneumatophore. Anatomical data are capable of predicting many of the important physiological and ecological features of mangrove species.

Biochemical studies in mangroves includes seasonal variations in total protein, total aminoacids, proline, tannin, epicuticular wax (ECW), etc. In all the above studies, well marked variations were observed in the monsoon, pre-monsoon and post-monsoon seasons. Maximum protein content was recorded in monsoon season and a decrease was observed in value in both pre and post-monsoon seasons. The total aminoacid content is minimum in monsoon and maximum in both pre and post-monsoon seasons. But proline content is found to be maximum in pre and post-monsoon seasons and minimum in monsoon season. Proline act as a solute which contribute the osmotic adjustment in mangroves during water stress. As a result of water stress, proline accumulated appreciably in leaves and stems of mangroves.

Physiological studies include calculation of dry weight percentage of mangrove leaf and stem; moisture content percentage of leaf and stem; seasonal variation in total chlorophyll content, chlorophyll a and b content and chlorophyll fluorescence. All the above data show seasonal variations, mainly due to water stress or salinity stress in the mangroves.

Mangroves are growing in saline habitat. The estuaries are subjected to seasonal variations which is reflected in the mineral composition of water and consequently that of mangroves. Salts are continuously absorbed by roots and transported into the shoots. In mangroves several mechanisms reduce the salt content, such as salt extrusion, salt excretion by salt glands as seen in species like *Avicennia, Aegiceras, Acanthus* and *Sonneratia* and salt accumulation in which mangroves deposit the Sodium and chloride ions in their bark, old leaves, etc. Excess salts are also removed by leaf fall, bark peeling, etc. as observed in *Bruguiera, Excoecaria* and *Sonneratia*. Salt exclusion includes ultrafiltration mechanism in which the salt ions are filtered out when water absorption takes place eg. *Rhizophora, Aegiceras, Bruguiera* etc.

In the present investigation, all the mangrove species showed seasonal variations in mineral composition in both leaf and stem. Mineral content is low in monsoon season and high in pre-monsoon seasons. The minerals identified in mangroves are Sodium, Potassium, Calcium, Magnesium and chloride. In all the above minerals, Sodium and chloride were found to be the main constituents of the ash and demonstrated a direct relationship with increased salt accumulations. Salt resistance of mangroves is based upon three different mechanisms, salt avoidance by roots, salt tolerance and salt evasion ie. secretion of some of the ions, but retention of others.

The mangrove habitat is physiologically dry because of salinity. So the mangroves show xerophytic characters like thick cuticle, thick waxy coating, sunken stomata and distribution of sclereids in leaf. Hypodermal aqueous tissues are present in most of the mangrove leaves, which increase their succulence. Often salt enter the mangroves, but as the leaves swell by absorbing water, concentrations do not increase significantly. This leads to the development of succulence in mangrove leaves, which is a common morphological feature of halophytes.

Mangroves are important scientifically due to their strange morphological and anatomical adaptations and special physiology like high osmotic potential of cell sap, reaction to salinity, desalination and vivipary. Mangrove ecosystems are commercially very significant and provide many direct and indirect services to man. So mangrove ecosystem must be conserved.

The mangrove vegetation that exists today in Kerala coast is just a vestige of what existed in the recent past. Many estuaries and backwaters of Kerala supported a rich mangrove flora until a few decades ago, were almost encroached by man for various purposes. This encroachment not only reduced the mangrove vegetation, and altered its habitat and changed the ecological niche of the estuarine ecosystem itself.

In conclusion, it may be noted that mangrove ecosystem must be protected. Intensive afforestation would certainly ensure formation of rich mangrove forests. Awareness programmes should be conducted by the Government for conserving the biodiversity of mangrove ecosystem.

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Table 1: Seasonal variations in Temperature (°C)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	29	31	30	31	31	30	29	31
Monsoon	27	30	28	25	26	28	29	30
Post-monsoon	31	32	30	29	30	31	28	29

Figure 1: Seasonal variations in Temperature (°C)

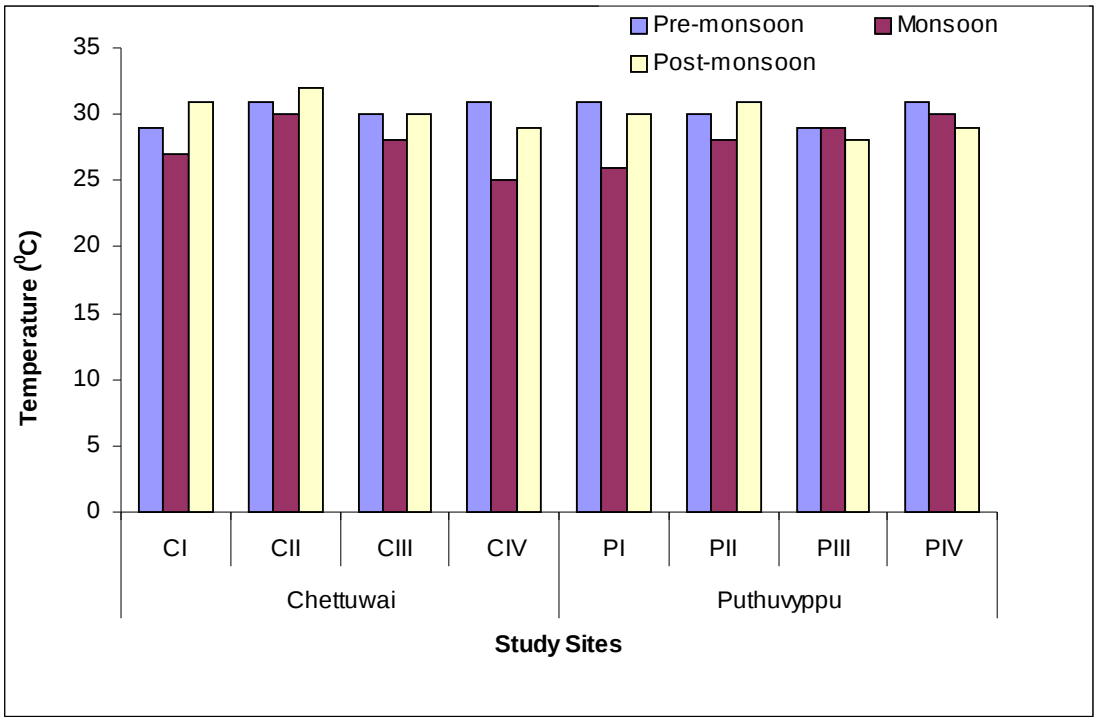


Table 2: Seasonal variations in pH

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	7.52	7.79	7.45	7.28	7.62	7.65	7.49	7.71
Monsoon	7.21	7.25	7.47	7.35	7.39	7.31	7.29	7.10
Post-monsoon	6.85	6.50	6.48	6.45	7.57	7.48	7.51	7.45

Figure 2: Seasonal variations in pH

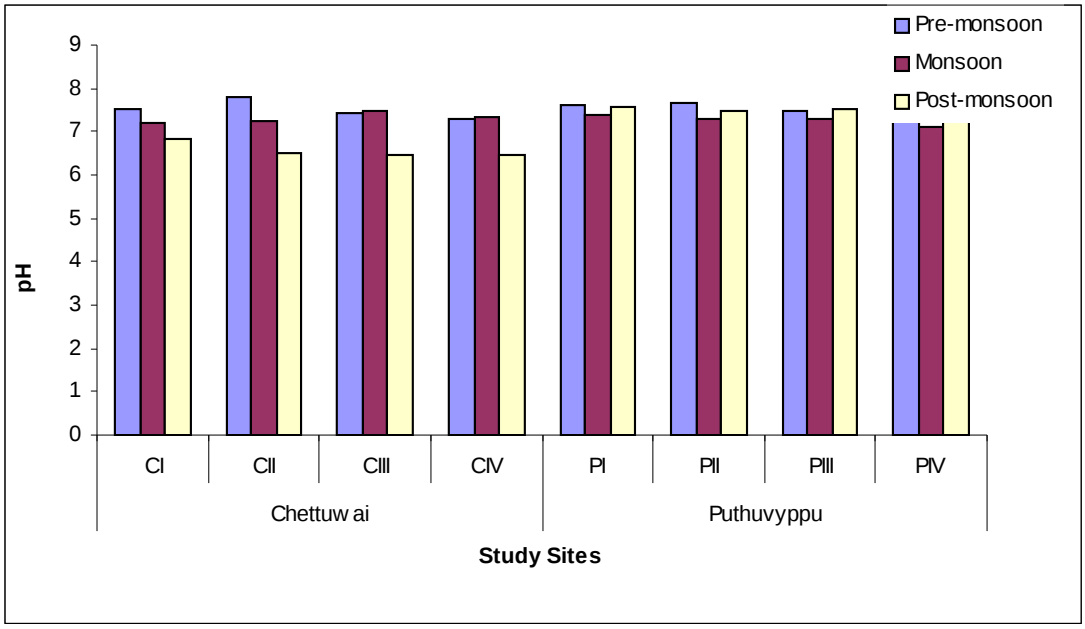


Table 3: Seasonal variations in Electrical conductivity (EC) (mhos cm^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	48.7	48.3	48.5	47.9	35.3	30.5	32.4	33.1
Monsoon	1.27	1.16	1.25	1.31	2.12	2.3	2.69	2.54
Post-monsoon	20.1	20.2	20.4	20.1	8.97	8.85	8.79	8.84

Figure 3: Seasonal variations in Electrical Conductivity (EC) (mhos cm^{-1})

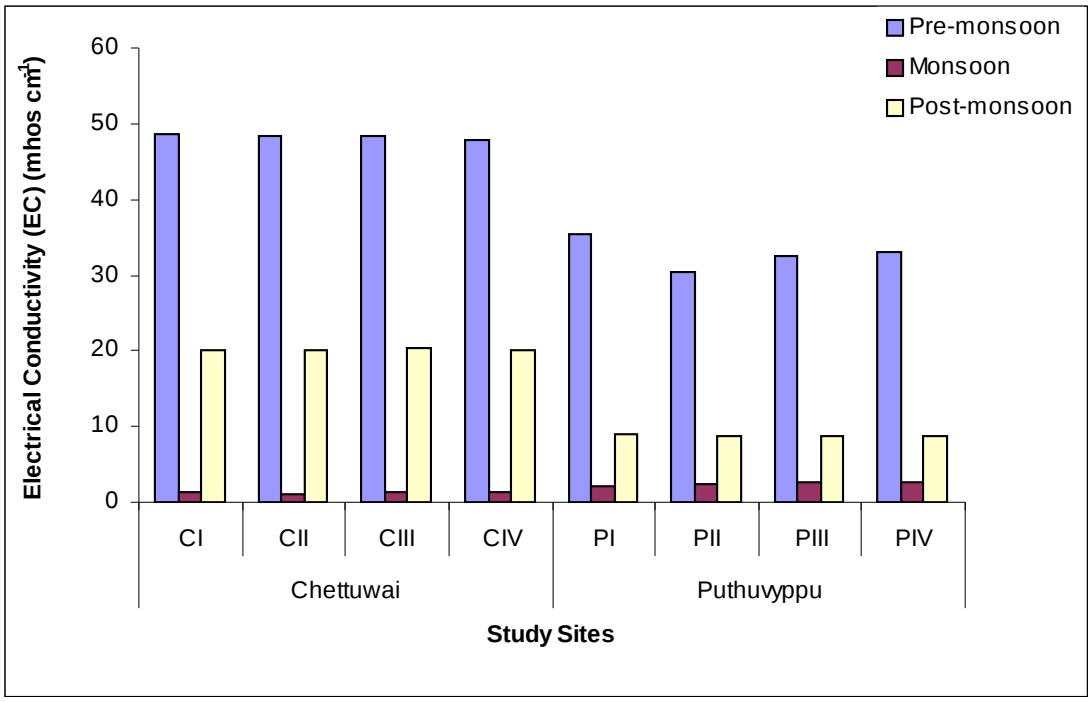


Table 4: Seasonal variations in Salinity (ppt)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	32.10	33.01	32.6	31	29.5	24.12	27.1	30.25
Monsoon	20.51	14.92	17.14	9.81	8.15	1.82	1.91	1.80
Post-monsoon	33.12	28.65	32.52	30.19	31.01	23.5	28.21	26.2

Figure 4: Seasonal variations in Salinity (ppt)

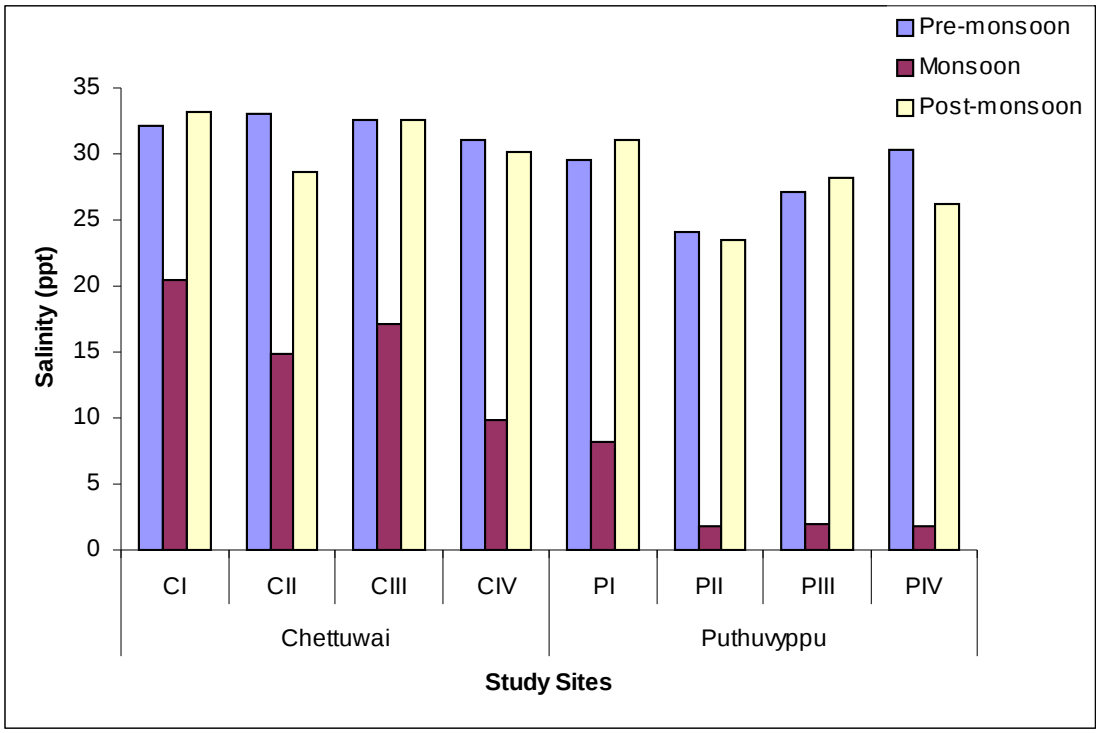


Table 5: Seasonal variations in Dissolved Oxygen (DO) (mgl^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	5.25	4.28	5.20	4.91	5.48	4.97	5.82	6.43
Monsoon	5.82	6.69	5.89	5.54	6.5	7.89	7.45	6.93
Post-monsoon	4.49	5.32	4.17	3.52	5.24	5.31	4.56	5.58

Figure 5: Seasonal variations in Dissolved Oxygen (DO) (mgl^{-1})

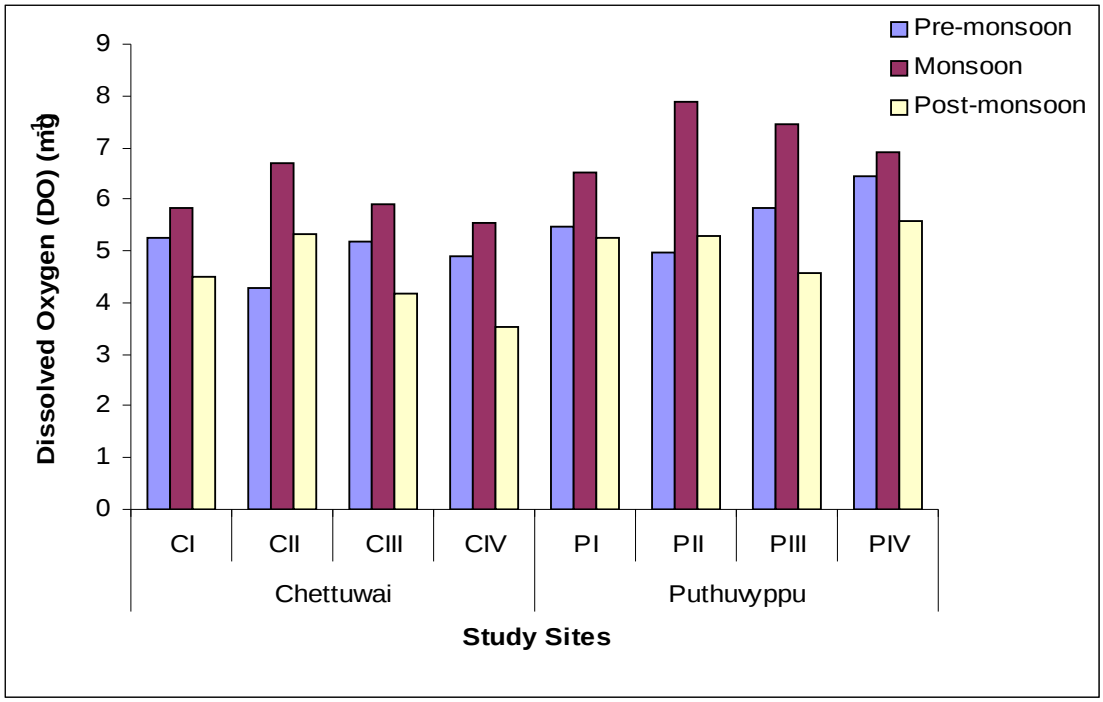


Table 6: Seasonal variations in BOD (mgl^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	3.4	2.2	0.92	3.1	2.4	1.15	1.11	1.13
Monsoon	0.76	0.43	0.91	1.12	0.69	0.45	1.01	1.41
Post-monsoon	2.80	3.62	2.85	3.42	2.80	2.65	3.28	3.68

Figure 6: Seasonal variations in BOD (mgl^{-1})

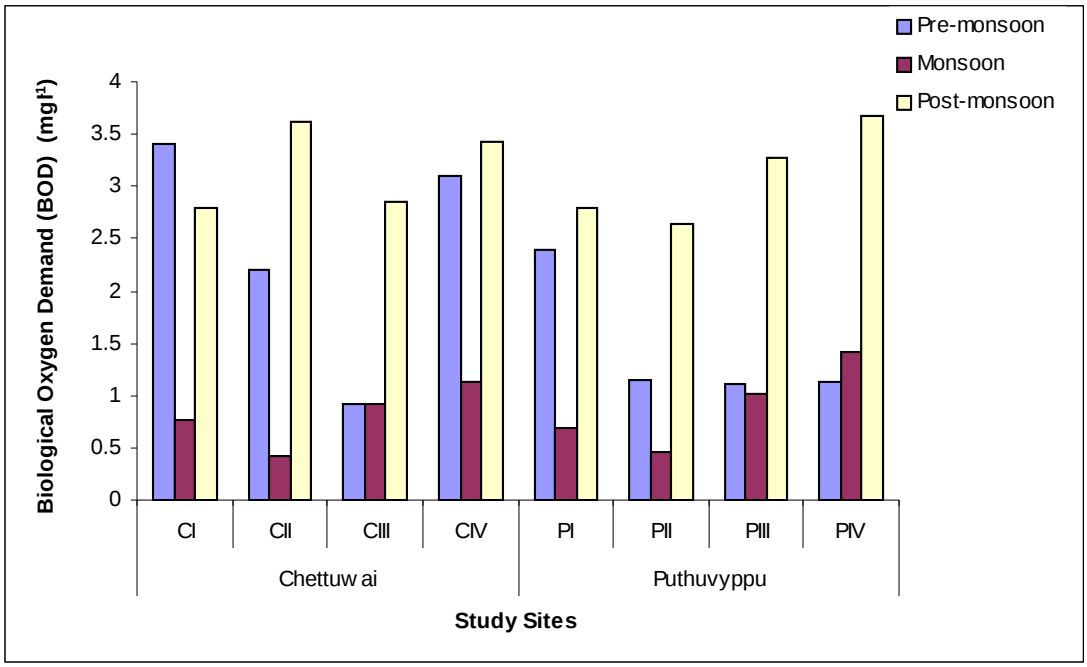


Table 7: Seasonal variations in Chloride (mgl^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	2593	2564	2381	2216	1985	1465	1545	1392
Monsoon	1301	1062	1512	1221	616	189	128	191
Post-monsoon	2185	2468	2120	2029	1852	1632	1789	1238

Figure 7: Seasonal variations in Chloride (mgl^{-1})

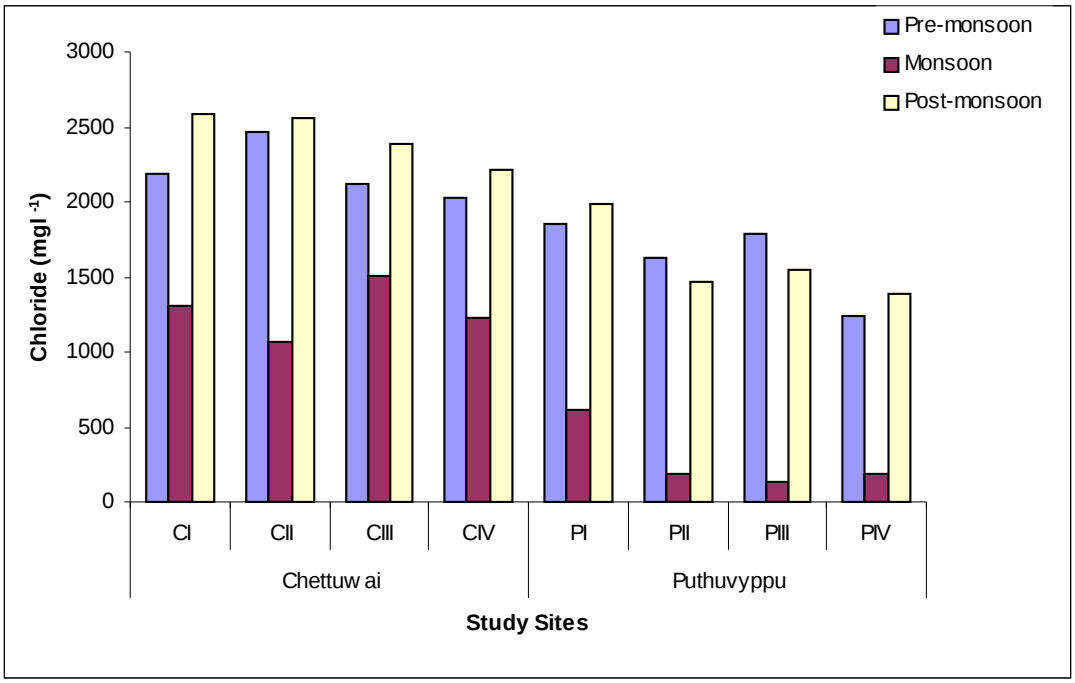


Table 8: Seasonal variations in Sodium (mg l^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	1172	1242	1081	1215	1028	1822	1038	1562
Monsoon	687	963	531	414	356	781	833	753
Post-monsoon	1665	1691	1712	1928	1158	6200	6718	7120

Figure 8: Seasonal variations in Sodium (mgl^{-1})

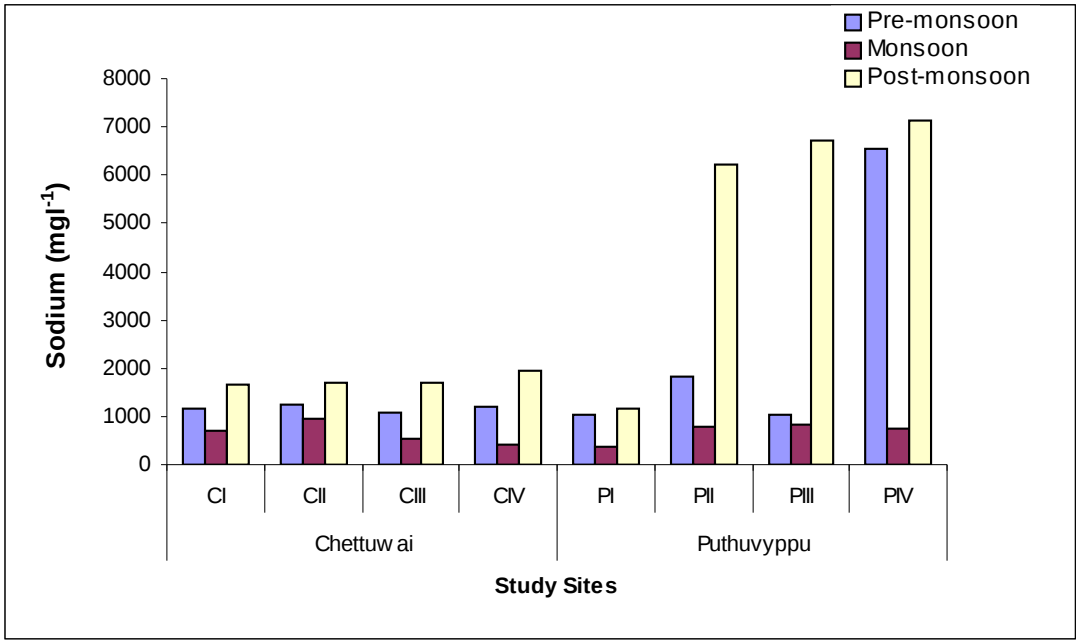


Table 9: Seasonal variations in Potassium (mg l^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	812	710	725	690	708	921	750	715
Monsoon	158	146	168	191	223	192	142	101
Post-monsoon	702	621	538	516	615	601	535	460

Figure 9: Seasonal variations in Potassium (mg l^{-1})

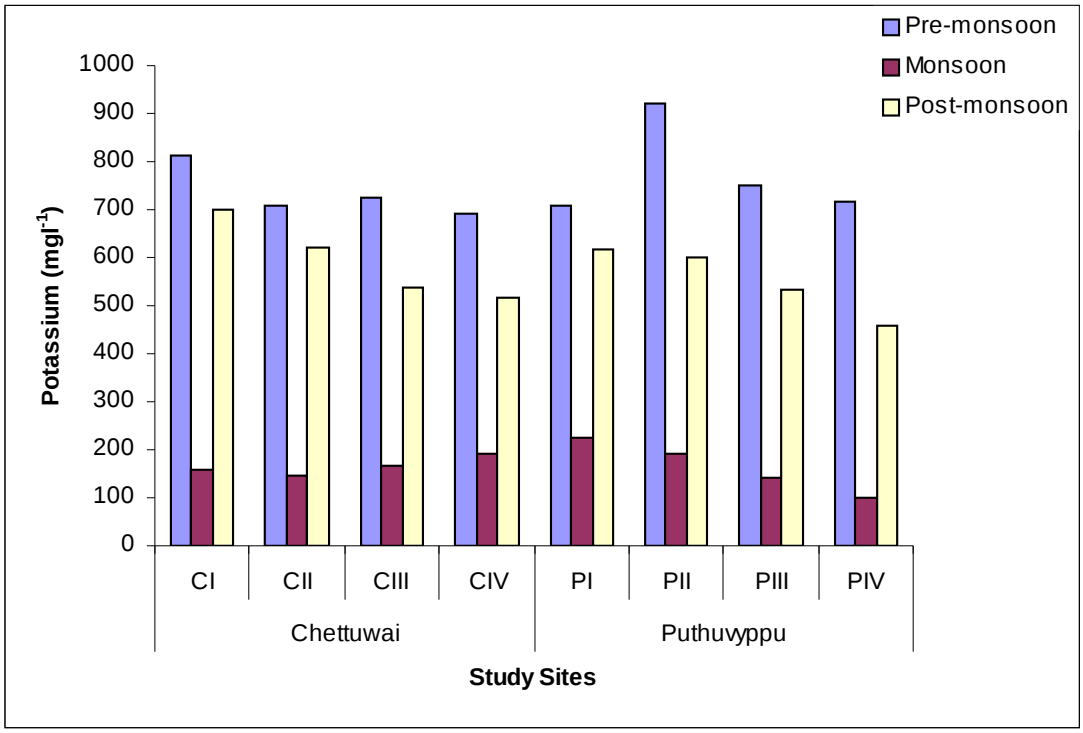


Table 10: Seasonal variations in Calcium (mg l^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	425	505	445	325	515	495	425	368
Monsoon	178	215	135	112	185	198	225	145
Post-monsoon	392	455	328	305	415	450	335	300

Figure 10: Seasonal variations in Calcium (mgl^{-1})

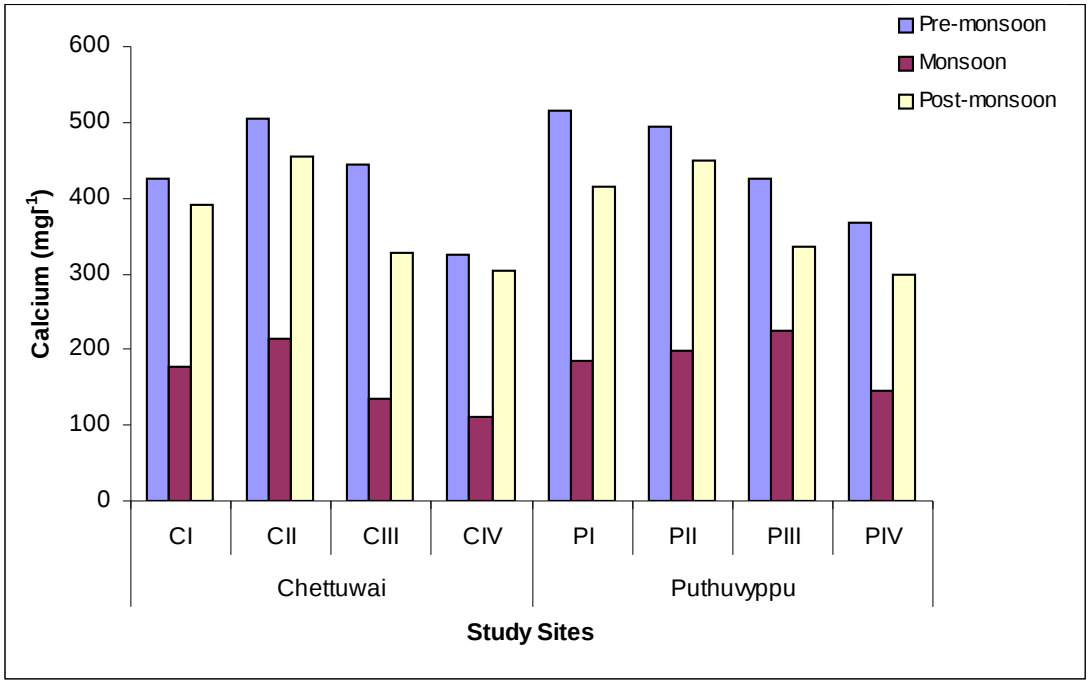


Table 11: Seasonal variations in Magnesium (mg l^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	15.20	13.18	16.90	12.50	20.10	22.10	24.51	18.52
Monsoon	8.5	10.28	9.15	5.18	10.1	11.12	12.15	12.14
Post-monsoon	13.82	18.15	16.55	14.92	15.12	19.80	18.25	17.12

Figure 11: Seasonal variations in Magnesium (mgl^{-1})

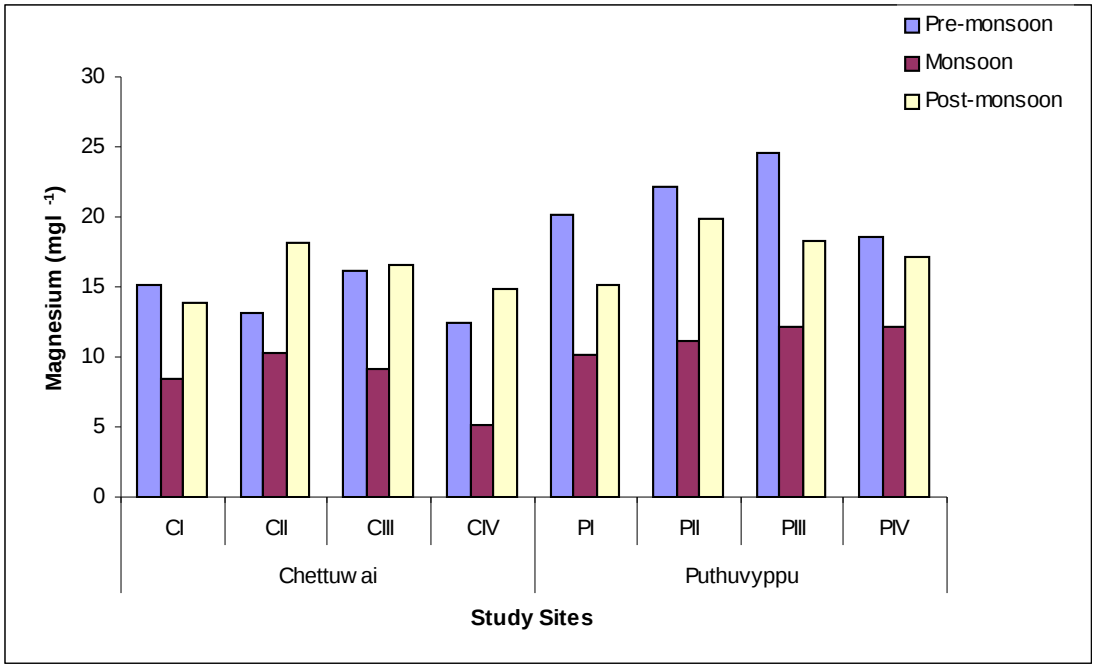


Table 12: Seasonal variations in moisture content (%)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	12.50	9.10	15.02	12.15	11.8	12.7	17.50	12.45
Monsoon	16.82	15.91	17.32	14.25	15.81	14.51	17.22	13.50
Post-monsoon	11.22	9.62	12.12	8.92	12.15	9.5	13.82	9.51

Figure 12: Seasonal variations in moisture content (%)

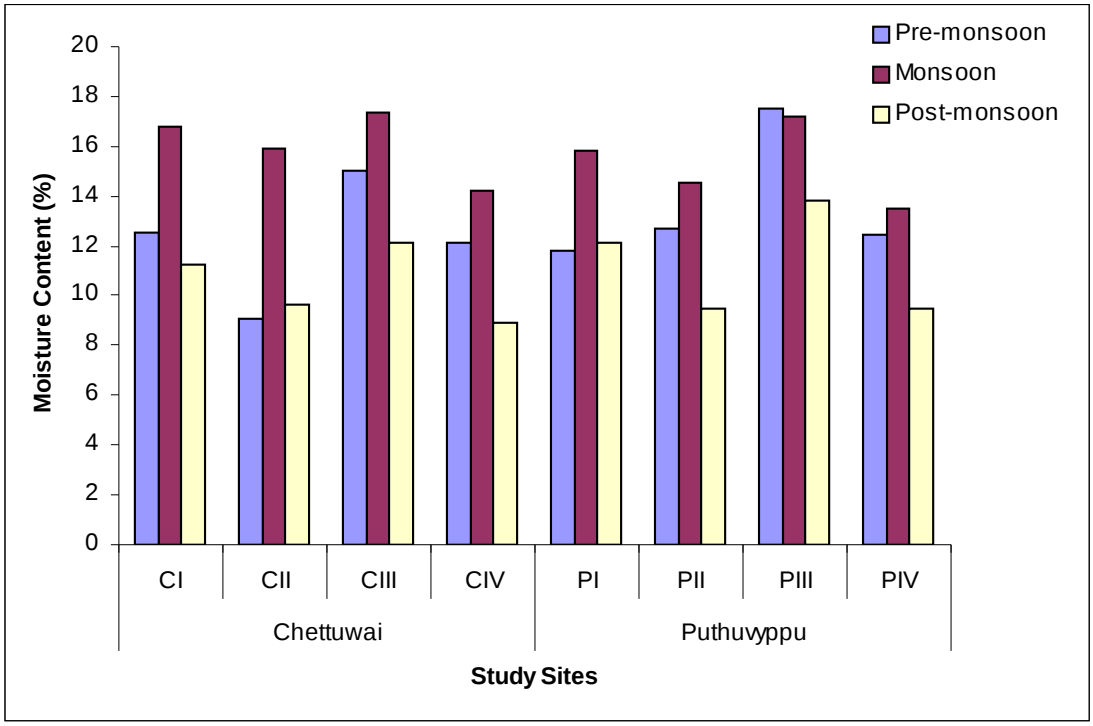


Table 13: Seasonal variations in pH

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	4.4	4.9	4.6	5.4	8.2	7.9	7.5	7.4
Monsoon	6.9	6.5	6.8	6.6	7.1	6.4	7.3	6.3
Post-monsoon	5.4	5.9	6.1	6.4	7.8	8.1	7.6	6.7

Figure 13: Seasonal variations in pH

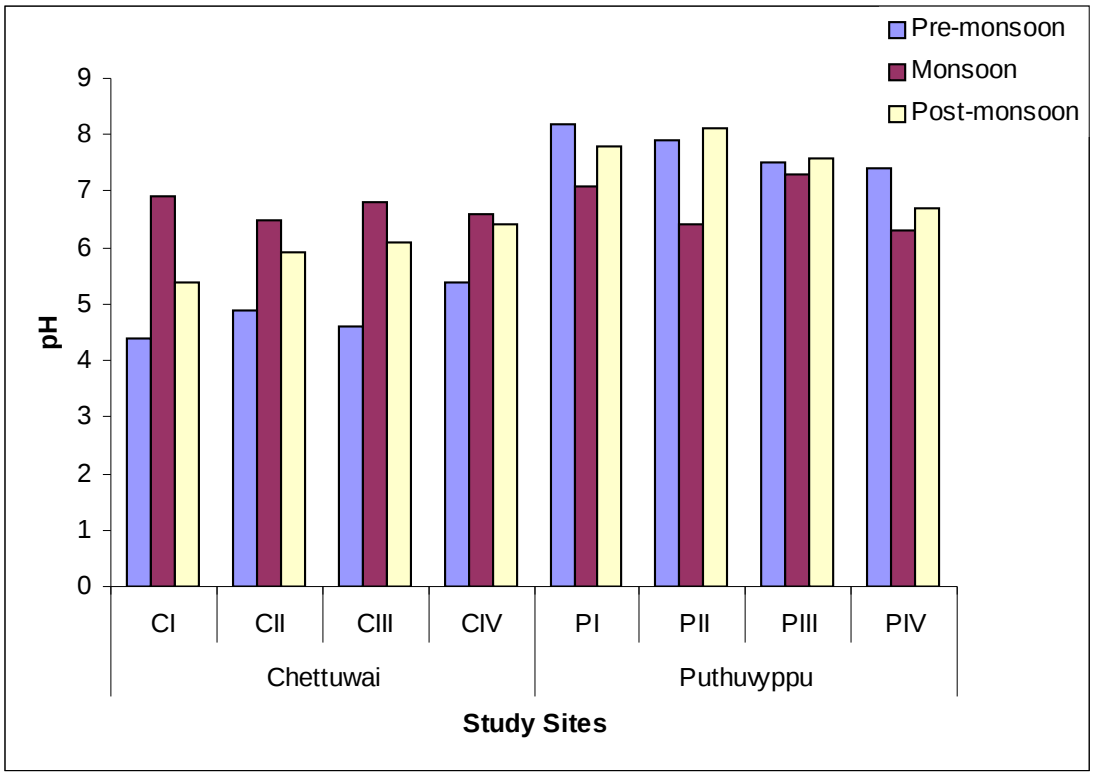


Table 14: Seasonal Variations in Electrical Conductivity (EC) (mhos cm^{-1})

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	2.5	2.8	2.1	2.0	2.14	1.33	4.3	2.45
Monsoon	1.27	1.16	0.8	1.8	1.40	0.81	1.32	0.75
Post-monsoon	3.8	3.5	2.4	2.8	3.49	4.14	6.82	4.02

Figure 14: Seasonal variations in Electrical Conductivity (mhos cm^{-1})

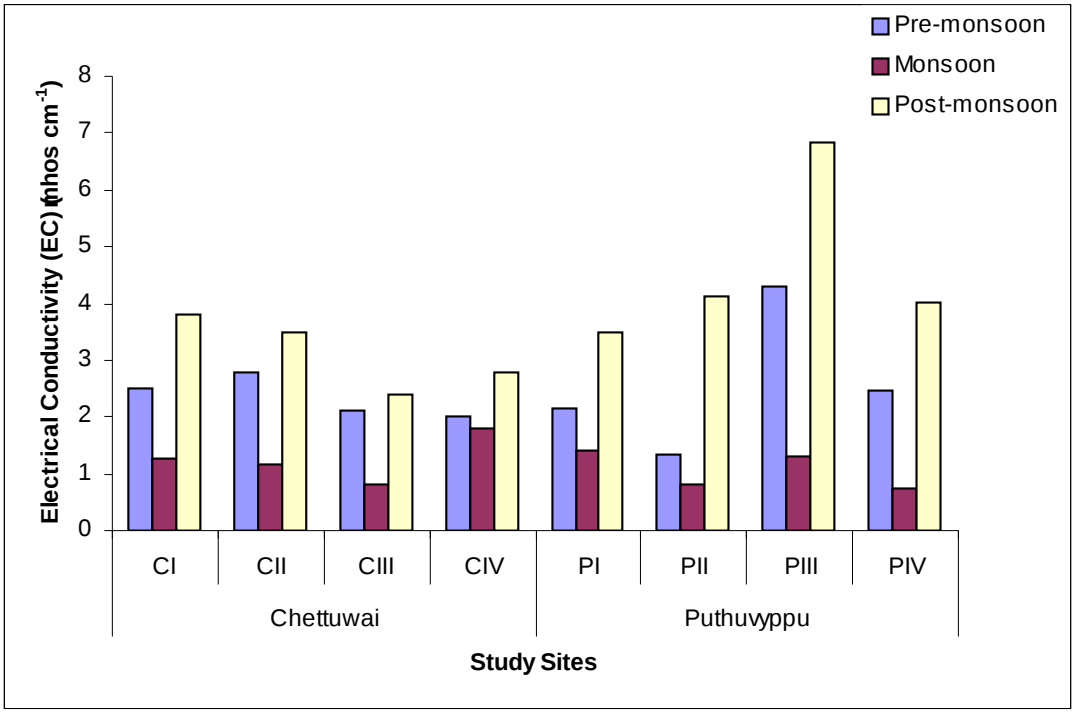


Table 15: Seasonal variations in Salinity (ppt)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	1.8	0.9	1.7	2.9	2.9	1.8	6.2	4.5
Monsoon	0.8	0.5	1.1	0.9	0.9	1.7	0.6	0.8
Post-monsoon	3.1	3.0	1.8	2.2	3.6	2.2	1.1	0.9

Figure 15: Seasonal variations in Salinity (ppt)

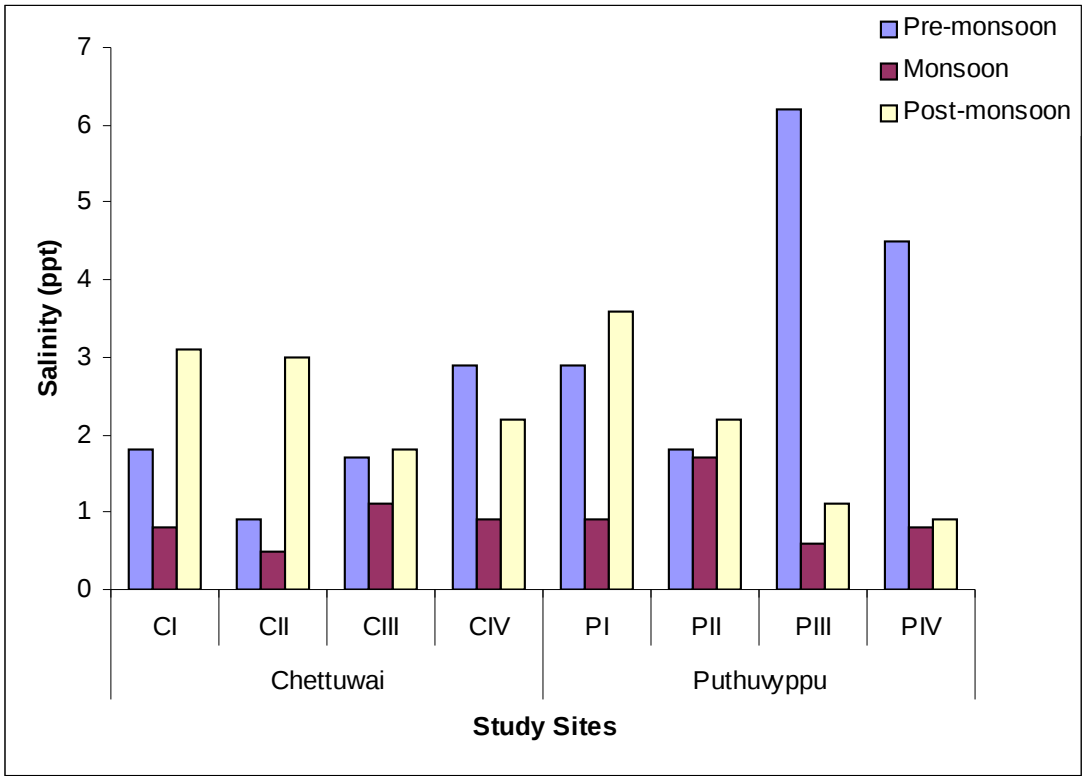


Table 16: Seasonal variations in Organic Carbon (%)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	0.61	0.59	1.25	2.92	0.41	0.52	2.12	1.82
Monsoon	0.38	0.68	0.45	0.65	0.66	0.29	1.85	0.55
Post-monsoon	0.97	1.15	1.30	0.55	0.75	0.38	2.21	1.86

Figure 16: Seasonal variations in Organic Carbon (%)

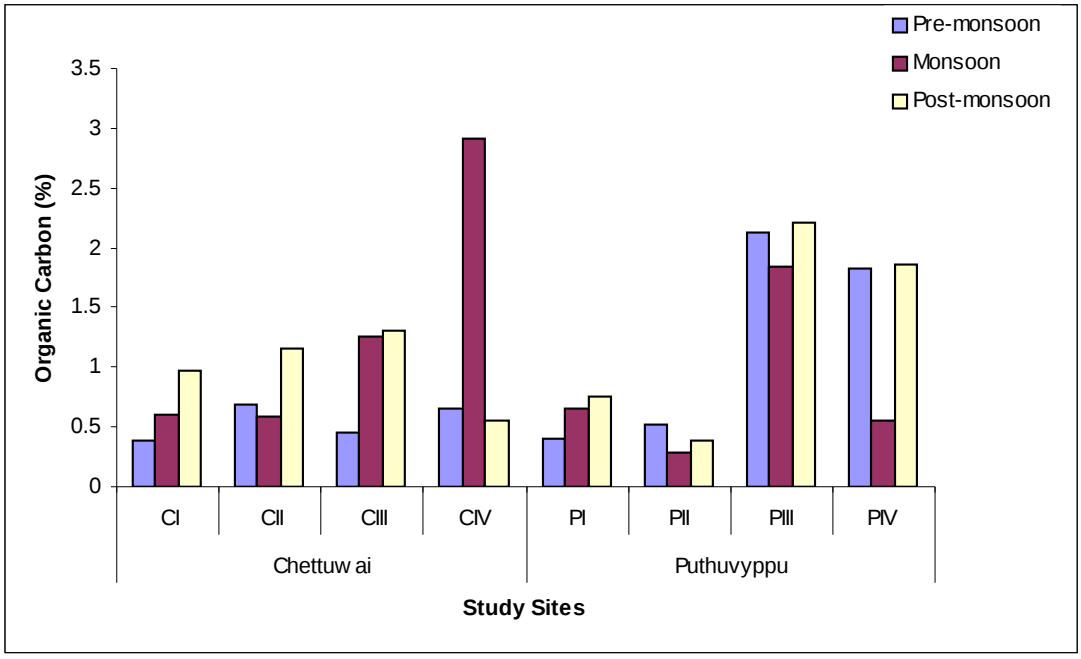


Table 17: Seasonal variations in Chloride (mg/100 gm)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	918	723	624	816	825	725	815	810
Monsoon	150	168	125	205	165	172	205	122
Post-monsoon	985	1028	1250	938	120	915	1515	1028

Figure 17: Seasonal variations in Chloride (mg/100gm)

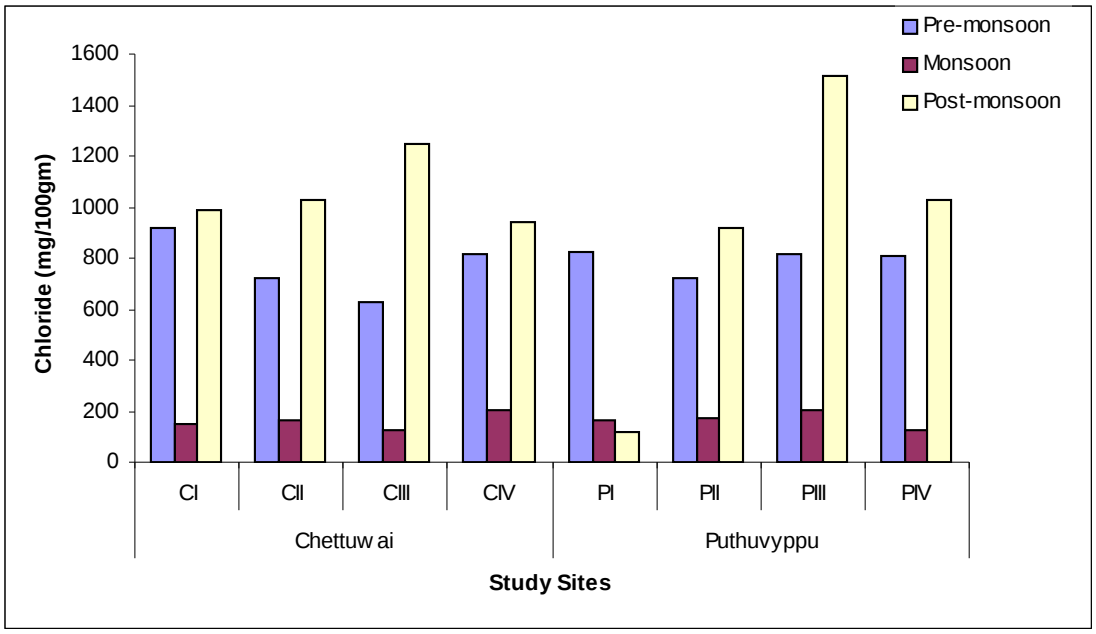


Table 18: Seasonal variations in Sodium (mg/100gm)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	17.5	14.3	10.9	15.5	18.3	9.5	22.4	12.5
Monsoon	2.5	1.8	5.6	2.1	4.2	2.8	7.8	3.5
Post-monsoon	8.9	7.6	4.2	8.5	8.1	7.2	8.5	18.9

Figure 18: Seasonal variations in Sodium (mg/100gm)

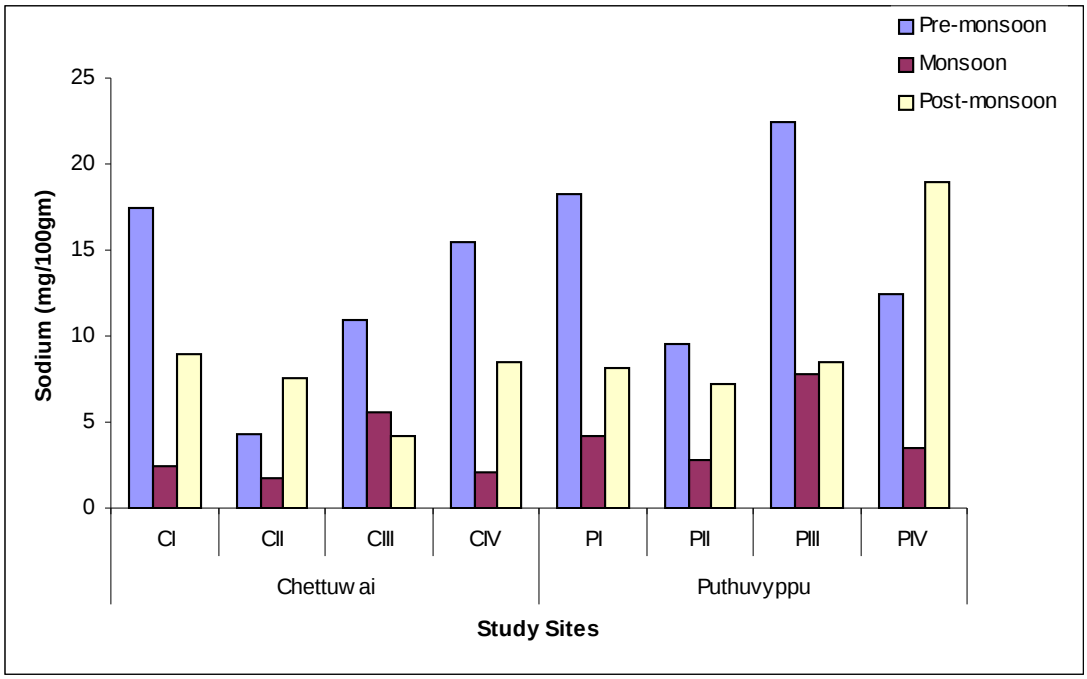


Table 19: Seasonal variations in Potassium (mg/100 gm)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	3.11	5.82	9.61	2.70	5.42	9.31	4.80	3.81
Monsoon	0.91	1.30	2.11	0.75	0.70	1.4	2.0	0.82
Post-monsoon	2.71	3.90	6.32	3.11	3.81	4.12	5.19	3.40

Figure 19: Seasonal variations in Potassium (mg/100gm)

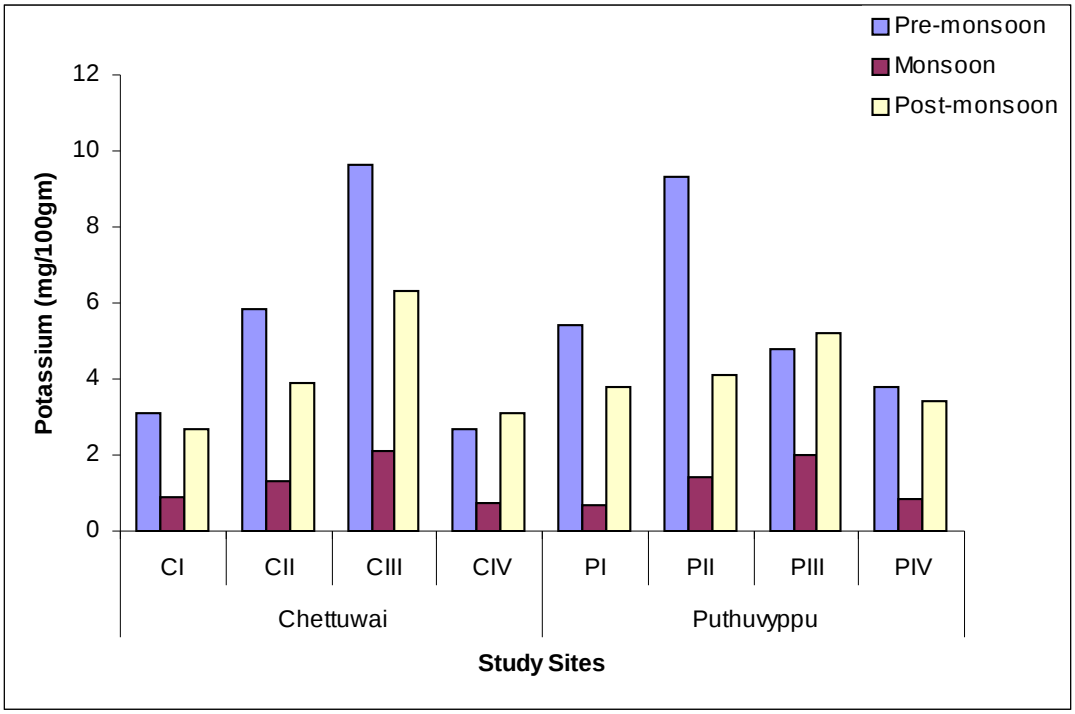


Table 20: Seasonal variations in Calcium (mg/100 gm)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	4.1	6.2	5.9	2.8	3.8	5.9	6.2	5.6
Monsoon	1.5	0.98	1.1	0.82	1.1	1.9	1.5	2.2
Post-monsoon	2.9	3.5	3.8	2.4	3.6	4.1	3.8	2.9

Figure 20: Seasonal variations in Calcium (mg/100gm)

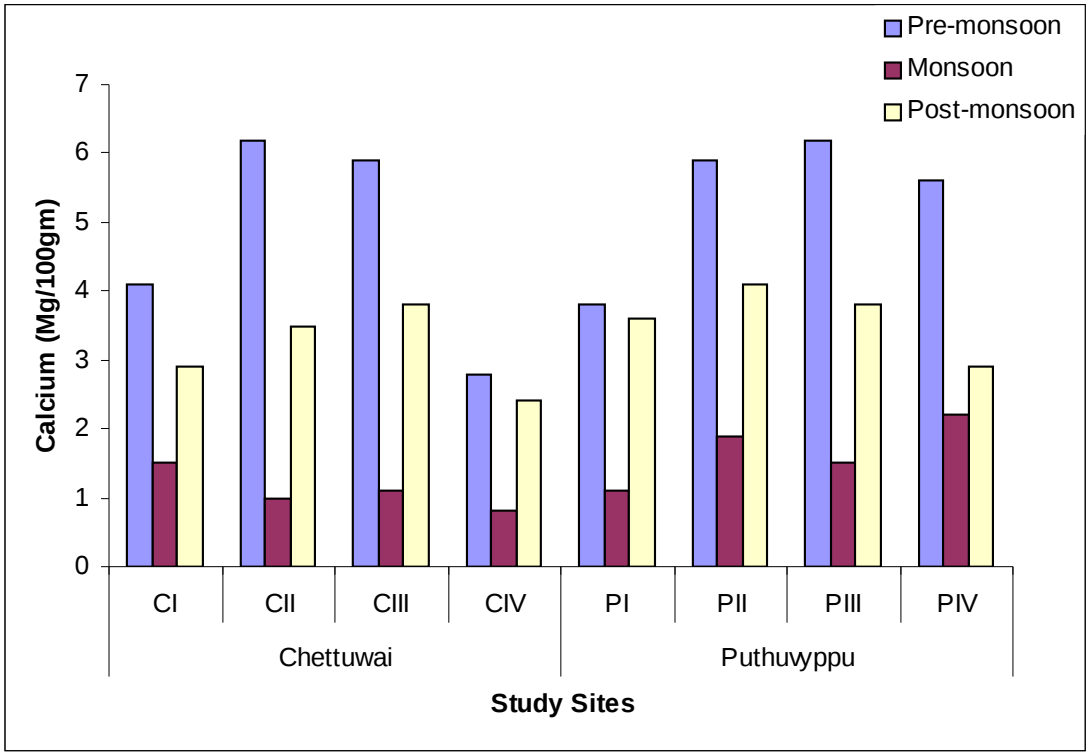


Table 21: Seasonal variations in Magnesium (mg/100 gm)

Seasons	Study Sites							
	Chettuwai				Puthuvyppu			
	CI	CII	CIII	CIV	PI	PII	PIII	PIV
Pre-monsoon	8.9	3.8	5.14	2.9	4.1	2.5	3.6	3.5
Monsoon	1.2	0.98	2.1	1.5	1.3	2.1	0.95	0.51
Post-monsoon	4.5	6.2	3.2	2.6	3.8	2.4	4.2	3.9

Figure 21: Seasonal variations in Magnesium (mg/100gm)

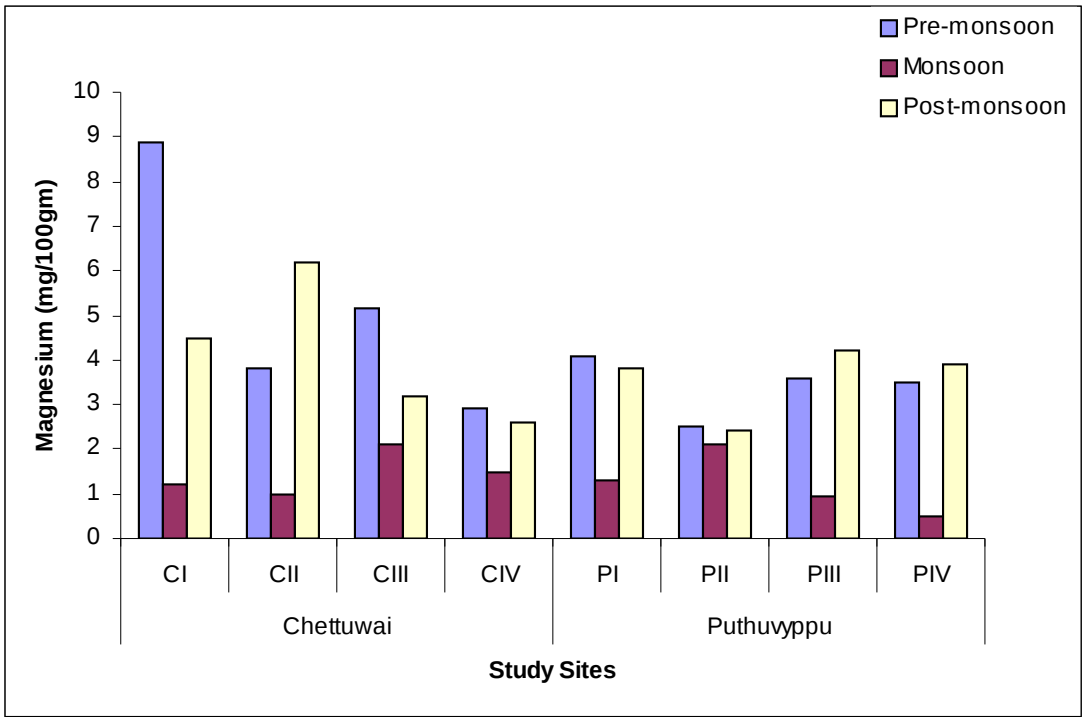


Table 22: Distribution of True Mangroves in Chettuwai and Puthuvyppu

Sl. No.	Scientific Name	Family	Study sites	
			Chettuwai	Puthuvyppu
1.	*Acanthus ilicifolius* L.	Acanthaceae	VC	VC
2.	*Aegiceras corniculatum* (L.) Blanco	Myrsinaceae	C	A
3.	*Avicennia officinalis* L.	Avicenniaceae	VC	VC
4.	*Bruguiera cylindrica* (L.) Blume	Rhizophoraceae	VC	VC
5.	*B. gymnorrhiza* (L.) Savigny	Rhizophoraceae	A	R
6.	*B. sexangula* (Laur.) Poir.	Rhizophoraceae	A	VR
7.	*Excoecaria agallocha* L.	Euphorbiaceae	R	C
8.	*Kandelia candel* (L.) Druce	Rhizophoraceae	A	R
9.	*Rhizophora apiculata* Blume	Rhizophoraceae	A	R
10.	*Rhizophora mucronata* Lamk.	Rhizophoraceae	VC	C
11.	*Sonneratia caseolaris* (L.) Engl.	Sonneratiaceae	A	R

VC - Very common A - Absent R - Rare C - Common

Table 23: Anatomical features of leaves of investigated taxa

Sl. No.	Name of the taxa	Leaf Symmetry	Leaf thickness µm	Cuticle thickness µm	Epidermal thickness µm	Hypodermal thickness µm	Mesophyll thickness µm
1.	*Acanthus ilicifolius*	Dorsiventral	937.6 ± 7.87	26.4 ± 0.98	42.4 ± 0.97	99.2 ± 3.66	609.6 ± 9.65
2.	*Aegiceras corniculatum*	Dorsiventral	393.6 ± 2.66	8.0 ± 0	42.3 ± 2.03	70.4 ± 2.52	218.4 ± 5.93
3.	*Avicennia officinalis*	Dorsiventral	623.2 ± 3.88	10.4 ± 0.98	32 ± 1.26	108.2 ± 3.53	295.2 ± 2.7
4.	*Bruguiera cylindrica*	Dorsiventral	614 ± 5.67	20.0 ± 0	27.0 ± 0.8	58.4 ± 5.62	377.6 ± 5.6
5.	*B. gymnorrhiza*	Dorsiventral	681.6 ± 4.03	28.0 ± 0	39.2 ± 1.49	84.8 ± 8.61	295.0 ± 3.58
6.	*B. sexangula*	Dorsiventral	581.6 ± 3.58	20.0 ± 1.26	35.2 ± 0.8	42.4 ± 1.6	238.4 ± 4.12
7.	*Excoecaria agallocha*	Dorsiventral	630.4 ± 8.04	23.2 ± 0.8	40.0 ± 0	33.0 ± 2.33	319.2 ± 5.51
8.	*Kandelia candel*	Isobilateral	876.0 ± 2.15	24.0 ± 1.78	34.4 ± 0.97	264.0 ± 1.66	540.8 ± 4.95
9.	*Rhizophara apiculata*	Dorsiventral	364.8 ± 6.75	16.4 ± 1.83	33.6 ± 0.97	20.8 ± 0.8	293.2 ± 1.55
10.	*Rhizophora mucronata*	Dorsiventral	710.4 ± 8.15	27.2 ± 0.80	36.8 ± 1.78	220.0 ± 7.09	435.2 ± 4.34
11.	*Sonneratia caseolaris*	Isobilateral	1037.2 ± 4.97	18.4 ± 1.6	30.4 ± 0.97	437.6 ± 5.57	325.6 ± 3.87

Table 24: Stomatal Study

Sl. No.	Name of the taxa	Stomatal index	Stomatal frequency
1.	*Acanthus ilicifolius*	21.25 ± 0.83	39.4 ± 0.91
2.	*Aegiceras corniculatum*	5.66 ± 0.60	17.7 ± 0.85
3.	*Avicennia officinalis*	ND	ND
4.	*Bruguiera cylindrica*	11.73 ± 0.68	35.7 ± 1.15
5.	*B. gymnorrhiza*	8.05 ± 0.78	32.4 ± 1.38
6.	*B. sexangula*	7.41 ± 0.56	29.4 ± 0.97
7.	*Excoecaria agallocha*	19.88 ± 1.43	76.2 ± 2.62
8.	*Kandelia candel*	5.51 ± 0.26	23.5 ± 0.88
9.	*Rhizophora apiculata*	5.69 ± 0.24	25.37 ± 0.75
10.	*Rhizophora mucronata*	4.42 ± 0.67	15.2 ± 0.81
11.	*Sonneratia caseolaris*	7.22 ± 0.32	35.37 ± 3.0

ND - Not Detected

Table 25: Comparison of Salt glands

Sl. No.	Name of the taxa	Frequency of salt gland mm^{-2}	Length of salt gland µm	Breadth of salt gland µm	Number of cells in salt glands	Occurrence
1.	*Acanthus ilicifolius*	9.8 ± 0.7	4.3 ± 0.10	5.6 ± 0.95	Single celled gland surrounded by 5-6 jacket cells	Both surfaces
2.	*Aegiceras corniculatum*	2.0 ± 0.10	3.3 ± 0.21	4.3 ± 0.62	14-16 celled gland surrounded by one-celled layer jacket	Both surfaces
3.	*Avicennia officinalis*	19.0 ± 1.09	5.0 ± 0.19	3.0 ± 0.26	Multicellular gland surrounded by 5-6 jacket cells	Dorsal surface
4.	*Sonneratia caseolaris*	10.8 ± 0.70	6.0 ± 0.38	6.5 ± 0.78	Multicellular gland surrounded by several jacket cells	Both surfaces

Table 26 : Seasonal variations in Dry weight percentage in mangrove leaves

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	26.10 ± 2.01	23.2 ± 1.13	22.5 ± 1.56
2.	*Aegiceras corniculatum*	38.21 ± 1.95	28.52 ± 2.13	35.21 ± 1.06
3.	*Avicennia officinalis*	46.0 ± 2.13	40.0 ± 1.05	33.20 ± 2.16
4.	*Bruguiera cylindrica*	66.0 ± 2.02	36.0 ± 0.15	28.0 ± 1.68
5.	*Excoecaria agallocha*	26.0 ± 1.05	22.0 ± 1.06	30.3 ± 1.53
6.	*Rhizophora mucronata*	64.0 ± 1.59	31.50 ± 0.86	30.0 ± 0.65
7.	*Sonneratia caseolaris*	73.0 ± 2.18	25.33 ± 1.81	55.52 ± 1.58

Table 27 : Seasonal variations in Dry weight percentage in mangrove Stem

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	22.0 ± 0.19	18.0 ± 0.50	20.0 ± 0.01
2.	*Aegiceras corniculatum*	38.25 ± 1.02	30.0 ± 0.85	32.18 ± 1.51
3.	*Avicennia officinalis*	72.0 ± 2.16	52.0 ± 0.95	44.0 ± 1.01
4.	*Bruguiera cylindrica*	68.0 ± 2.01	36.0 ± 1.02	37.25 ± 1.01
5.	*Excoecaria agallocha*	34.0 ± 1.85	26.21 ± 0.91	32.0 ± 1.06
6.	*Rhizophora mucronata*	66.0 ± 1.25	38.0 ± 1.86	46.25 ± 1.92
7.	*Sonneratia caseolaris*	76.0 ± 2.31	33.33 ± 1.08	44.0 ± 1.82

Table 28 : Seasonal variations in Moisture content percentage (MC%) in mangrove leaves

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	73.90	76.80	77.5
2.	*Aegiceras corniculatum*	61.79	71.48	64.79
3.	*Avicennia officinalis*	54.0	60.0	66.80
4.	*Bruguiera cylindrica*	34.0	64.0	72.0
5.	*Excoecaria agallocha*	74.0	78.0	69.70
6.	*Rhizophora mucronata*	36.0	68.5	70.0
7.	*Sonneratia caseolaris*	27.0	74.67	44.48

Table 29 : Seasonal variations in Moisture content percentage (MC%) in mangrove stem

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	78.0	82.0	80.0
2.	*Aegiceras corniculatum*	61.75	70.0	67.82
3.	*Avicennia officinalis*	28.0	48.0	56.0
4.	*Bruguiera cylindrica*	32.0	64.0	62.75
5.	*Excoecaria agallocha*	66.0	73.79	68.0
6.	*Rhizophora mucronata*	34.0	62.0	53.75
7.	*Sonneratia caseolaris*	24.0	66.67	56.0

Table 30 : Seasonal variations in Total Protein Content of Mangrove leaf mg g^{-1} dry wt.

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	88.70 ± 1.01	115.17 ± 2.02	120.37 ± 1.13
2.	*Aegiceras corniculatum*	76.82 ± 0.91	114.12 ± 0.85	91.58 ± 0.71
3.	*Avicennia officinalis*	116.01 ± 1.01	154.96 ± 1.50	135.93 ± 0.65
4.	*Bruguiera cylindrica*	147.28 ± 1.50	204.61 ± 0.86	85.94 ± 1.02
5.	*Excoecaria agallocha*	221.14 ± 0.85	273.09 ± 1.11	174.72 ± 1.05
6.	*Rhizophora mucronata*	120.12 ± 0.50	410.39 ± 1.25	310.42 ± 1.86
7.	*Sonneratia caseolaris*	263.50 ± 1.01	312.01 ± 1.50	212.58 ± 1.50

Figure 22: Seasonal Variations in Total Protein Content of Mangrove leaf (mg g^{-1} dry wt.)

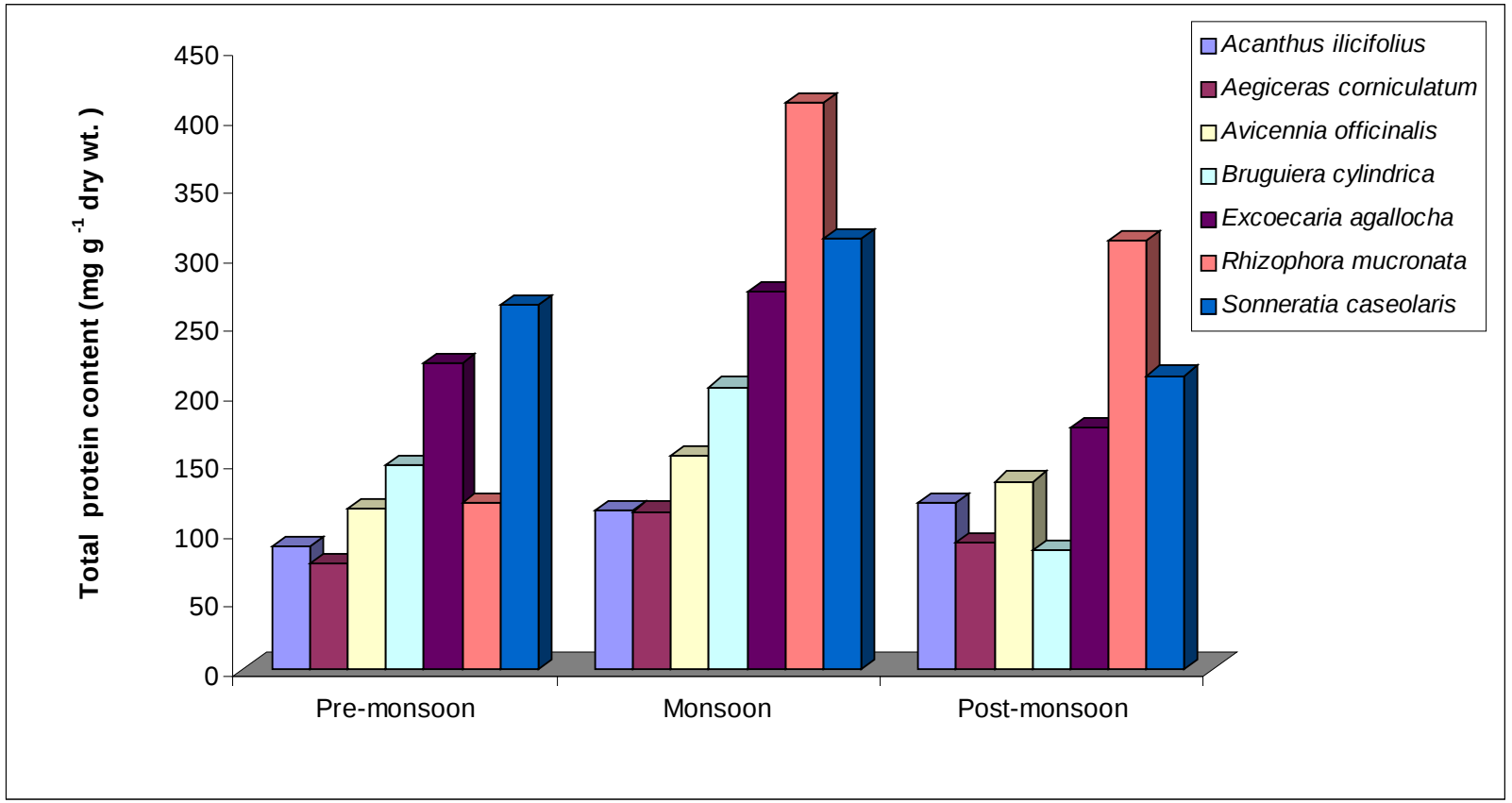


Table 31: Seasonal variations in Total Protein Content of Stem of Mangroves (mg g^{-1} dry wt.)

Sl. No.	Name of the taxa	Seasons

		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	93.76 ± 0.50	281.71 ± 1.01	178.35 ± 1.05
2.	*Aegiceras corniculatum*	108.75 ± 1.02	159.07 ± 1.52	105.76 ± 0.65
3.	*Avicennia officinalis*	112.41 ± 1.55	236.03 ± 1.62	80.86 ± 0.55
4.	*Bruguiera cylindrica*	96.88 ± 1.81	270.68 ± 1.50	172.94 0.95
5.	*Excoecaria agallocha*	207.4 ± 1.25	216.44 ± 0.95	198.82 ± 0.61
6.	*Rhizophora mucronata*	192.25 ± 1.01	324.78 ± 1.22	148.62 ± 0.50
7.	*Sonneratia caseolaris*	118.43 ± 0.91	134.07 ± 0.85	108.25 ± 0.81

Figure 23: Seasonal Variations in Total Protein Content of Stem of Mangroves (mg g^{-1} dry wt.)

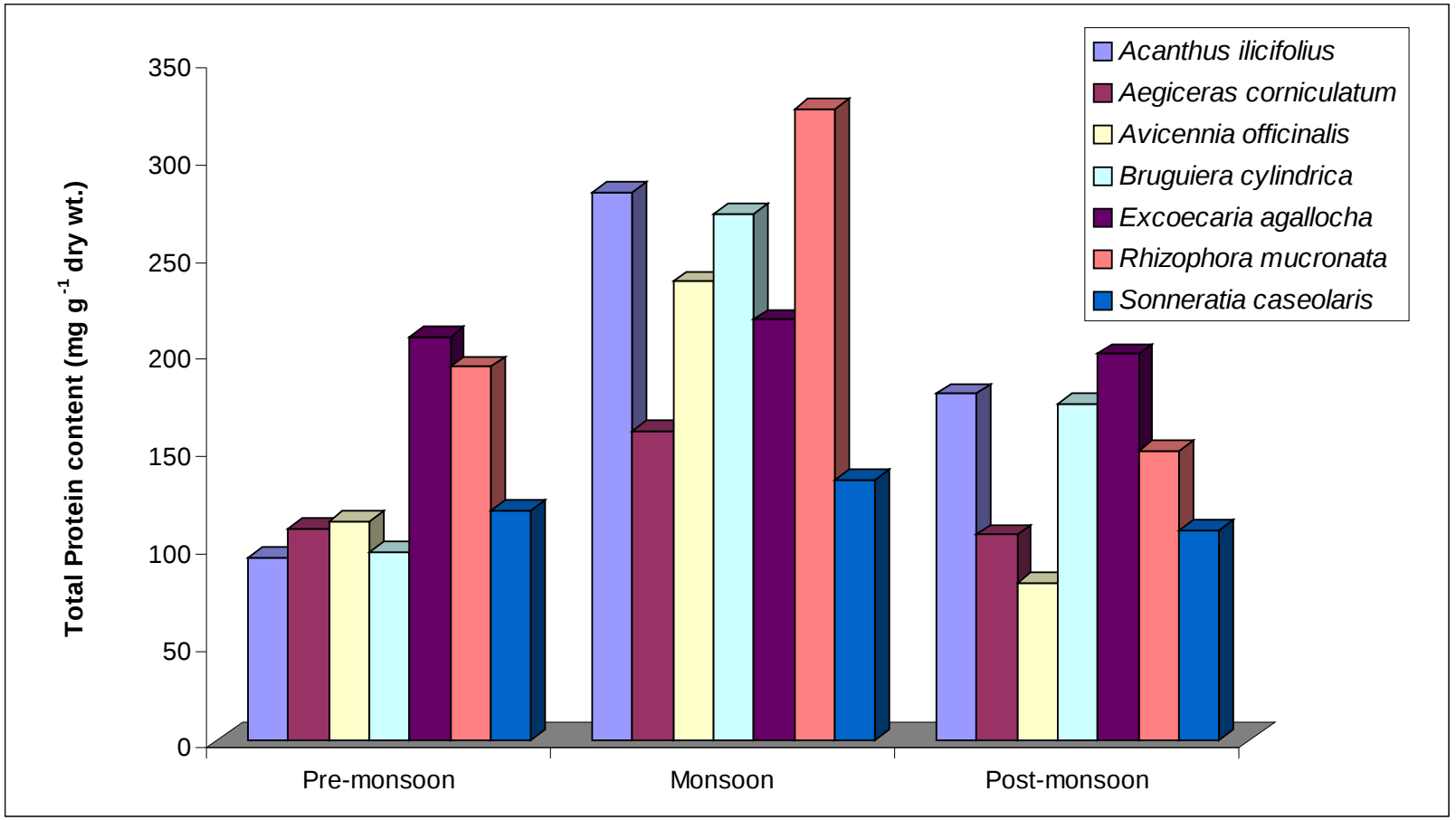


Table 32 : Seasonal variations in Total Amino acid Content of Mangrove leaf (mg g^{-1} dry wt.)

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	2.25 ± 0.01	0.92 ± 0.12	3.37 ± 0.16
2.	*Aegiceras corniculatum*	2.93 ± 0.11	0.83 ± 0.01	4.61 ± 0.11
3.	*Avicennia officinalis*	2.24 ± 0.15	0.41 ± 0.13	7.08 ± 0.61
4.	*Bruguiera cylindrica*	3.34 ± 0.10	1.76 ± 0.16	4.91 ± 0.05
5.	*Excoecaria agallocha*	3.19 ± 0.41	1.56 ± 0.13	5.63 ± 0.05
6.	*Rhizophora mucronata*	4.69 ± 0.06	0.59 ± 0.02	9.26 ± 0.85
7.	*Sonneratia caseolaris*	3.70 ± 0.13	0.33 ± 0.05	11.25 ± 0.19

Figure 24: Seasonal variations in Total Amino acid Content of Mangrove leaf (mg g^{-1} dry wt.)

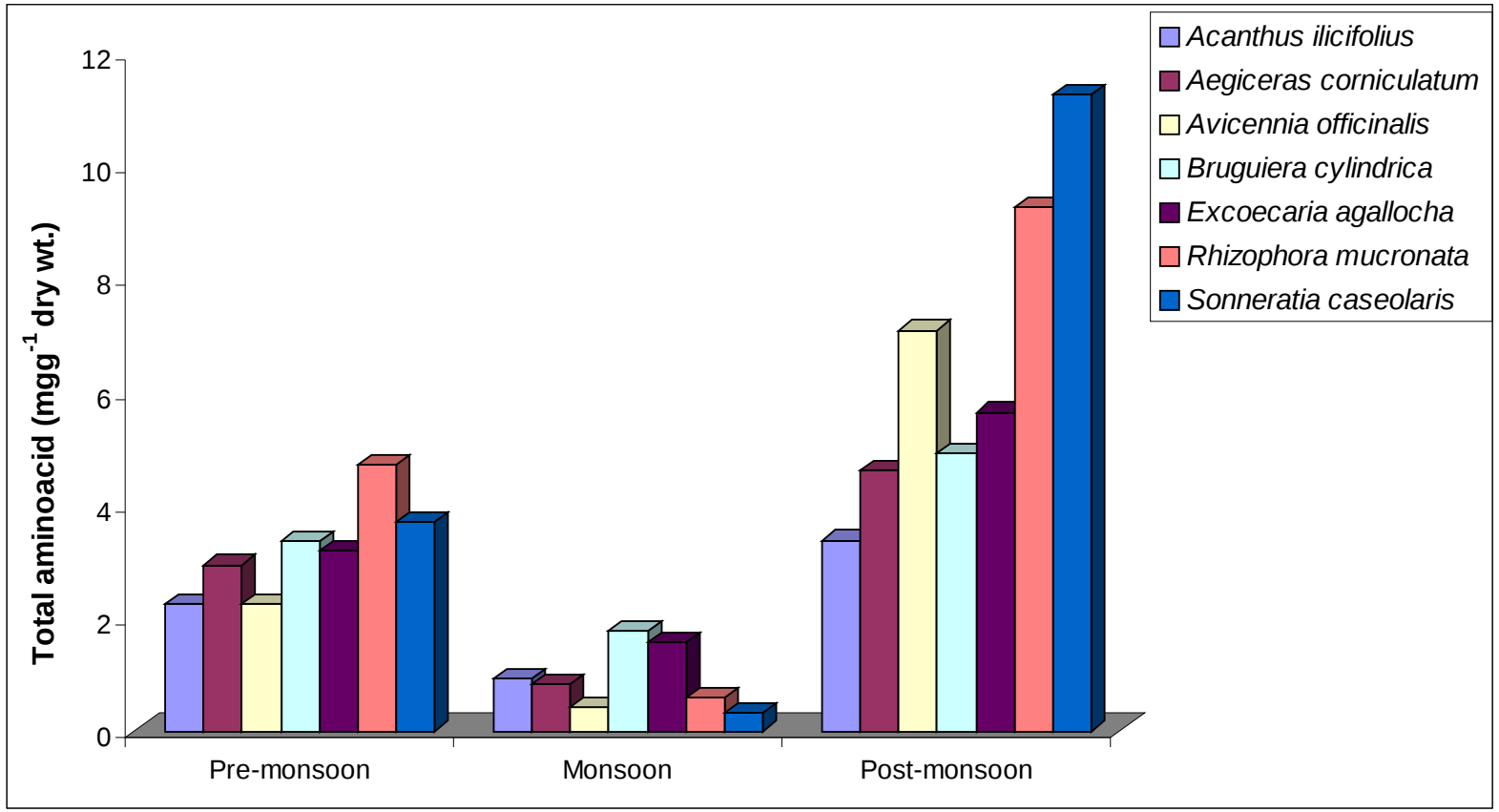


Table 33 : Seasonal variations in Total Amino acid content of Mangrove Stem (mg g^{-1} dry wt.)

Sl. No.	Name of the taxa	Seasons

		Pre-monsoon	Monsoon	Post-monsoon
1.	*Acanthus ilicifolius*	2.18 ± 0.15	1.87 ± 0.01	4.38 ± 0.20
2.	*Aegiceras corniculatum*	3.92 ± 0.25	0.78 ± 0.03	8.13 ± 0.15
3.	*Avicennia officinalis*	2.77 ± 0.18	0.66 ± 0.01	6.48 ± 0.21
4.	*Bruguiera cylindrica*	2.19 ± 0.16	1.84 ± 0.02	3.34 ± 0.11
5.	*Excoecaria agallocha*	5.43 ± 0.10	2.34 ± 0.10	8.59± 0.23
6.	*Rhizophora mucronata*	2.03 ± 0.19	1.22 ± 0.12	3.25 ± 0.15
7.	*Sonneratia caseolaris*	2.12 ± 0.02	0.94 ± 0.01	8.44 ± 0.16

Figure 25: Seasonal variations in Total Amino acid content of Mangrove Stem (mg g^{-1} dry wt.)

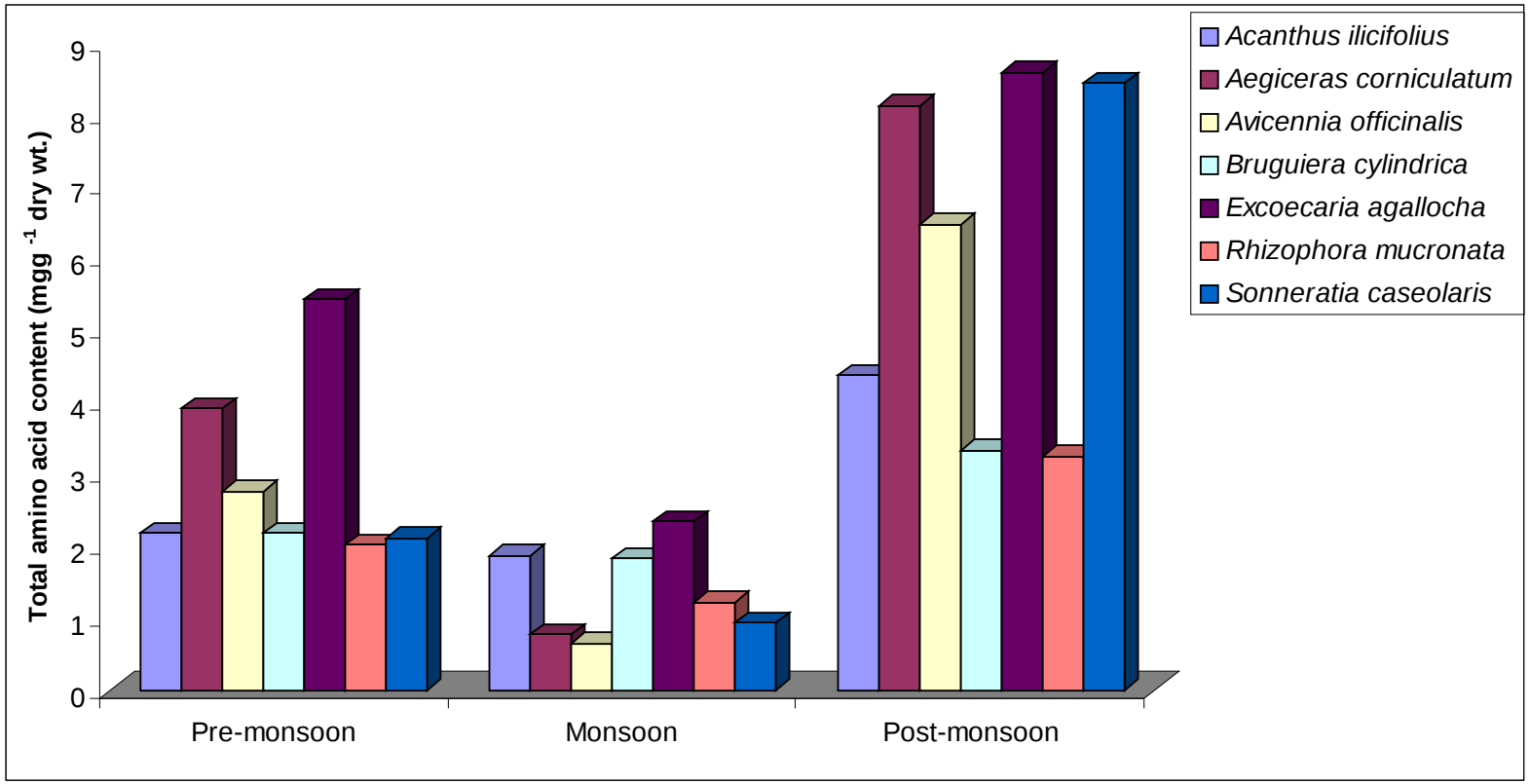


Table 34: Seasonal variations in Proline Content of Mangrove leaf (mg g^{-1} dry wt.)

Sl. No.	Name of the taxa	Seasons

		Pre-monsoon	Monsoon	Post-monsoon
1.	*Acanthus ilicifolius*	0.354 ± 0.01	0.169 ± 0.02	0.449 ± 0.3
2.	*Aegiceras corniculatum*	0.402 ± 0.02	0.166 ± 0.001	0.421 ± 0.02
3.	*Avicennia officinalis*	0.254 ± 0.01	0.180 ± 0.03	0.270 ± 0.01
4.	*Bruguiera cylindrica*	0.258 ± 0.02	0.126 ± 0.01	0.303 ± 0.02
5.	*Excoecaria agallocha*	0.241 ± 0.03	0.161 ± 0.01	0.491 ± 0.01
6.	*Rhizophora mucronata*	0.265 ± 0.02	0.196 ± 0.02	0.458 ± 0.03
7.	*Sonneratia caseolaris*	0.247 ± 0.01	0.112 ± 0.01	0.294 ± 0.01

Figure 26: Seasonal Variations in Proline Content of Mangrove leaf (mg g^{-1} dry wt.)

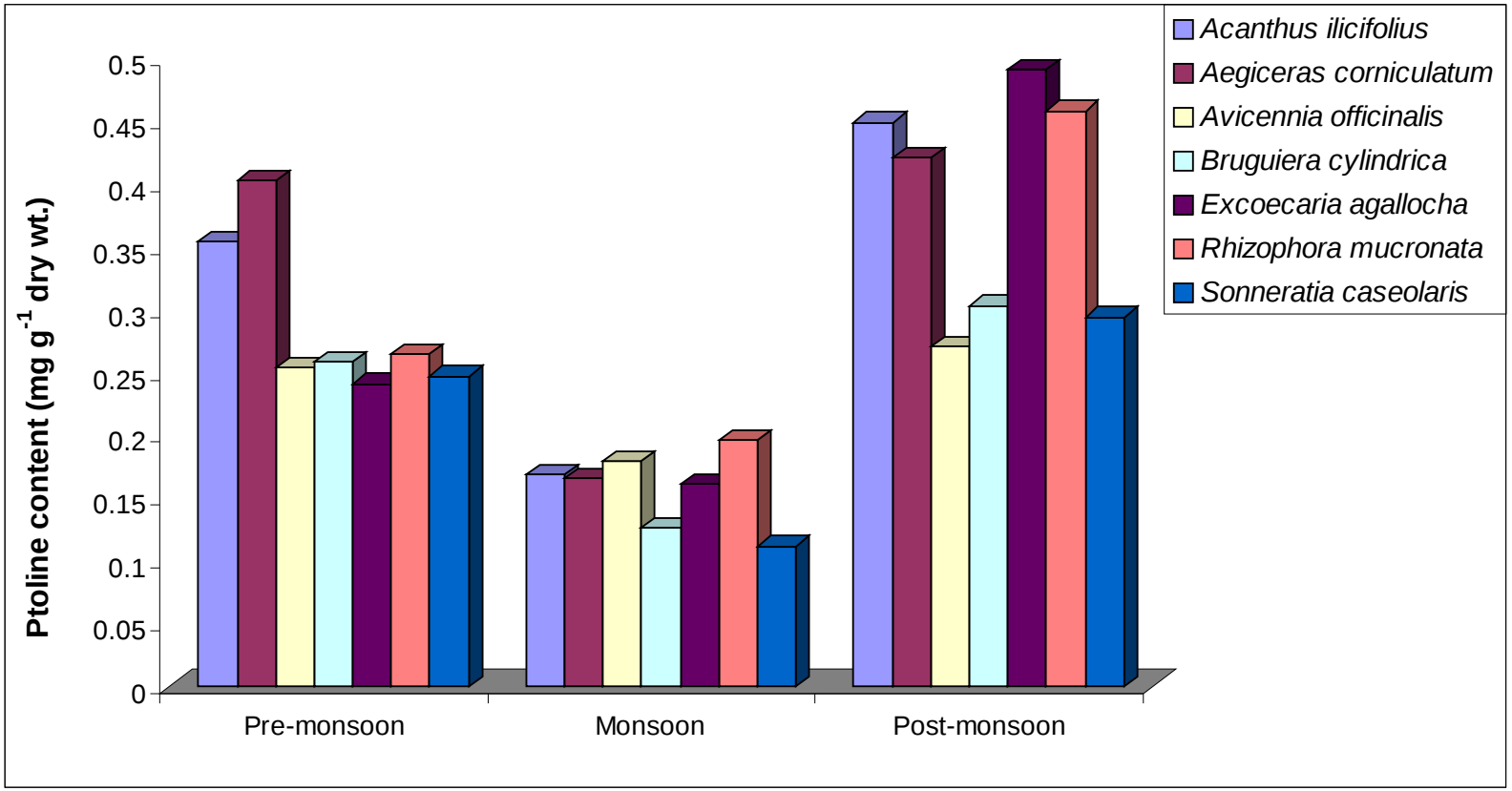

Ptoline content (mg g-1 dry wt.)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pre-monsoon
Monsoon
Post-monsoon
Acanthus ilicifolius
Aegiceras corniculatum
Avicennia officinalis
Bruguiera cylindrica
Excoecaria agallocha
Rhizophora mucronata
Sonneratia caseolaris

Table 35: Seasonal variations in Proline Content of Mangrove stem (mg g^{-1} dry wt.)

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	0.267 ± 0.1	0.206 ± 0.02	0.423 ± 0.1
2.	*Aegiceras corniculatum*	0.286 ± 0.02	0.209 ± 0.01	0.354 ± 0.02
3.	*Avicennia officinalis*	0.223 ± 0.01	0.175 ± 0.01	0.364 ± 0.02
4.	*Bruguiera cylindrica*	0.258± 0.03	0.140 ± 0.01	0.286 ± 0.01
5.	*Excoecaria agallocha*	0.346 ± 0.04	0.147 ± 0.001	0.241 ± 0.02
6.	*Rhizophora mucronata*	0.264 ± 0.01	0.130 ± 0.01	0.247 ± 0.02
7.	*Sonneratia caseolaris*	0.207 ± 0.02	0.115 ± 0.02	0.258 ± 0.01

Figure 27: Seasonal Variations in Proline Content of Mangrove Stem (mg g^{-1} dry wt.)

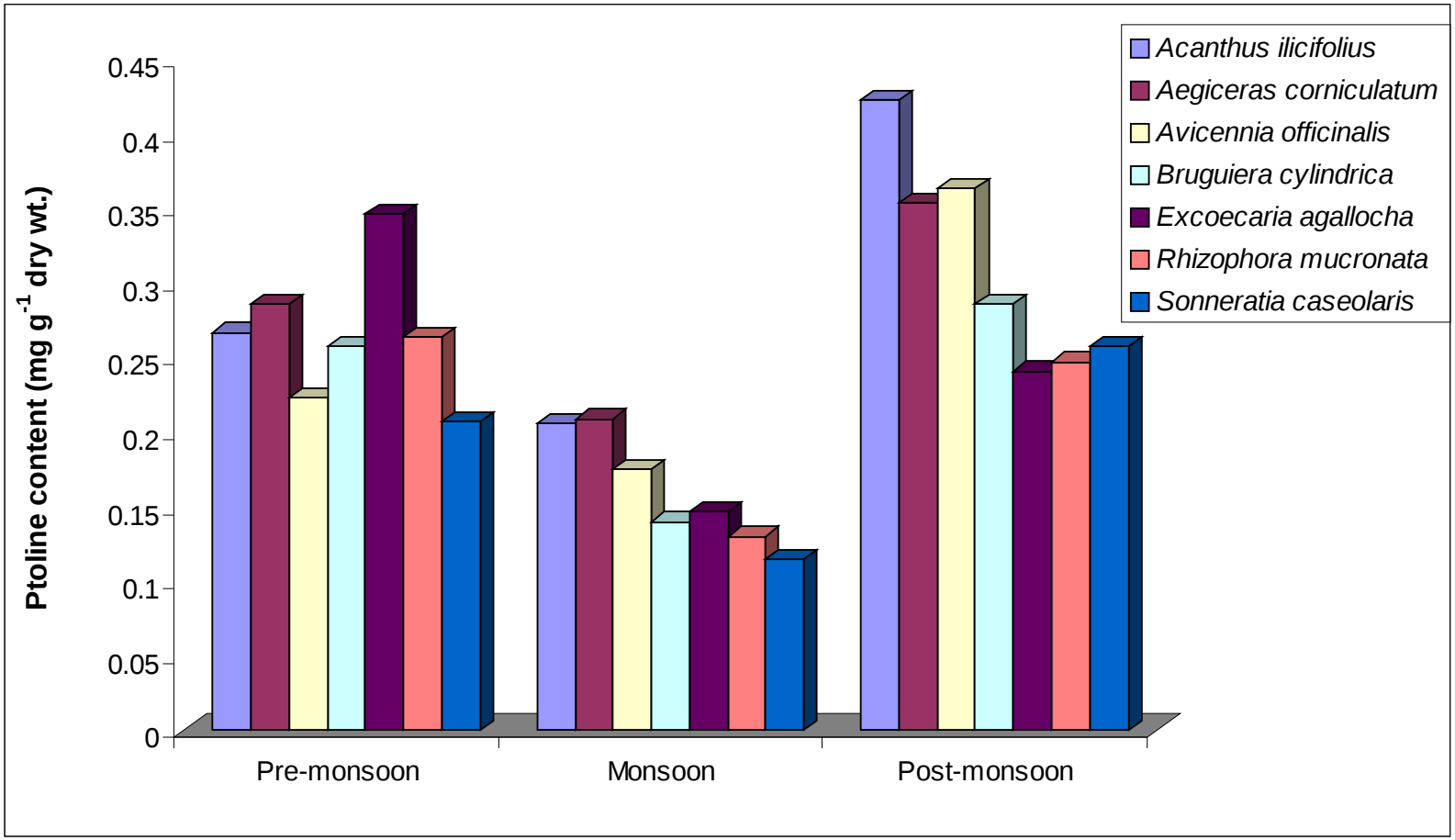

Ptoline content (mg g-1 dry wt.)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pre-monsoon
Monsoon
Post-monsoon
Acanthus ilicifolius
Aegiceras corniculatum
Avicennia officinalis
Bruguiera cylindrica
Excoecaria agallocha
Rhizophora mucronata
Sonneratia caseolaris

Table 36 : Seasonal variations in Tannin Content of Mangrove leaf (µg g^{-1} dry wt.)

Sl. No.	Name of the taxa	Seasons		
		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	253.25 ± 1.82	216.38 ± 1.56	294.56 ± 2.10
2.	*Aegiceras corniculatum*	212.40 ± 1.75	186.46 ± 1.01	303.30 ± 2.08
3.	*Avicennia officinalis*	289.55 ± 0.95	130.99 ± 0.55	393.14 ± 1.50
4.	*Bruguiera cylindrica*	208.46 ± 1.25	184.54 ± 1.25	472.68 ± 2.01
5.	*Excoecaria agallocha*	401.78 ± 0.85	147.17 ± 1.9	452.72 ± 1.50
6.	*Rhizophora mucronata*	230.67 ± 1.26	150.58 ± 1.55	330.86 ± 1.60
7.	*Sonneratia caseolaris*	459.13 ± 1.11	361.74 ± 1.11	557.03 ± 2.02

Figure 28: Seasonal Variations in Tannin Content of mangrove leaf (µg g^{-1} dry wt.)

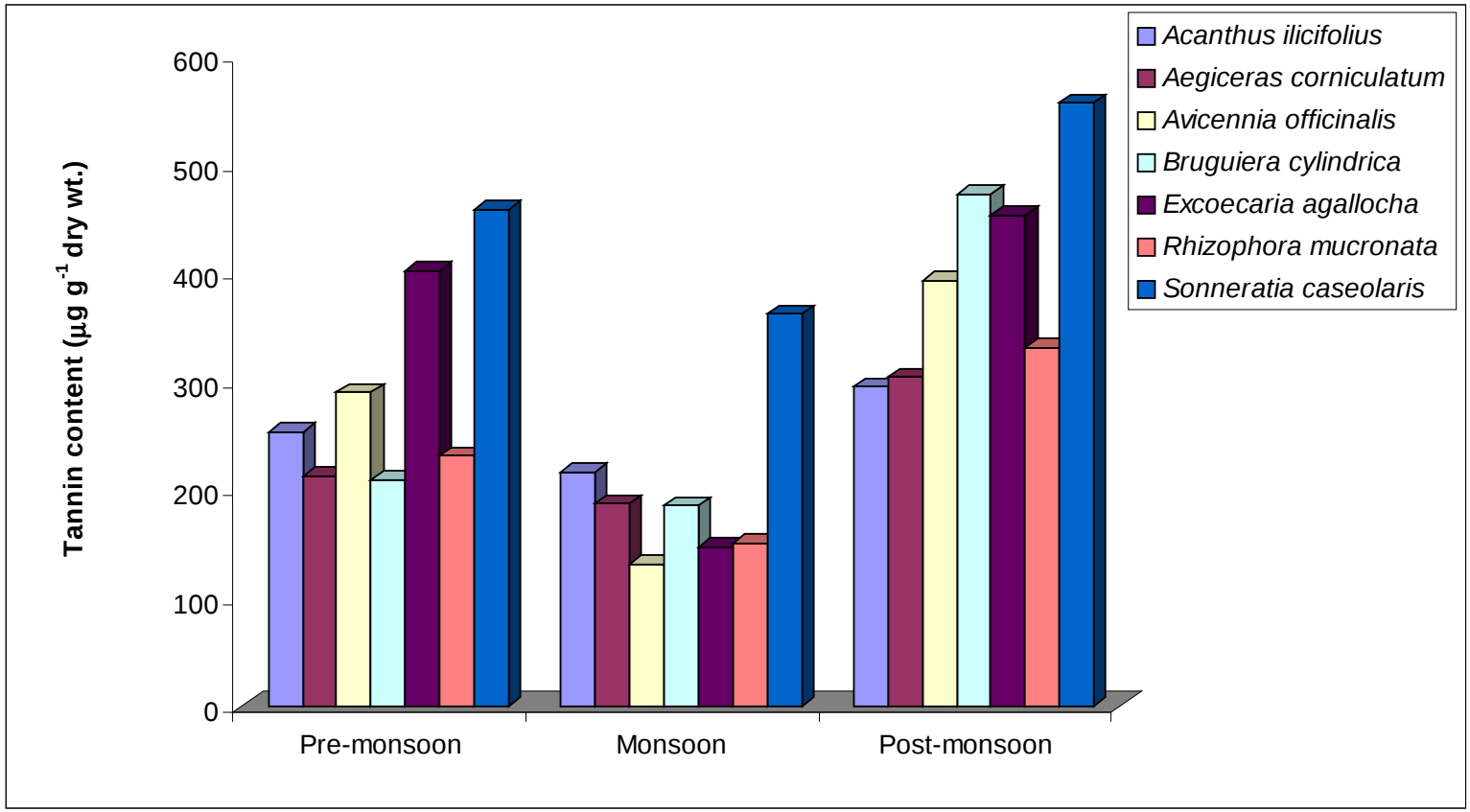
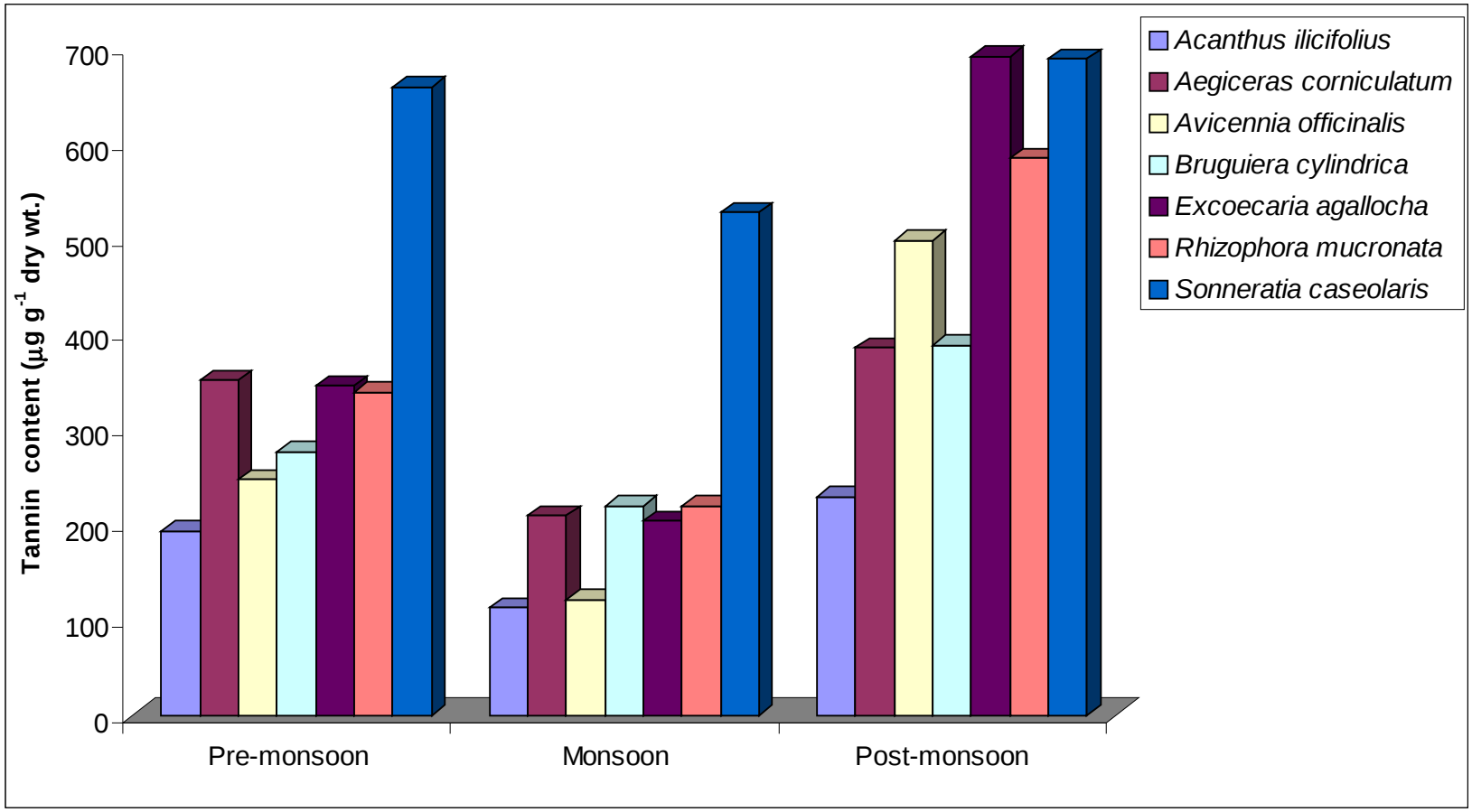


Table 37 : Seasonal variations in Tannin Content of Mangrove Stem (µg g^{-1} dry wt.)

Sl. No.	Name of the taxa	Seasons

		Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	192.92 ± 1.01	112.68 ± 0.95	228.74 ± 1.05
2.	*Aegiceras corniculatum*	351.08 ± 1.56	208.64 ± 1.51	384.91 ± 1.12
3.	*Avicennia officinalis*	246.86 ± 1.05	121.04 ± 1.51	497.56 ± 1.11
4.	*Bruguiera cylindrica*	276.57 ± 0.95	219.16 ± 1.50	387.80 ± 2.01
5.	*Excoecaria agallocha*	345.58 ± 0.66	203.03 ± 1.05	691.19 ± 0.85
6.	*Rhizophora mucronata*	338.28 ± 0.95	219.71 ± 1.01	583.56 ± 1.01
7.	*Sonneratia caseolaris*	658.28 ± 0.81	527.30 ± 0.95	687.80 ± 1.05

Figure 29: Seasonal Variations in Tannin Content of Mangrove Stem (μg g^{-1} dry wt.)



Table

38 : Seasonal variations in mineral composition of mangrove leaves (gm/100gm dry tissue)

Sl. No.	Name of the taxa	Season	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{++})	Magnesium (Mg^{++})	Chloride (Cl^{-})
1.	*Acanthus ilicifolius*	Pre-monsoon	3.47±0.01	2.49±0.l1	0.83±0.01	0.94±0.02	4.85±0.05
		Monsoon	1.58±0.04	0.65±0.01	0.21±0.02	0.33±0.01	1.28±0.01
		Post-monsoon	3.40±0.11	2.75±0.03	1.62±0.05	1.11±0.02	3.96±0.10
2.	*Aegiceras corniculatum*	Pre-monsoon	2.65±0.10	0.35±0.02	0.46±0.01	0.32±0.01	3.66±0.15
		Monsoon	0.85±0.05	1.10±0.01	0.20±0.01	0.66±0.02	1.42±0.02
		Post-monsoon	2.34±0.16	0.70±0.01	0.57±0.02	0.43±0.01	2.75±0.02
3.	*Avicennia officinalis*	Pre-monsoon	5.01±0.15	1.63±0.01	1.18±0.02	1.15±0.02	3.88±0.11
		Monsoon	1.59±0.05	0.36±0.05	1.23±0.02	0.64±0.01	1.77±0.02
		Post-monsoon	3.37±0.12	1.49±0.01	1.22±0.10	1.28±0.02	2.85±0.01
4.	*Bruguiera cylindrica*	Pre-monsoon	4.03±0.15	1.33±0.03	1.30±0.02	0.89±0.02	3.57±0.16
		Monsoon	1.59±0.05	0.51±0.01	1.20±0.05	0.50±0.01	2.02±0.05
		Post-monsoon	3.73±0.18	1.02±0.05	1.25±0.02	0.75±0.04	3.25±0.02
5.	*Excoecaria agallocha*	Pre-monsoon	3.05±0.11	1.87±0.02	1.36±0.01	0.41±0.02	5.57±0.01
		Monsoon	1.44±0.01	1.33±0.01	1.15±0.03	0.30±0.01	3.20±0.15
		Post-monsoon	3.34±0.15	1.33±0.03	1.25±0.01	0.96±0.01	4.66±0.18
6.	*Rhizophora mucronata*	Pre-monsoon	3.40±0.02	0.66±0.01	1.02±0.03	0.76±0.05	5.51±0.16
		Monsoon	0.71±0.01	1.61±0.14	0.48±0.01	0.29±0.01	3.80±0.15
		Post-monsoon	3.26±0.01	0.61±0.01	1.01±0.03	0.85±0.02	4.16±0.11
7.	*Sonneratia caseolaris*	Pre-monsoon	5.01±0.21	0.84±0.03	1.47±0.01	0.73±0.02	6.85±0.15
		Monsoon	1.60±0.01	0.84±0.02	0.55±0.02	0.38±0.02	3.75±0.14
		Post-monsoon	4.18±0.15	0.94±0.03	1.23±0.11	0.81±0.01	5.50±0.03

Figure 30: Seasonal variation in mineral composition of mangrove leaves (gm/100gm dry tissue)

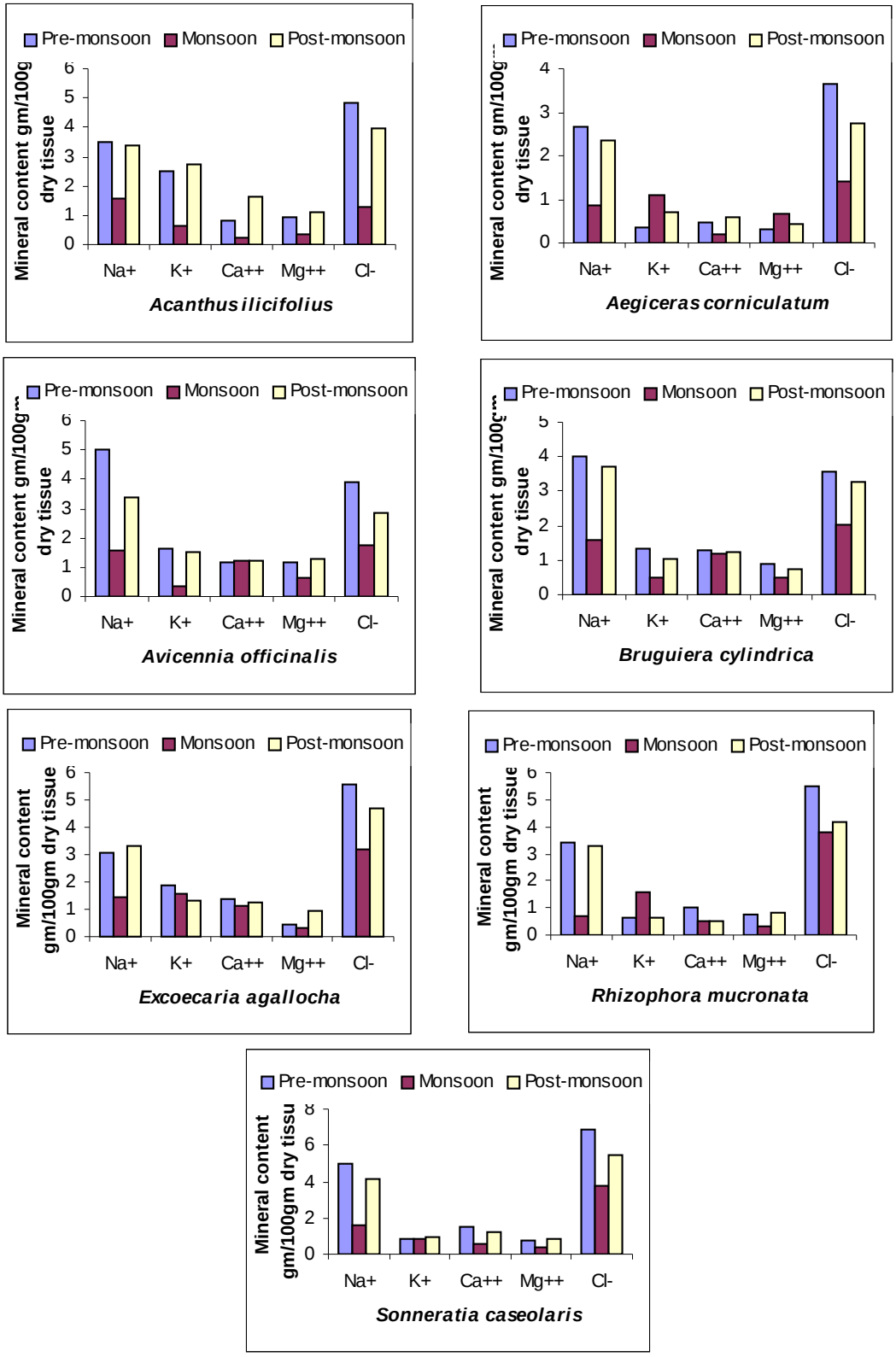
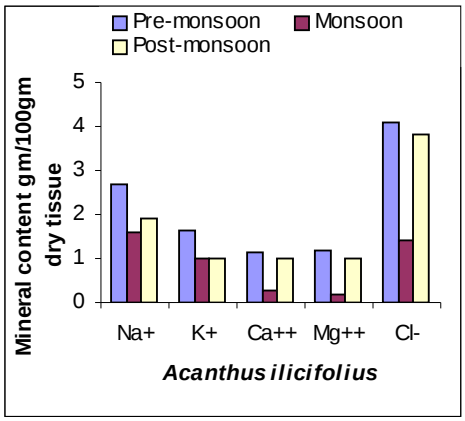
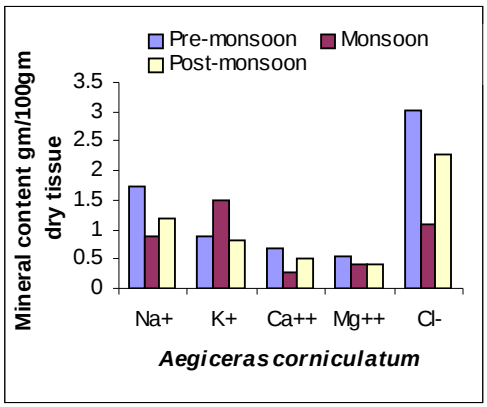


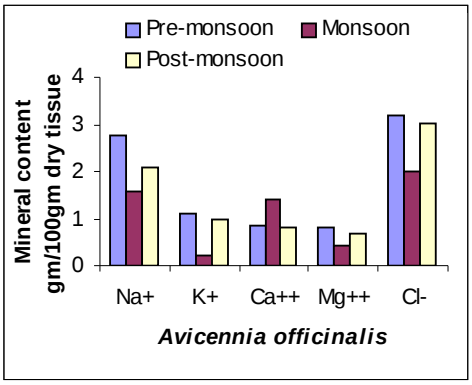
Table 39: Seasonal variations in mineral composition of mangrove stem (gm/100gm dry tissue)

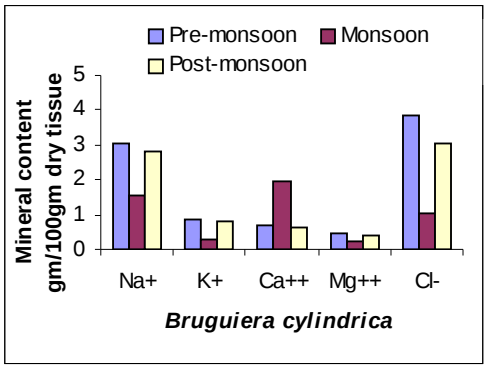
Sl. No.	Name of the taxa	Season	Sodium (Na^+)	Potassium (K^+)	Calcium (Ca^{++})	Magnesium (Mg^{++})	Chloride (Cl^-)
1.	*Acanthus ilicifolius*	Pre-monsoon	2.68±0.01	1.64±0.15	1.12±0.12	1.18±0.16	4.11±0.18
		Monsoon	1.58±0.19	0.98±0.05	0.29±0.03	0.17±0.01	1.41±0.06
		Post-monsoon	1.89±0.16	1.01±0.14	0.98±0.05	1.01±0.15	3.81±0.15
2.	*Aegiceras corniculatum*	Pre-monsoon	1.72±0.01	0.90±0.06	0.68±0.03	0.54±0.02	3.02±0.03
		Monsoon	0.89±0.06	1.48±0.01	0.26±0.03	0.41±0.10	1.08±0.02
		Post-monsoon	1.18±0.05	0.83±0.04	0.50±0.01	0.42±0.05	2.27±0.95
3.	*Avicennia officinalis*	Pre-monsoon	2.76±0.01	1.12±0.15	0.84±0.02	0.81±0.10	3.20±0.08
		Monsoon	1.59±0.04	0.21±0.06	1.39±0.04	0.41±0.03	2.01±0.05
		Post-monsoon	2.10±0.01	0.96±0.02	0.79±0.01	0.68±0.06	3.01±0.11
4.	*Bruguiera cylindrica*	Pre-monsoon	3.04±0.05	0.84±0.04	0.68±0.05	0.45±0.02	3.84±0.14
		Monsoon	1.53±0.13	0.29±0.01	1.93±0.04	0.23±0.06	1.05±0.10
		Post-monsoon	2.80±1.10	0.80±0.05	0.61±0.03	0.39±0.02	3.05±0.14
5.	*Excoecaria agallocha*	Pre-monsoon	1.28±0.15	0.52±0.02	0.78±0.05	0.68±0.04	3.89±0.15
		Monsoon	0.80±0.01	1.11±0.04	1.70±0.05	0.31±0.01	2.50±0.15
		Post-monsoon	1.02±0.10	0.46±0.05	0.70±0.05	0.56±0.06	2.96±0.11
6.	*Rhizophora mucronata*	Pre-monsoon	2.44±0.12	1.76±0.06	1.14±0.05	0.84±0.02	4.41±0.18
		Monsoon	0.49±0.01	0.79±0.03	0.18±0.02	0.15±0.04	3.30±0.27
		Post-monsoon	2.01±0.51	1.03±0.04	0.98±0.07	0.76±0.03	3.16±0.27
7.	*Sonneratia caseolaris*	Pre-monsoon	2.04±0.60	1.44±0.31	1.56±0.20	0.96±0.05	4.12±0.41
		Monsoon	0.90±0.05	0.66±0.01	0.29±0.01	0.21±0.03	2.41±0.21
		Post-monsoon	1.96±0.07	1.08±0.01	1.32±0.05	0.89±0.04	3.91±0.35

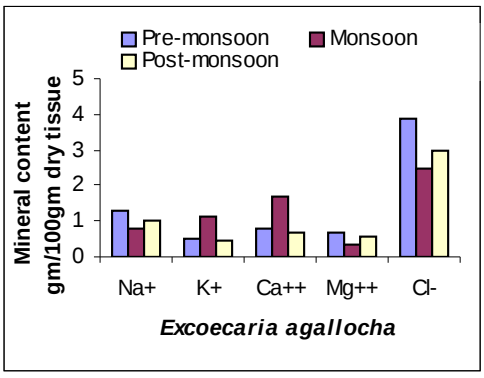
Figure 31: Seasonal variation in mineral composition of mangrove stem (gm/100gm dry tissue)

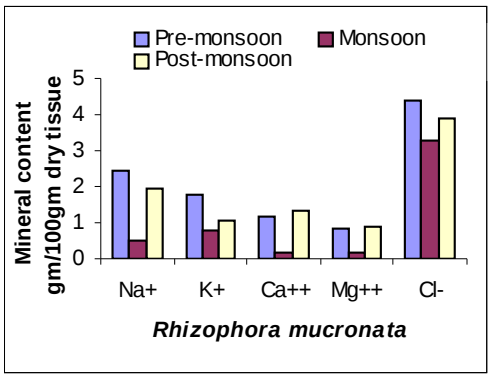












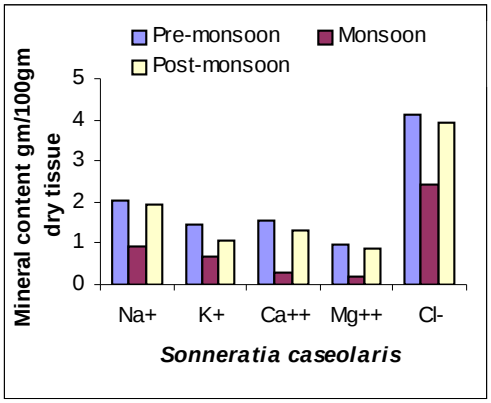


Table 40: Seasonal variations in the amount of Epicuticular wax (ECW) in mangrove leaves (gm/leaf)

Sl. No.	Name of taxa	Seasons		
		Pre-monsoon	Monsoon	Post-monsoon
1.	*Acanthus ilicifolius*	0.11	0.22	0.41
2.	*Aegiceras corniculatum*	0.10	0.25	0.21
3.	*Avicennia officinalis*	0.15	0.20	0.14
4.	*Bruguiera cylindrica*	0.13	0.23	0.14
5.	*Excoecaria agallocha*	0.12	0.30	0.21
6.	*Rhizophora mucronata*	0.21	0.35	0.27
7.	*Sonneratia caseolaris*	0.25	0.38	0.28

Figure 32: Seasonal Variations in Epicuticular Wax (ECW) in mangrove leaves (gm/leaf)

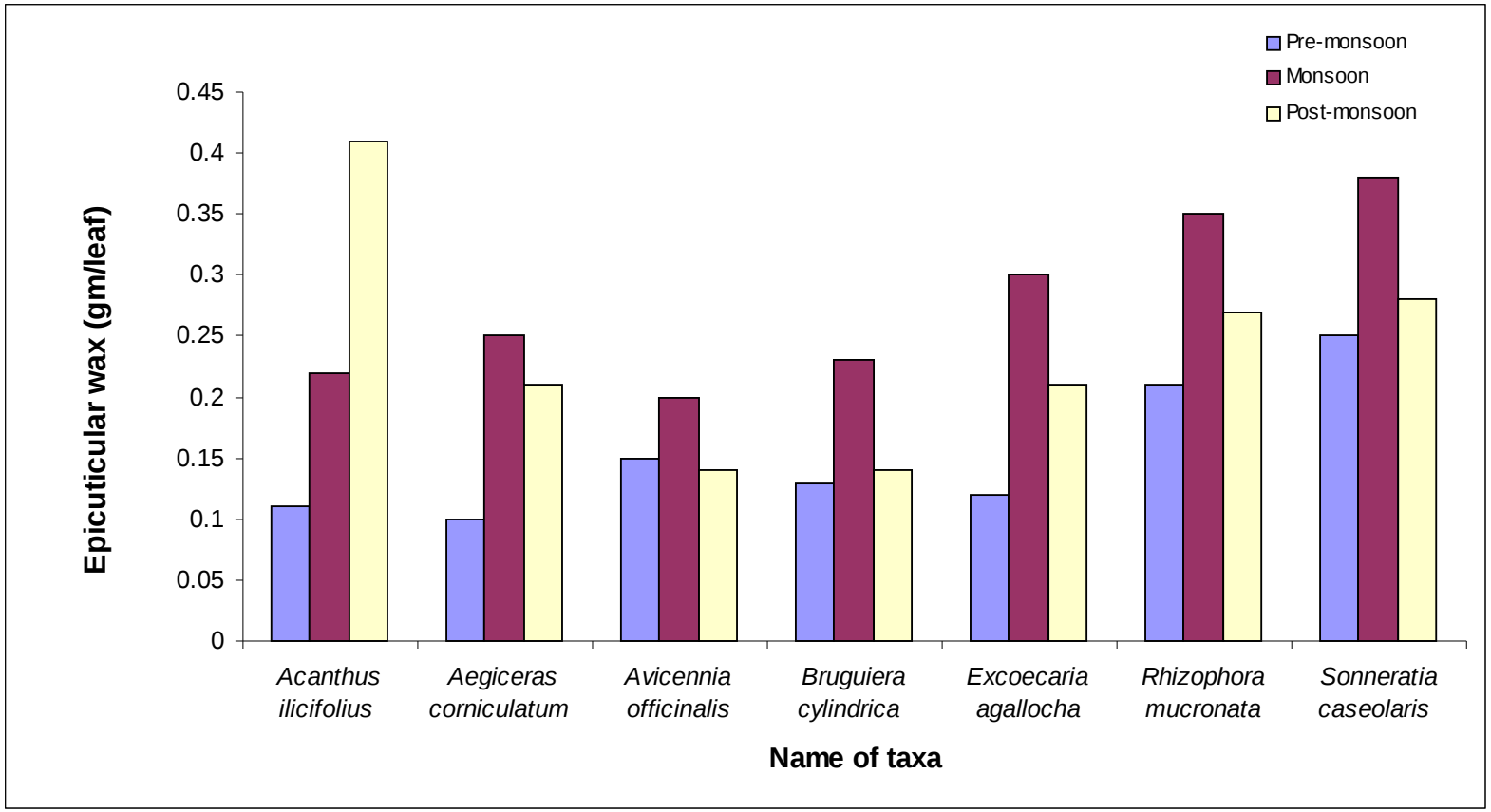


Table 41 :

Seasonal variations in Chlorophyll Content of Mangrove leaf (mg g^{-1} fresh wt.)

Sl. No.	Name of the taxa	Chlorophyll	Seasons		
			Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	Chl.a	0.168 ± 0.01	0.570 ± 0.01	0.829 ± 0.02
		Chl.b	0.159 ± 0.001	0.487 ± 0.01	0.508 ± 0.01
		Total Chl.	0.317 ± 0.001	1.057 ± 0.01	1.337 ± 0.02
2.	*Aegiceras corniculatum*	Chl.a	0.29 ± 0.01	0.209 ± 0.02	0.884 ± 0.01
		Chl.b	0.231 ± 0.001	0.379 ± 0.01	1.306 ± 0.02
		Total Chl.	0.525 ± 0.02	0.588 ± 0.02	2.190 ± 0.02
3.	*Avicennia officinalis*	Chl.a	0.584 ± 0.02	0.688 ± 0.01	1.373 ± 0.02
		Chl.b	0.384 ± 0.01	0.479 ± 0.01	0.743 ± 0.01
		Total Chl.	0.968 ± 0.02	1.167 ± 0.01	2.116 ± 0.20
4.	*Bruguiera cylindrica*	Chl.a	0.211 ± 0.02	0.382 ± 0.01	0.857 ± 0.01
		Chl.b	0.148 ± 0.01	0.221 ± 0.01	0.449 ± 0.02
		Total Chl.	0.359 ± 0.01	0.603 ± 0.02	1.306 ± 0.02
5.	*Excoecaria agallocha*	Chl.a	0.533 ± 0.03	0.936 ± 0.01	1.546 ± 0.001
		Chl.b	0.480 ± 0.01	0.612 ± 0.01	0.741 ± 0.02
		Total Chl.	1.013 ± 0.02	1.548 ± 0.01	2.287 ± 0.03
6.	*Rhizophora mucronata*	Chl.a	0.462 ± 0.01	0.512 ± 0.02	0.567 ± 0.02
		Chl.b	0.282 ± 0.01	0.301 ± 0.01	0.409 ± 0.01
		Total Chl.	0.744 ± 0.02	0.813 ± 0.02	0.977 ± 0.03
7.	*Sonneratia caseolaris*	Chl.a	0.269 ± 0.01	0.617 ± 0.03	0.833 ± 0.02
		Chl.b	0.145 ± 0.01	0.296 ± 0.01	0.396 ± 0.02
		Total Chl.	0.414 ± 0.02	0.912 ± 0.02	1.229 ± 0.03

Figure 33: Chlorophyll Content of Mangrove leaf (mg g^{-1} fresh wt.)

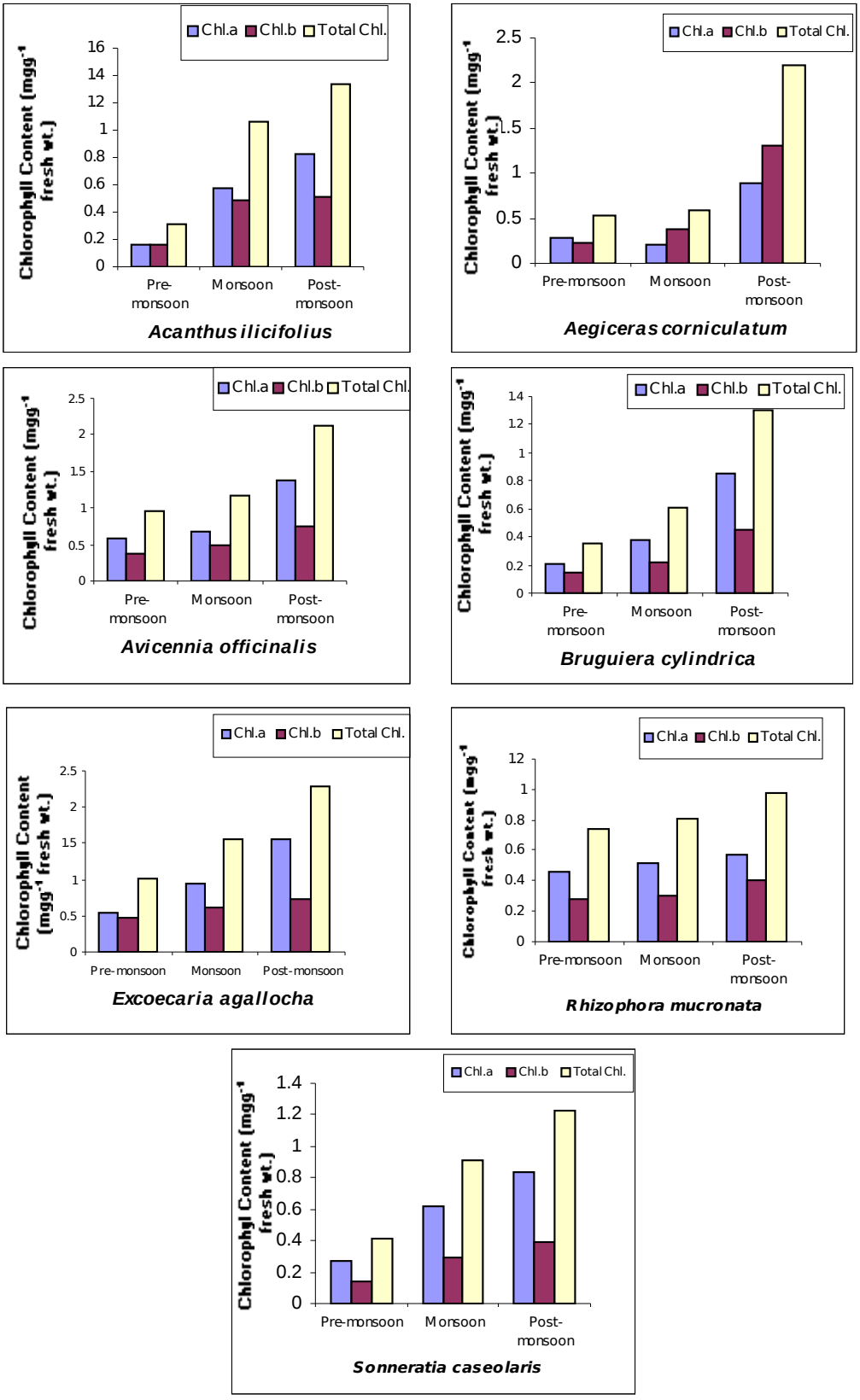


Table 42 : Seasonal variations in Chl a/Chl b ratio

Sl. No.	Name of the taxa	Chlorophyll ratio	Seasons		
			Pre-monsoon	**Monsoon**	**Post-monsoon**
1.	*Acanthus ilicifolius*	Chl a/ Chl b	1.056 ± 0.01	1.170 ± 0.01	1.636 ± 0.03
2.	*Aegiceras corniculatum*	Chl a/ Chl b	1.273 ± 0.02	0.551 ± 0.03	0.676 ± 0.001
3.	*Avicennia officinalis*	Chl a/ Chl b	1.521 ± 0.01	1.436 ± 0.01	1.848 ± 0.04
4.	*Bruguiera cylindrica*	Chl a/ Chl b	1.426 ± 0.03	1.728 ± 0.03	1.907 ± 0.02
5.	*Excoecaria agallocha*	Chl a/ Chl b	1.110 ± 0.02	1.529 ± 0.01	2.086 ± 0.02
6.	*Rhizophora mucronata*	Chl a/ Chl b	1.638 ± 0.01	1.701 ± 0.02	1.386 ± 0.01
7.	*Sonneratia caseolaris*	Chl a/ Chl b	1.855 ± 0.02	2.084 ± 0.02	2.103 ± 0.02

Figure 34: Seasonal Variations in Chl a/Chl b ratio

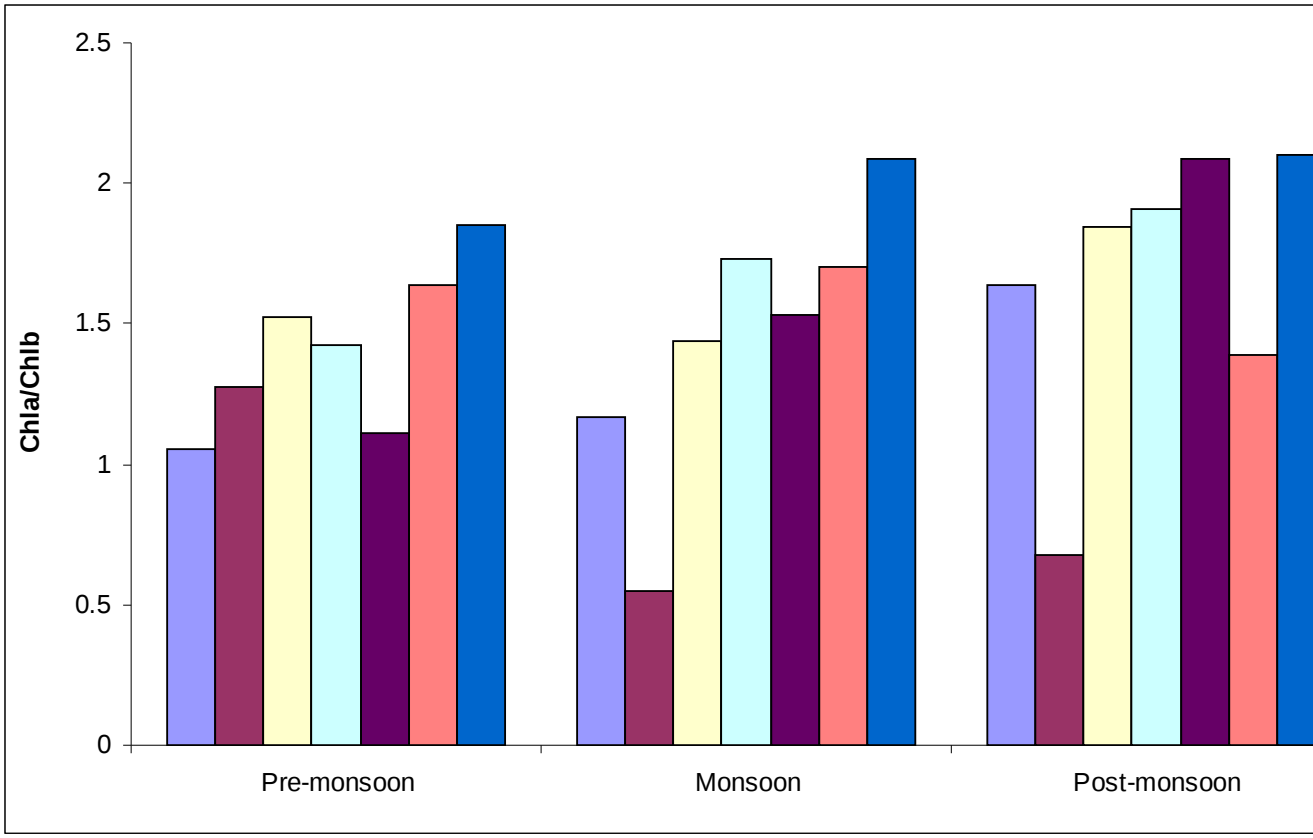


Table 43: Chlorophyll fluorescence

Name of taxa	Fv/Fm	ETo/RC	DIo/RC	Pl(abs)
Acanthus ilicifolius	0.657698	0.8586	0.6644	23.2139
	0.705385	0.9133	0.4369	32.2645
	0.715625	1.00	0.6309	23.8239
	0.741474	0.9133	0.4369	56.312
	0.74882	0.6744	0.4328	22.7125
	0.759104	0.6639	0.3645	34.1832
	0.76501	0.6223	0.3131	45.3132
	0.768743	0.7928	0.3186	93.7716

Table 44: Chlorophyll fluorescence

Name of taxa	Fv/Fm	ETo/RC	DIo/RC	Pl(abs)
Aegiceras corniculatum	0.618056	0.6148	0.7821	8.4764
	0.650558	0.4435	0.5853	7.9296
	677043	0.5037	0.78	11.4548
	0.73931	0.5572	0.522	10.1838
	0.749337	0.7482	0.3948	39.483
	0.761905	0.6788	0.3802	29.917
	0.771252	0.819	0.375	47.1342
	0.801735	0.7884	0.2736	93.1794

Table 45: Chlorophyll fluorescence

Name of taxa	Fv/Fm	ETo/RC	DIo/RC	Pl(abs)
Avicennia officinalis	0.747986	0.4038	0.4398	16.0554
	0.68543	0.6421	0.4909	24.1227
	0.704611	0.4743	0.3647	25.1795
	0.711048	0.4702	0.3531	27.1795
	0.719735	0.747	0.4084	53.182
	0.726471	0.5508	0.3381	39.2902
	0.789644	0.7037	0.2546	105.5966
	0.790402	0.7905	0.2741	118.3036

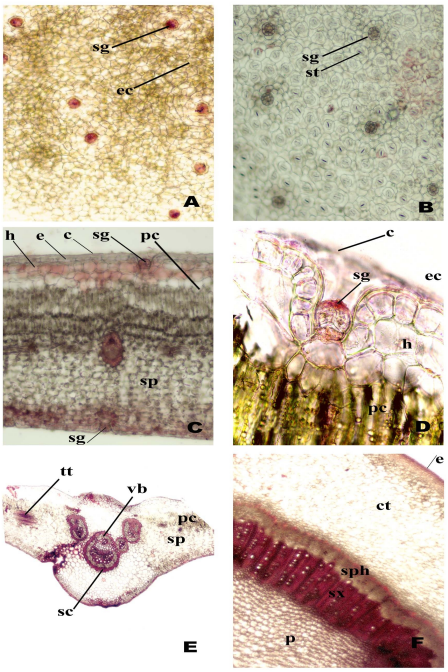
Table 46: Chlorophyll fluorescence

Name of taxa	Fv/Fm	ETo/RC	DIo/RC	Pl(abs)
Bruguiera cylindrica	0.663446	0.8245	0.7319	14.5142
	0.677384	0.7869	0.4786	1064.37
	0.724886	0.4113	0.3509	18.909
	0.741713	0.6655	0.3623	43.1277
	0.751276	0.6089	0.3185	46.7642
	0.786108	0.733	0.2883	73.9016
	0.817156	0.6211	0.2154	83.1843
	0.818414	0.555	0.1918	92.3471

Table 47: Chlorophyll fluorescence

Name of taxa	Fv/Fm	ETo/RC	DIo/RC	Pl(abs)
Rhizophora mucronata	0.651032	0.4978	0.6401	8.3544
	0.68906	0.7069	0.5195	24.516
	0.73487	0.4244	0.3314	22
	0.757772	0.5992	0.3317	36.5053
	0.778037	0.5871	0.3024	38.3715
	0.778195	0.5534	0.2378	78.0251
	0.787944	0.5839	0.263	53.3974
	0.790698	0.6383	0.2695	60.9246

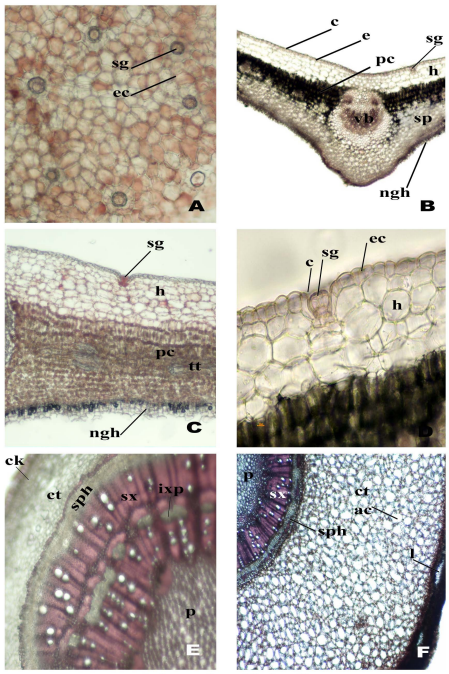
PLATE IV



Acanthus ilicifolius

Fig. A - E: Leaf Fig. F: Stem

PLATE VI

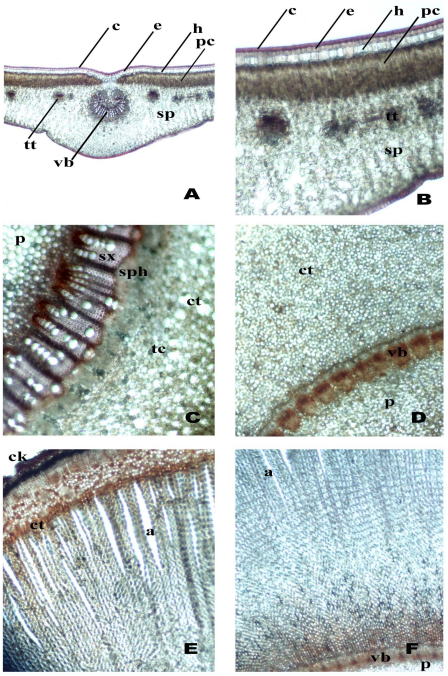


Avicennia officinalis

Fig. A - D: Leaf

Fig. E: Stem T.S. Fig. F: Pneumatophore T.S.

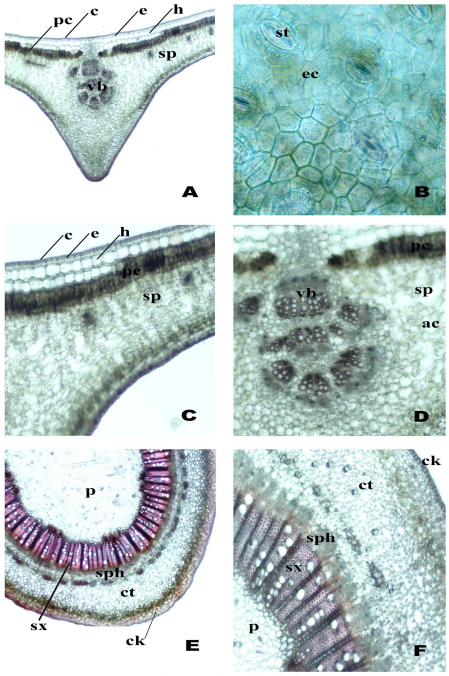
PLATE VII(b)



Bruguiera gymnorrhiza

Fig. A-B: Leaf, Fig. C: Stem T.S., D-F: knee root T.S.

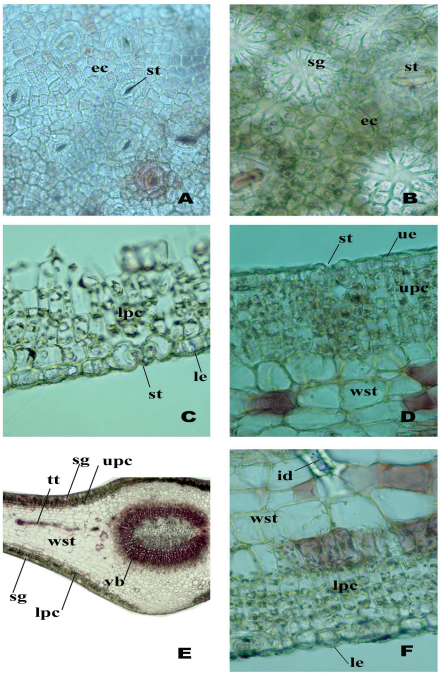
PLATE IX



Kandelia candel

Fig. A-D: Leaf, Fig. E-F: Stem

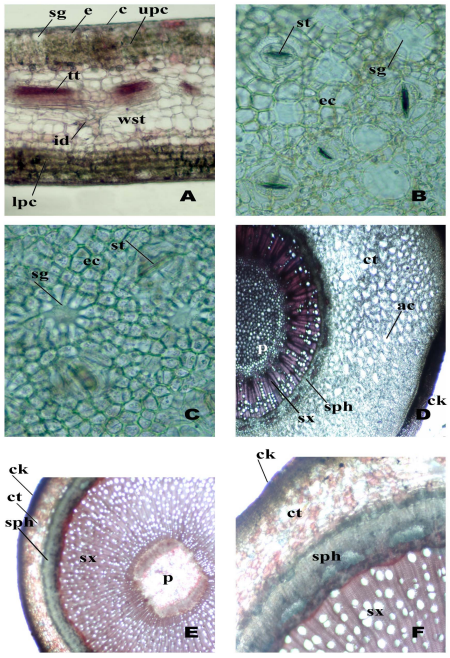
PLATE XI



Sonneratia caseolaris

Fig. A - F: Leaf

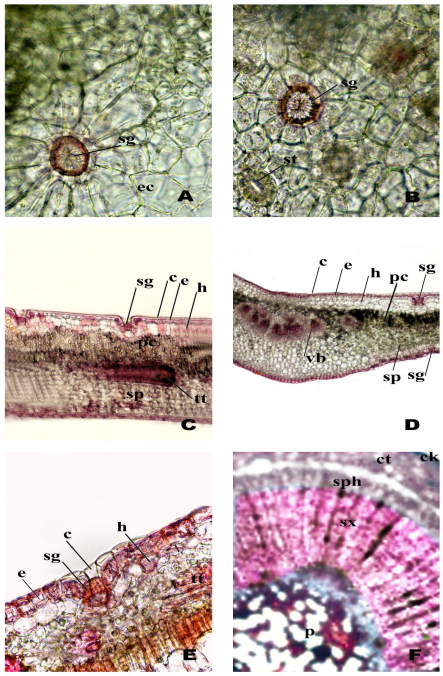
PLATE XII



Sonneratia caseolaris

Fig. A - C: Leaf, D: Pneumatophore T.S., E-F: Stem T.S.

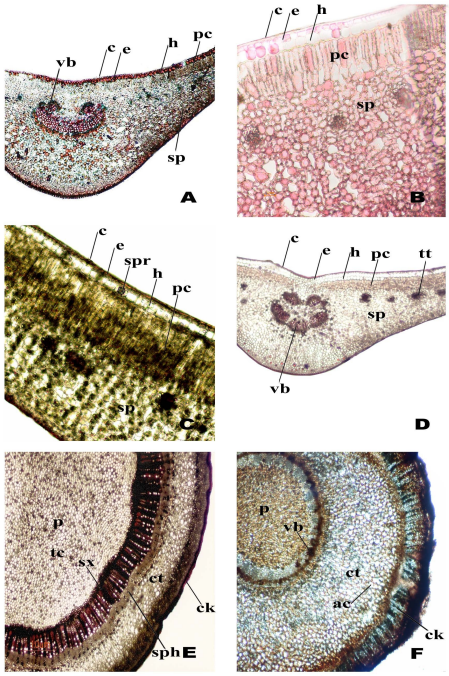
PLATE V



Aegiceras corniculatum

Fig. A-E: Leaf, Fig. F: Stem T.S.

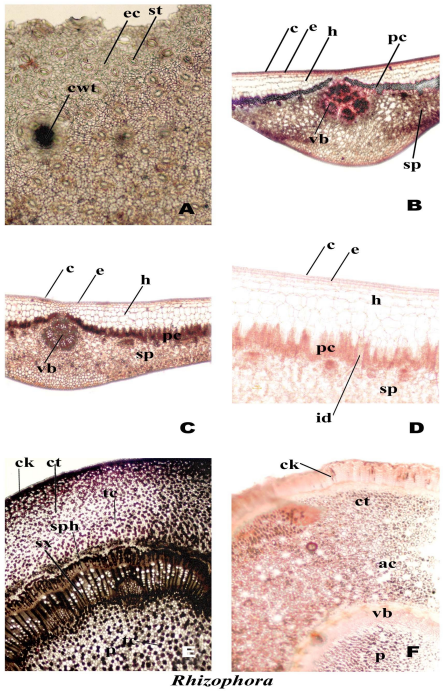
PLATE VII(a)



Bruguiera sexangula, B. cylindrica

Fig. A-D: Leaf, Fig. E: Stem T.S., Fig. F: Stilt root T.S.

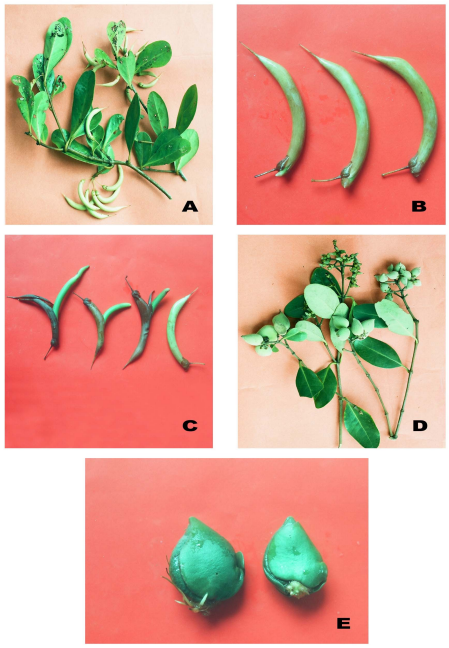
PLATE X



Rhizophora

Fig. A-B: Leaf (*R.mucronata*), Fig. C-D: Leaf (*R.apiculata*),
Fig. E: Stem T.S., Fig. F: Stilt root T.S.

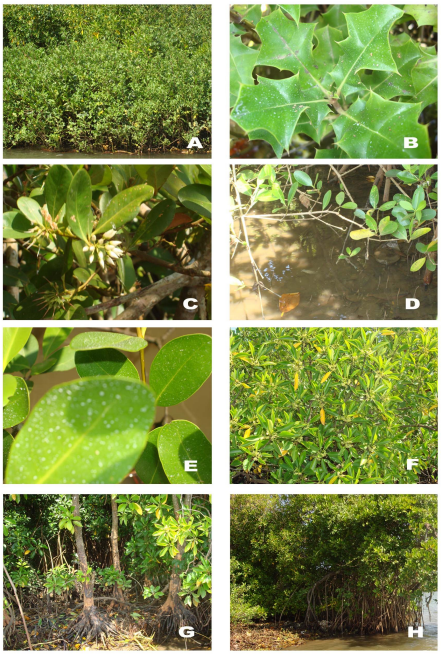
PLATE III



A-E: *Cryptovivipary*

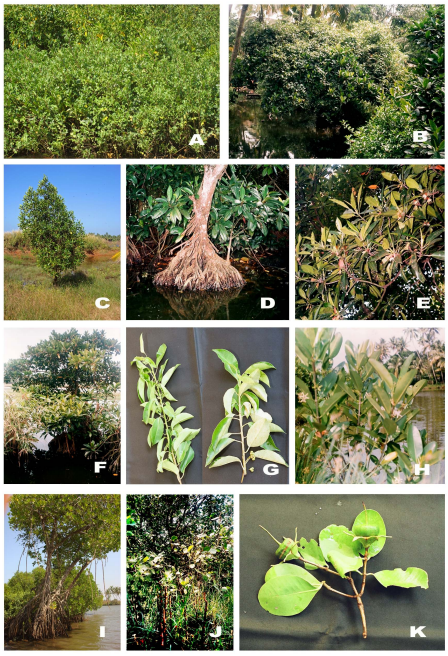
Fig. A-C: *Aegiceras corniculatum*
Fig. D-E: *Avicennia officinalis*

PLATE I(a)



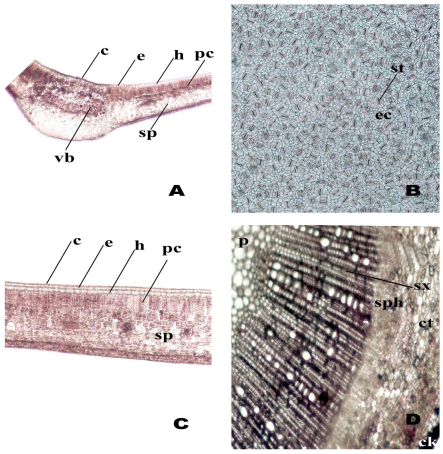
A-B: *Acanthus ilicifolius;* C: *Aegiceras corniculatum*
D-E: *Avicennia officinalis;* F-G: *Bruguiera cylindrica*
H: *Rhizophora mucronata*

PLATE I(b)



A: *Acanthus ilicifolius;* B: *Avicennia officinalis*
C: *Bruguiera cylindrica;* D-E: *B. gymnorrhiza*
F: *B. sexangula;* G: *Excoecaria agallocha*
H: *Kandelia candel;* I: *Rhizophora mucronata*
J-K: *Sonneratia caseolaris*

PLATE VIII



Excoecaria agallocha

Fig. A-C: Leaf, Fig. D: Stem T.S.

PLATE II

A-F: Vivipary

A-B: *Bruguiera*; C-F: *Rhizophora*

PLATE IV

sg, salt gland; ec, epidermal cells; st, stomata; c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; vb, vascular bundle; ct, cortex; sph, secondary phloem; sx, secondary xylem; p, pith.

PLATE V

sg, salt gland; ec, epidermal cells; st, stomata; c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; vb, vascular bundle; tt, terminal tracheid; ck, cork; ct, cortex; sph, secondary phloem; sx, secondary xylem; p, pith.

PLATE VI

sg, salt gland; ec, epidermal cells; c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; ngh, non-glandular hair; tt, terminal tracheid; ck, cork; ct, cortex; sph, secondary phloem; sx, secondary xylem; ixp, inter xylary phloem; p, pith; ac, air cavity; l, lenticel.

PLATE VII(a)

c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; vb, vascular bundle; spr, sphaeraphide; ck, cork; ct, cortex; sph, secondary phloem; sx, secondary xylem; p, pith; ac, air cavitiy.

PLATE VII(b)

c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; vb, vascular bundle; tt, terminal tracheid; ck, cork; ct, cortex; sph, secondary phloem; sx, secondary xylem; tc, tannin cells; p, pith, a, air space.

PLATE VIII

c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; vb, vascular bundle; st, stomata; ec, epidermal cells; ck, cork; ct, cortex; sph, secondary phloem; sx, secondary xylem; p, pith.

PLATE IX

c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; vb, vascular bundle; st, stomata; ec, epidermal cells; ac, air cavity; ck, cork; ct, cortex; sph, secondary phloem; sx, secondary xylem; p, pith.

PLATE X

ec, epidermal cells; st, stomata; cwt, corkwart; c, cuticle; e, epidermis; h, hypodermis; pc, palisade cells; sp, spongy cells; vb, vascular bundle; id, idioblast; ck, cork; ct, cortex; sph, secondary phloem; sx, secondary xylem; tc, tannin cells; p, pith, ac, air cavity.

PLATE XI

ec, epidermal cells; st, stomata; sg, salt gland; uc, upper epidermis; le, lower epidermis; lpc, lower palisade cells; upc, upper palisade cells; wst, water storage tissue; id, idioblast; tt, terminal tracheid.

PLATE XII

sg, salt gland; e, epidermis; c, cuticle; ec, epidermal cells; upc, upper palisade cells; wst, water storage tissue; id, idioblast; tt, terminal tracheid; st, stomata; ck, cork; ct, cortex; ac, air cavity; sph, secondary phloem; sx, secondary xylem; p, pith.