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1.1 MANGROVES

"If there are no mangrove forests, then the sea will have no meaning. It is like having a tree with no roots, for the mangroves are the roots of the sea" (MAP, 1999). Mangroves are important, complex and dynamic ecosystems, occurring in thick fringes in the intertidal zone along tropical and subtropical coastlines. This unique ecological niche is inhabited by a variety of plants and animals, which utilize the environment for food, shelter and reproduction. Ong (1982) has commented, "The mangrove is nature's own aquaculture system with a number of advantages like it is more stable and less susceptible to disease and epidemics."

1.1.1 Mangrove Ecology

Mangrove forest generally embodies two different concepts. Firstly it refers to an ecological group of evergreen plants belonging to several families but possessing marked similarity in their physiological characteristics and structural adaptation to similar habitat preferences. Secondly, it implies a complex of plant communities fringing sheltered tropical shores with a rich diversity of both floral and fauna resources. Mangrove plants are adapted for growth in a saline environment on loose wet soil that is periodically submerged by tides.

1.1.2 Mangrove Zonation

Mangrove systems are classified on the basis of physical appearance (forest structure), hydrology, and productivity. Riverine forests, the most productive, are those that lie along river and creek channels. These forests are the largest in stature and experience a constant flow of water both in the dry season (through daily tidal activity) and wet season (from terrestrial runoff). Fringe forests are moderately productive intertidal mangrove wetlands that occupy protected shorelines and the mouths of channels. Fringing mangroves are known for their capacity to trap sediments from both marine and terrestrial sources. Overwash forests are subtidal to intertidal marine-dominated systems that have productivity values resembling fringe forests. This forest type is commonly found in the form of a small island that is constantly washed by tides. Basin forests are also moderately productive forests that are found in more inland areas. These mangroves are rarely inundated by tidal action nor terrestrial runoff. Dwarf (scrub) forests are the least productive. This
forest type is dominated by a stunted form of mangrove (usually Rhizophora mangle). These wetlands, although long in hydroperiod, are low in both nutrients and hydrologic energy. Hammock mangrove wetlands appear as tree islands along fringing coastlines. They grow in depressions and have characteristics similar to basin and dwarf mangroves (Lugo and Snedaker, 1974).

1.1.3 Mangrove Environment

Plants which grow in areas of tidal influence must be able to deal with environmental extremes not experienced by other plants.

Direct effect of the tide - Plants growing in the lower portion of the tidal range have their root systems covered by water at least twice a day. Water logging displaces air from the soil and effectively prevents diffusion of oxygen through the spaces in the soil. One of the most obvious effects of the tide is the regular replenishment of the soil water across the whole area. Where water logging occurs, the soil rapidly becomes anoxic and takes on the typical sulphide smell of the mangrove swamp. This is a natural phenomenon due to the restriction of oxygen supply by water logging and the presence of bacteria which carry out anaerobic forms of respiration where sulphur is the final electron acceptor and is not due to pollution or environmental degradation.

Salinity of water - Mangrove plants live in an environment having salinity equal to or greater than that of seawater. Mangroves, being quite large trees, require a plentiful supply of water. The water which evaporates from their leaves is pure but the water which is available to their roots contains a large amount of salt.

1.1.4 Morphology and physiology of mangroves

Since they lie at the interface of land and sea, mangrove wetlands, like salt marshes, display ranges in salinity from fresh to brackish to marine (and even to hypersaline in highly evaporative areas). Mangrove species dominate these ecotones because they have evolved several mechanisms that allow them to be successful under these highly variable salinity regimes (Chapman, 1976; Clough, 1984).

Although regularly inundated with seawater, mangroves live in a 'dry' environment as a desert. When the salt content of the surrounding water is high, the plant will lose water out of its cell. When water evaporation rates are high, there is
a deficiency of water. The plants close their stomata to reduce further water loss, which also halts the uptake of carbon dioxide and reduces photosynthesis. This problem of obtaining water is termed "physiological dryness".

Mangroves are termed facultative halophytes. This means that while they can grow in salt water, they can also do well in freshwater. They generally do not thrive in freshwater because competition from other species crowds them out. i.e., one particular advantage to growing in a salty environment is the lack of competition. Only a limited number of plants have invested evolutionary energy into adapting to such harsh conditions. In the optimum conditions of a tropical rainforest, diversity is great and competition fierce.

Mangroves have two internal methods to survive in the saline environment. They can either exclude salt (not take it into the plant), or extrude salt (take salt in, transport it up their trunks and dispense it through glands in their leaves).

*Salt excluder* - Some separate freshwater at the root surface by means of a non-metabolic ultra filtration system. This reverse osmosis process is powered by high negative pressure in the xylem resulting from transpiration at the leaf surface. Some species can exclude more than 90 per cent of salt in sea water. (Rhizophora, Ceriops, Bruguiera and Osbornia species are all 'salt-excluders'.)

*Salt extruders* - Another method, is to quickly excrete salt which has entered the system. i.e., regulating ionic concentration by extruding salt through glands on the leaf surface. This is a temperature sensitive enzymatic process, and requires that energy be spent to actively transport sap. The leaves of many mangroves have special salt glands which are among the most active salt-secreting systems known. (Examples of 'salt-secreters include Avicennia, Sonneratia and Acanthus.)

A third method of coping with salt is to concentrate it in bark or in older leaves which carry it with them when they drop. (Lumnitzera, Avicennia, Ceriops and Sonneratia species all use this trick).

As can be seen from the examples given, some mangroves use only one of these methods but many use two or more. In addition, a number of features serve to conserve water. These include a thick waxy cuticle (skin on the leaf) or dense hairs to reduce transpiration - the loss of water. Most evaporation loss occurs through
stomata - pores in the leaves - so these are often sunken below the leaf surface where they are protected from drying winds. Leaves are also commonly succulent, storing water in fleshy internal tissue.

**Roots** - One of the characteristics of mangroves is the development of roots, which are exposed to air, at least at low tide. These allow gas exchange in roots systems in substrates that are generally anoxic and waterlogged. Many species have highly specialised roots structures, which are typical of particular genera. These can be divided in four types; stilt roots, pneumatophores, knee roots and buttress roots.

*Stilt roots (drop roots)* - Stilt roots are characteristic of Rhizophora, but also occur in Bruggeria and Ceriops. They may also occur in Avicennia alba and A. officinalis. They grow downwards from the trunk and branches, providing water uptake in the sections below the sediment. They also possess many lenticels for the exchange of gases needed for respiration and will enable the tree to root even in mud lacking oxygen for diffusion of gases. Once aerial roots extend into the bottom they will provide adequate protection from displacement and ensure the continuing subsistence of the plant. Thus they provide support in older trees. They are also known as aerial roots or prop roots.

*Pneumatophores* - Pneumatophores project through the sediment surface from underlying cable roots and function primarily in gas exchange. They are characteristic of Avicennia and Sonneratia.

*Knee and blade roots* - Knee roots are raised loop sections of cable roots, with thickening on the upper exposed side, forming "knees". These are characteristic of species of Brugueira and Ceriops.

*Buttress or plank roots* - In Xylocarpus granatum, horizontal cable roots develop vertically blade growth along their length, forming extended blade or plank roots above the sediment surface. Similar development from the base of the trunk in Heriteira species results in the development of buttress roots.

*Germination* - Through "viviparity," embryo germination begins on the tree itself; the tree later drops its developed embryos, called seedlings, which may take root in the soil beneath. Viviparity may have evolved as an adaptive mechanism to prepare the seedlings for long-distance dispersal, and survival and growth within a
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harsh saline environment. During this viviparous development, the propagules are nourished on the parent tree, thus accumulating the carbohydrates and other compounds required for later autonomous growth. The structural complexity achieved by the seedlings at this early stage of plant development helps acclimate the seedlings to extreme physical conditions which otherwise might preclude normal seed germination. Many mangrove species including Bruguiera, Ceriops, Kandelia, and Rhizophora, display vivipary. Another special adaptation is the dispersal of certain mangroves' "propagules" which hang from the branches of mature trees. These fall off and eventually take root in the soil surrounding the parent tree or are carried to distant shorelines. Depending on the species, these propagules may float for extended periods, up to a year, and still remain viable. Viviparity and the long-lived propagules allow these mangrove species to disperse over wide areas.

1.1.5 Mangrove diversity

Three mangrove species dominate the wetland areas, the red mangrove (Rhizophora mangle), black mangrove (Avicennia germinans) and white mangrove (Laguncularia racemosa). The red mangrove is the tallest, with recorded heights of 25 m. The leaves are long (12 cm), waxy, dark green above and pale below. The roots, trunk and branches have a thin grey bark covering a dark red wood. Notable characteristics include the prop roots derived from the trunk and drop roots from aerial branches. Small yellow flowers are most common in the summer, but the long (15 cm), cigar shaped propagules may be found hanging on the tree at any time of the year.

The second tallest species is the black mangrove, which may reach heights of 20 m. The small (10 cm) leaves are elliptical or oblong, and green on the upper surface. The undersurface is covered with dense hairs often encrusted with salt. The bark is dark and scaly. This tree displays distinctive aerial roots (pneumatophores), which stick up from the ground like thin fingers. Flowering occurs during summer months, and result in bean-shaped propagules (2-3 cm long) in late summer and early fall.

The white mangrove is the smallest of the three mangroves (sometimes it appears to be a shrub) with maximum heights of 15 m. It has broad, flat oval leaves
up to 7 cm long that are rounded at both ends. Two salt glands are found at the base of each leaf at the apex of the petiole. Flowering occurs in mid to late summer and produces very small (<0.5 cm) propagules resembling peas a month later.

1.1.6 Physical Functions and Economic Value

Mangroves provide a wide variety of direct and indirect services to society and the economy. Mangroves are vital natural systems that need to be protected as a near shore nutrient source, as breeding, feeding and nursery grounds of marine organisms, and for land building, stabilization and protection purposes. Their importance to biological, chemical, physical and geological processes occurring in the coastal zone is evident (Kristensen et al., 1991; 1992; Alongi et al., 1992; 1993; Woodroffe, 1992; Robertson et al., 1992; Hemminga et al., 1994).

Sediment Stabilisers - The mangrove plants are important stabilisers of fine sediments, with a substantial amount of sediment being deposited with each retreating tide. The algae on the surface of the mud help to bind together sediment particles, and soil is also trapped between roots. They act as a buffer against coastal erosion.

Nutrient Sink - Mangrove, and the sediments associated with them, can assimilate substantial quantities of nutrients such as nitrogen and phosphorus, thereby preventing contamination of nearshore waters and may reduce the incidence of eutrophication and possibility of red tides (Robertson et al. 1992). Toxins may also be retained in mangrove and associated sediments. Mangroves have also been useful in treating effluent.

Biodiversity and Genetic Value - Primary mangrove is reasonably diverse, and is habitat for several endangered species. Mangroves are physiologically unique in their ability to live in salt and brackish water.

1.1.7 Mangrove use

Mangrove forests have been widely and variously used by the people who live in or close to them and who traditionally have made a living from the mangrove ecosystem for thousands of years. Mangroves are so productive that they are the source of livelihood for many people. The wide variety of traditional products from mangroves utilised by coastal communities is well-documented (Bandaranayake,
Basic necessities such as food, shelter, fuel, and medicines are all obtained from mangroves. Some mangrove products have been useful to man in the past. Fruits of the red mangrove are edible, and the leaves have been used for tea, medicinal purposes and as livestock feed. The wood from the red mangrove is durable and water resistant, and has been used for boats, houses, pilings, fence posts and furniture. Black mangrove flowers produce nectar for honey, and the bark has been used for tannin and dyes. The dense wood of the black mangrove and buttonwood has been burned for charcoal. Traditionally the mangroves of India and Bangladesh have been exploited for timber and fuelwood, bark tannin, animal fodder, native medicines and food (fish, shellfish, honey, wild animals). Many of these activities still continue, and include collection of thatching material (Nypa), gathering of shells to produce lime and wild honey collection (in the Sundarbans especially). Mangrove timber has always been important to traditional coastal communities for house and boat building (FAO, 1982), and remains so today. The importance of bark tannins has declined in many Asian countries, but some mangrove tannin is still used in India and Bangladesh for leather curing and there are some other traditional uses, e.g. for curing fishing nets in Sri Lanka (FAO, 1982). The gathering of mangrove leaves (Avicennia) for animal fodder remains widespread in the Middle East and Southern Asia, for feeding camels in Iran and India, for example; in fact grazing by domestic animals is a serious cause of mangrove degradation in parts of India. Mangrove honey is an important economic product extracted from the Sundarbans (Bandaranayake, 1998). Although impossible to quantify, hunting also remains a significant activity in the Sunderbans and in many other areas in Asia where mangroves are still extensive.

Numerous medicines are derived from mangroves. Skin disorders and sores, including leprosy, may be treated with ashes or bark infusions of certain species. Headaches, rheumatism, snakebites, boils, ulcers, diarrhoea, haemorrhages and many more conditions are traditionally treated with mangrove plants. The latex from the leaf of the blind-your-eye mangrove (Exoecaria agallocha) can indeed cause blindness, but the powerful chemicals in it can be used on sores and to treat marine stings. Mangrove plants are a rich source of steroids, triterpenes, saponins, flavonoids, alkaloids and tannins (Bandaranayake, 1998). The use of saponins as natural detergents and fish poison were known to the primitive people. The
interesting pharmacological properties associated with the Chinese drug “ginseng”, which is considered a panacea and a drug for longevity, are attributed to the various saponins present in it. Plant saponins have other interesting biological activities such as spermicidal (Kamboj et al., 1976) and molluscsicidal (Marston and Hostettmann, 1985), antimicrobial, inflammation-inhibiting, antiviral, analgesic, antifungal, mosquito larvicidal, piscicidal and cytotoxic activities (Mahato et al., 1988; Bandaranayake, 1998). Their potential value as cytotoxic and antineoplastic agents and as antimicrobial agents, for example in wood preservation or prevention of dental caries has been demonstrated (Scalbert, 1991). Novel inhibitors of HIV-1 reverse transcriptase have been characterized from the Malaysian tree *Calophyllum inophyllum* (Patil et al., 1993). Chemicals identified from *Calophyllum inophyllum* are prospective lead compounds for anticancer drugs (Tosa et al., 1997).

### 1.2 DISTRIBUTION OF MANGROVES

#### 1.2.1 Global distribution of mangroves

Mangroves once covered 3/4 of the world's tropical coastlines. Asia contains most of the world's mangroves with 46%, followed by America with 35% and Africa with 17% (MAP, 1999). Mangrove wetlands are the salt marshes of tropical and subtropical regions of the world. They are most commonly found along favorable coastlines between 25°N and 25°S latitude (Kuenzler, 1974). World wide, during 1980's the mangrove forest covered about 24 million hectares and are found in the coastal zones of sub-tropical and tropical countries (Twilley et al., 1992). According to Spalding (1997), the total area of mangroves in the world is approximately 181,399 sq.km. Furthermore, the largest mangrove area occurs in Indonesia, (30%) Brazil (10%) Australia (8%) and in India only (3%). The mangrove ranges differ globally quite clearly regarding numbers and diversity of species. Indian ocean and the pacific region have a large diversity of species whereas low diversity of species distinguish the America and West Africa regions (Jordan, 1991). Most of the species belong to the families of the *Combretaceae* followed by *Rhizophoraceae* and *Avicenniaceae*. According to Aksornkoae (1995), 79 mangrove species are found in the world.
Substantial areas of mangrove forest occur in Asian countries like Pakistan, India, Bangladesh, Myanmar, Thailand, Cambodia, Vietnam, Malaysia, Philippines and Indonesia. About two fifth of all mangrove forests in the world occur in Asia. The major mangrove forests of South and Southeast Asia can be divided into two broad groups. The mangroves of South Asia are dominated by non-rhizophore species while the most dominant and commercially important species in the mangrove forests in Southeast Asian countries are a number of species from the family Rhizophoraceae.

1.2.2 Status of Mangroves in India

The coastal areas of India accommodate about one fourth of country's population that is dependent to a large extent on marine resources. On the Indian coast, mangroves are found along the islands, major deltas, estuaries and backwaters and constitute an important resource in India. Like terrestrial tropical forests, mangroves have been a significant part of the Indian economy for thousands of years and are a reservoir of valuable natural resources. Mangroves constitute a significant portion of the coastal wetlands on which a large percentage of coastal population is depended directly or indirectly.

In India, the mangrove forest covers about 360,000 ha (Govindasamy and Kannan, 1996). Sunderbans is the largest single block of mangrove forest in the South East Asian Region occupying about 4000 square kilometres. Mangrove areas of lesser extent of 5000-15000 hectares are encountered elsewhere in the estuaries of Mahanadi, Godavari, Krishna, Cauvery and along smaller river systems and salt water creeks along the west coast. The Andaman-Nicobar islands contain some of the least disturbed.

A total of 65 mangrove species is recorded throughout India. Of these, 62 are found in the Sundarbans, 63 in Mahanadi delta, 29 towards the Godavari- Krishna- Cauvery and west coast region and 30 in the Andaman and Nicobar Island. The dominant mangrove species are Rhizophora, Bruguiera, Sonneratia and Kandalia.

1.2.3 Status of mangroves in Kerala

According to authentic records, about 70,000ha of mangroves which once fringed the backwaters of Kerala, have now been reduced to a few isolated patches
consisting of a few species. The important mangrove patches existing now in Kerala are scattered across the state at Veli, Quilon, Kumarakom, Kannamali, Mangalavanam, Vypeen, Chetwai, Nadakkavu (Calicut), Edakkad, Pappinisseri, Kunchimangalam and Chittari (Ramachandran et al., 1986). Mangroves and associated species reported include Sonneratia caseolaris, Kandelia candel, Bruguiera sp., Lumnitzera racemosa, Excoecaria agallocha, Aegiceras sp., Ardisia littoralis (unique to Kerala mangals), Caesalpinia crista, Dolichandron spathecea, Heritiera littoralis, Phoenix humilis var. pedunculata, Flagellaria indica, Viscum orientale, Derris trifoliata, Dalbergia candeitensis, Dendrophthoe falcaia, Acampe praemorsa, Samadera indica, Hopea ponga, Phragmites karka, Cyperus javanicas, Paspalam vaginatum, Carallia brachiata, Syzygium travancorium (unique to Kerala mangals), Premna serratifolia, Morinda citrifolia, Scalvolserica, Aerostichum aureum.

The mangroves in and around Greater Cochin comprise of woody species such as Avicennia, Rhizophora, Bruguiera, Excoecaria etc. and shrubby forms like Acanthus, Clerodendron, Aegicaras, etc. and also a mangrove fern Aerostichum aureum. Towards the land ward fringes, mangrove associated ferns like Thespesia populnea, Hibiscus tiliaceous, Terminalia catappa, Pandanus sp., Artocarpus spp. are often encountered. Towards the beach side of lagoons, strand vegetation such as Ipomoea pescaprae, Acanthus sp., Panicum spp. are common. From the Cochin estuary, Acanthus ilicifolius, Rhizophora sp. and Bruguiera sp. were reported (Naskar and Mandal, 1999).

1.3 MANGROVE DESTRUCTION

1.3.1 Causes for the deterioration of mangroves

The mangrove ecosystem is a very dynamic one, where changes are taking place regularly, and within the range of mangrove habitats most major species grow within a given set of conditions. Any major changes in these conditions may start to bring about changes in the growth pattern of different species, a complete elimination of one or more species resulting from changes in the composition of the forests, or in extreme cases a complete disappearance of the forest. Because of this severe sensitivity to change in habitat conditions, mangrove forests are very
susceptible to destruction. Human activities create stress on the ecosystem beyond its tolerance limit that can pose hazards to the coastal and marine environment, and to the health and safety of the population living in the coastal areas.

The causes of mangrove destruction around the world are many. They may be classified as: overexploitation by traditional users; conversion to aquaculture; conversion to agriculture; conversion to salt pans; conversion to urban development; construction of harbours/port and channels; mining; liquid waste disposal; solid waste of garbage disposal; oil spillage, and other hazardous chemicals. Natural stresses such as cyclones and freshwater discharges also destroy mangrove forests, but the areas are minimal compared with those lost from human activity.

The mangroves, with their swampy soils, clusters of breathing roots, prop roots and tangle of trees and twiners have often been considered as a waste land or dangerous place inhabited by harmful wild animals. Mangroves are often thought of as smelly, grassy "wastelands" cut by numerous channels, oozing with mud, and often swarming with blood-sucking insects and thus their intrinsic values have often been overlooked when any development activity is undertaken due to compulsions of population pressure and the consequent socio-economic development needs. In the past, mangrove areas were generally regarded as useless and hostile territory. Because of their bad reputation, mangroves are the ecosystems most in danger of disappearing. Despite their significance, these ecosystems at frequently at great risk in both developed and undeveloped countries. Regardless of the social circumstances, the habitat is often regarded as prime for conversion to some other use and may be indiscriminately cleared for industrial, agricultural or residential purposes.

Mastaller (1996) have shown that in Kerala, which once boasted of having about 70000ha. of mangrove, what remaining is only 250ha. i.e. only 4% of the initial area is remaining within the period 1911-1989. The Cochin Backwater was originally fringed by mangroves and was famous for prawn fishery; the mangroves were cut down to convert the backwater to agriculture farms or purposes. Mangroves have been ruthlessly felled because of their prime seafront location.
1.3.2 Ecological and Economical Impacts of Mangrove Destruction

Although mangrove systems are floristically "simple" compared to other tropical forests, they have complex trophic structures and intricate interrelationships among physical, chemical and biological components that are not well understood. Thus, a change in a single component may not necessarily cause immediate change in ecosystem function, but continued pressure on this component may eventually alter ecosystem function through feedback effects on other components and processes.

Mangrove forest tends to react sensitively towards disturbances from outside the system. The major problems associated with indiscriminate use of the coastal wetlands are increasing soil acidification, loss of nutrients, soil erosion, and decreasing fishery potential, which in turn have led to many ecological and economic problems along the coast (Untawale, 1992). Mangrove destruction may lead to a reduction in the number of species or number of individuals in large water birds and mammals, mass fish mortality and decreasing levels of spawning in fish and prawns. Inevitably most people living in or associated with mangroves suffer economic losses once this ecosystem is disturbed or eliminated. The destruction of mangrove ecosystems, the local fisheries is affected, economically and socially. Industrial fisheries experience a decline in near shore fish and shrimp catches which are directly or indirectly linked to the status and spatial extent of tidal forests. On a global scale, the loss of mangrove wet lands means a loss of critically important wet land for many migratory species. Theories of global warming, polar cap melting and coastal flooding have been linked to global rain forest destruction and consumption of fossil fuels.

Deterioration of soil (acid sulphate soils) - Mangrove soils developed from sea water sediments contain high sulphides which occur in the form of iron sulphide (FeS) and pyrites (FeS₂). Drainage of mangrove soil for agricultural purposes and the exposure of the pyretic sediments during excavation of ponds lead to their oxidation, resulting in the formation of sulphuric acid which is released in the soil, thereby increasing the acidity of the soil, and in such cases pH may drop below 3.0 (Alongi et al., 1998). Under conditions of severe acidity, solubility of aluminium, iron and manganese increases and this may cause phytotoxicity. This creates a situation where the substrate becomes toxic to the growth of any
organism. At low pH the availability of nutrients also decreases greatly and important nutrients become unavailable to plants, and as a result, soil fertility is greatly reduced. Acid sulphate soils with low pH are toxic to the growth of both plants and animals and most plants and animals, invertebrates and fish die at high levels of acidity. At moderate levels of acidity, the rate of growth of plants and production of fish and other organisms are substantially reduced. In case of reclaimed rice fields, the production of rice decreases gradually with each crop while acidity steadily increases. The same is true in the case of fish and shrimp ponds, where with increased acidity the production level falls steadily. At some point soon the agriculture/aquaculture practices do not remain viable and are abandoned, because of unfavorable growing conditions created by the toxicity. As strongly acid sulphate soil is unable to support any vegetation, the barren soil becomes highly degraded and is prone to erosion.

Erosion - Drainage of mangrove forest after clearance, together with breakdown of the root system, results in land subsidence and leaves soils that are susceptible to erosion.

1.4 MANGROVE PRODUCTIVITY

The mangrove ecosystem is a good example of how each part is dependent on the whole for survival. Mangrove ecosystems are among the most productive ecosystems and their carbon stock per unit area can be enormous (Twilley et al., 1992). Mangrove communities produce much of the essential nutrients to support the organisms comprising the low end of the food chain, and support both large and small food webs. Mangrove plants produce litter (mainly leaves, twigs, bark, fruit and flowers) some of which is consumed by crabs but most must be broken down before the nutrients become available to other animals. Bacteria and protozoa colonize in the plant litter and break it down chemically into organic compounds, minerals, CO₂ and nitrogenous wastes. They feast on the litter, increasing its food value by reducing unusable carbohydrates and increasing the amount of protein - up to four times on a leaf which has been in seawater for a few months. Amphipods and other small grazers speed up this reduction process by shredding the litter. This increases the surface area, which aids microbial colonization and speeds up decomposition. In seawaters, where shredding organisms such as crabs and
amphipods are active, decomposition is faster than in freshwater or dry conditions. Faster decomposition is also apparent with an increase in tidal fluctuation. The resultant detritus, enriched nutritionally by its microbial population, is a food source for a variety of organisms. Partly decomposed leaf particles, loaded with colonies of protein-rich micro-organisms, are then eaten by fish and prawns. They in turn produce waste which, along with the smallest mangrove debris, is munched up by molluscs and small crustaceans. Even dissolved substances are used by plankton or, if they land on the mud surface, are browsed by animals such as crabs.

The plants and animals found in a salt marsh are a unique assemblage of terrestrial and aquatic species, as the salt marsh is an 'overlap zone' between the land and the sea. The important associated species are bacteria, fungi, algae, bryophytes/ferns lichens, monocotyledons, dicotyledons, sponges/bryozoa, coelenterata/ctenophora, non-polychaete worms, polychaetes, crustaceans, insects/arachnids, molluscs, echinoderms, ascidians, fish, reptiles, amphibians, birds and mammals. Many annelid worms, clams, mussels, snails, smaller crustaceans etc. depend wholly on detritus for their diet. Terrestrial animals enter the salt marsh at low tide, including native rat species, snakes, while birds such as ibis, herons and spoonbills feed on prawns and shrimps in pools of water.

In general, Red mangroves have the greatest net production, Blacks intermediate, and Whites the lowest figures of net primary production. Primary consumers are the decomposers.

Regularly influenced and disturbed by seasonal freshwater and diurnal tidal flooding, mangrove forest exhibits features of an immature ecosystem, namely low species diversity and high productivity. Mangroves are among the most productive ecosystems and play a key role in the coastal food chain and nutrient cycles (e.g. Robertson & Alongi, 1992). They are believed to enhance near-shore primary and secondary production (Mann, 1982). The shallow mangrove waters, abundance of food, and absence of predators are ideal for young organisms to thrive. Underneath the mangroves, soft soils provide an excellent habitat for burrowing prawns and other mud dwellers. The nutrient rich layer provides food for the herbivores found in the mangroves. Detritus and dissolved organic and inorganic nutrients exported from mangroves provides a major energy source in tropical coastal waters to support high productivity in food chains involving large numbers of detritus-
feeding species, such as mullets and penaeid shrimp. This release of excess nutrients is essential for resources such as oysters. Many high value, commercially exploited fish and shellfish utilize mangroves during part of their life cycles.

Although shelter from predators or special food requirements could possibly be amongst the reasons for the type of migration, it appears more likely that such migration is worth while only if productivity in mangroves is greater than that in the sea, and there is good reason to believe that this is indeed the case. In mangrove swamps, primary productivity can be attributed to several sources: the mangrove tree themselves, from their associated attached macrophytic vegetation and algae, from free-floating macrophytic vegetation, and from phytoplankton or benthic microalgae. On the marine system, on the other hand, primary productivity can only come from the last of these sources and from seaweeds and seagrasses if they happen to be present.

1.5 ORGANIC COMPOUNDS IN MANGROVE ECOSYSTEMS

Mangrove swamps are example of estuarine ecosystems that receive large quantities of senescent leaf material that are an important source of carbon and other nutrients to food webs and to pools of dissolved and particulate organic matter. The decomposition of mangrove leaf material occurs primarily through microbial action and the leaching of water-soluble compounds. During the initial stages of decomposition, large quantities of dissolved organic matter (DOM) leach from decaying leaves resulting in a rapid massive loss (Benner et.al.1988). Waters in the vicinity of decaying leaves are often "tea-coloured" due to the relatively high concentrations of DOM that contains tannins and other phenolic compounds. After the initial leaching phase, rates of mass loss from the remaining leaf material are much lower (Woodruffe, 1982; Benner & Hodsen, 1985). The remaining leaf material has been presumed to be composed primarily as structural polysaccharides and lignin. Mangrove plant tissues are important sources of organic matter and often rich in tannin and polymethylene - type polymers that are likely precursors of geopolymers such as humic substances and kerogens (Benner et al., 1990b).
1.5.1 Types of Organic Compounds

Carbohydrates

Carbohydrates are important structural and storage components of aquatic organisms. They exist as monosaccharides, disaccharides, trisaccharides, polysaccharides etc. They are important carbon and energy sources for microheterotrophs in both freshwater and marine ecosystems (Romankevich, 1984; Thurman, 1985) and contribute essentially to the bacterial production (Hanisch et al., 1996; Rich et al., 1996). Carbohydrates are some of the major biochemicals produced by living organisms, and constitute an important fraction of dissolved, particulate and sedimentary organic matter (Skoog and Benner, 1997; Borsheim et al., 1999; Burdige et al., 2000). The extracellular degradation of macromolecular POC to a range of organic carbon intermediates is an important part of sediment carbon remineralization (Henrichs, 1992; Burdige and Gardner, 1998), and carbohydrates are known to be produced and consumed as intermediates during remineralization (Boschker et al., 1995; Arnosti and Holmer, 1999).

Due to the high percentage of structural carbohydrates in vascular plant tissues, most carbon and energy flow results directly from the oxidation of carbohydrates. Storage carbohydrates such as starch and sucrose, which play critical roles in cellular metabolism, also contribute to the total carbohydrate reserves in plants (Loewus and Tanner, 1981). Additionally, certain carbohydrates are either peripheral or integral components of other major compounds such as lignins and tannins (Sjöström, 1981; Zucker, 1983).

Despite the well-recognized importance of carbohydrates in the aquatic carbon food web, there is surprisingly little information about the in situ composition, concentrations and dynamics of the different fractions of the carbohydrates such as monosaccharides and the polysaccharides in dissolved and particulate forms as well as in sediments. As compared with other regions, very little information is available on the distribution of sugars in the mangroves of Cochin.

Amino acids and Proteins

Amino acids are the building blocks of protein in living biomass. In the aquatic environment most of the amino acids occur as polymers. Proteins are
formed by condensation of amino groups and carboxyl groups of α-amino acids to form a peptide bond. Amino acids, the components of proteins, are essential organic nitrogen compounds in living organisms (Lehninger 1972). In the aquatic environment, amino acids account for 13% to 45% of the particulate organic carbon flux and 31% to almost 80% of the particulate organic nitrogen flux (Lee and Cronin 1982; Ittekkot et al., 1984a,b; Montani and Okaichi 1985). Amino acids are, therefore, a significant fraction of the carbon flux, and can be used to estimate decomposition and process rates (Sigleo & Shultz, 1993). Changes in relative abundances of individual amino acids, as well as changes in the absolute totals, may indicate the amount or type of remineralization occurring in the water column (Lee and Cronin 1982; Montani and Okaichi 1985). Amino acids in fact have a short time scale of supply and removal and for this reason they can provide more detailed insight into specific processes, such as uptake and release by bacteria and benthic animals and adsorption on sediment particles (Henrichs and Sugai, 1993). Moreover, amino acids can influence trace elements speciation because of the formation of complexes (Ianni et al., 2000).

Lipids

Lipids are operationally defined as substances that are practically insoluble in water but extractable with non-polar organic solvents. After amino acids and carbohydrates, lipids are the next most abundant biochemical in organisms. Lipids typically account for 10-60% of organic carbon (OC) in aquatic organisms (Sargent and Henderson, 1986; Wakeham et al. 1997a,b). Lipids are important biochemicals in organisms where they play roles in energy storage and mobilization, membrane structure, and hormonal regulation of metabolic processes. They are common in naturally occurring fats, waxes, resins and essential oils.

The low water solubility of the lipids derives from their hydrocarbon-like structures which are responsible for their higher survival rates during sedimentation compared to other biogenic compound classes like amino acids or sugars. Due to their wide assortment of organic functional groups, the diverse molecular structures of lipids make them valuable “biomarkers” useful for tracing organic matter sources, alterations, transport and other biogeochemical reaction pathways (Wakeham and Lee, 1993; Sun and Wakeham, 1994). Lipids are relatively labile toward degradation in the aquatic system, potentially more reactive than amino
acids and carbohydrates (Wakeham et al., 1997a). Rapid degradation of lipid components, either by autolysis or by hydrolytic attack by enzymes from heterotrophic consumers, usually follows the death of the producer organism. Degradation results in qualitative changes in composition as the more labile compounds are lost. Lipids are rapidly degraded as particulate material moves from surface waters where it is produced to sediments where a tiny fraction of production is buried and preserved. The behavior of specific lipids is highly dependent on molecular structure, whereby short-chain compounds and highly unsaturated compounds tend to be more reactive than long-chain, unsaturated molecules. The nature of the water column and sediment bed, whether oxic or anoxic, influences the form of organic matter degradation (aerobic vs. anaerobic), and resulting differences in biochemical reaction mechanisms will influence the structure of decomposition products thus formed. Yet some structures are stable toward diagenetic reactions and are preserved in sediments, even to ancient sediments and fossil fuels. This stability provides an unambiguous link between ancient sedimentary organic matter and its contemporary biological analog, allowing geochemists to infer past oceanographic conditions (Brassell, 1993). Terrigenous, higher plant-derived compounds tend to be more efficiently preserved in sediments than are marine-derived compounds; this preferential preservation is likely related to differences in molecular structure.

**Phenolic compounds (Tannin and Lignin)**

The mangrove tree roots contain a large amount of tannins and the leaves contain lignins. Lignocellulose, the structural component of mangrove leaves become gradually enriched in lignin content during decomposition due to the rapid degradation of structural polysaccharide components. Simple phenolic compounds are common microbial degradation products of lignin and the occur in other substances such as tannin (Hedges 1988); both lignin & tannin are major classes of secondary products of plant metabolism and are ecologically important. However the processes involved in the decomposition of organic matter or the effects of high amounts of recalcitrant phenolic substances resulting from decomposition on the biota of the water body are not fully understood. Contrary to what has been observed in a variety of other vascular plant tissues, the lignin component of mangrove leaves is lost at approximately the same rate as the polysaccharide components (Benner et
Phenolic materials are abundant in the soil and water of eutrophic environments and are the main components of soil and aquatic humic substances (Haslam 1989). They result in adverse environmental conditions such as high BOD, undesirable aesthetic effects, fish fainting or toxicity to fish and other aquatic life. The very resistant nature of lignins is suggestive of long term damaging effects on the ecosystem. Several investigations have suggested that reduction of algal productivity and biomass in brown waters could occur due to diminished light intensity and changes in light quality (Collier 1988). Tannins inhibit plant growth (Mahadevan et al., 1984; Herrera and Ramirez, 1996). The effect of tannins on microorganisms and plant growth is described by Mahadevan et al., (1984). The natural phenolic materials have some negative effects on degradation activity of the microflora associated with the mangrove leaves at different stages of decomposition (Lee et al., 1990; Herrera-Silveira and Ramirez-Ramirez, 1996). Tannins significantly decrease the lipid content in the tissues of certain fishes (Beena, 1991). The toxicity of tannins on several enzymes has been established (Gupta and Haslam, 1980). Plant-produced polyphenols entering the soil in litter or canopy throughfall may influence the pools and fluxes of inorganic and organic soil nutrients in terrestrial ecosystems. Environmental factors, such as pH, temperature, and solution polarity are known to affect chemical reactivity. Such effects could have far-ranging consequences for nutrient competition among and between plants and microbes, and for ecosystem nutrient cycling and retention. Polyphenol concentrations increase with decreasing soil fertility (Hattenschwiler &. Vitousek, 2000). In nature phenol will form complexes with nitrogenous compounds and makes them less susceptible for microbial degradation as compared to free proteins and amino acids. This reduces mineralization and release of nutrients. Therefore, the abundance of phenolics in sediment plays an important role in nutrient cycling (Joseph & Chandrika, 2000). Natural phenolic materials can influence the cycles of metals and other elements in the aquatic environment and some investigators have explained decreases in primary productivity by deficiency in Fe or other metals caused by metal complexation by dissolved humic substances (Guild fort et.al.1987; Fuller and Davis 1989). Another explanation is that when natural phenolic material react with proteins, these compounds can inhibit the performance of many enzymes (Franco, 1986; Herrera-Silveira & Ramirez-Ramirez, 1996).
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Lignins play a significant role in the coal formation. As vegetable matter decomposes in water, some lignin degrades as long as oxygen is present. As the materials settles to the bottom where anaerobic conditions prevail, the cellulose portion will be decomposed via hydrolytic and fermentative reactions but the lignin portion will accumulate. The process contributes to build-up of organics in sediments and to the formation of bogs and ultimately to coal formation (Francis, 1954). The lignin component of vascular plant tissue represents a source - specific tracer that can uniquely characterize terrestrial organic matter (Hedges and Mann, 1979a, b). Hedges and co-workers (e.g., Hedges and Ertel, 1982 and Hedges et al., 1984) have shown that it is possible to identify land - derived organic matter in aquatic systems, through the analysis of the oxidation products of lignin. This lignin, together with other compounds such as tannins, polyphenols and quinones can undergo condensation reactions to form the humic material that shapes a considerable part of organic material (Kononava, 1966).

Humic substances

A major fraction of the organic matter in sediments cannot be readily characterized in terms of its chemical composition. Instead, it is described by purely operational definitions based upon solubility properties. They are used to distinguish between alkali insoluble humins, and alkali soluble (extractable) humic compounds, and further more, to subdivide the humic compounds into fulvic acids, which are soluble at all pH values, and humic acids which are insoluble under acid conditions, especially where the pH is <2.0. Humic 'compounds' are not compounds in the normal chemical sense of the term because they have no fixed composition, and as they are not made up of fixed monomeric units they are 'macromolecules' rather than 'polymers' (Tyson, 1994). Because of these imprecision, there is an increasing tendency to regard this materials just 'uncharacterized organic matter', rather than using the apparently more formal label 'humic compounds'.

Humic and fulvic acids are heterogeneous and disorganized assemblages of aliphatic and aromatic compounds that together form complex high molecular weight macromolecules. The carbon skeleton of these macromolecules consists of a complex, three-dimensional network of cross-linked paraffinic structures.
covalently bonded and in association with various amounts of aromatic moieties (Tyson, 1994). Their structural core is surrounded by a variety of labile hydrophilic complexes including oxygen containing functional groups such as carboxyls, phenolic and alcoholic hydroxyls, carbonyls, and also acetyl, methoxyl and amino groups (Tyson, 1994). The acid character of marine humic compounds is due mainly to carboxyl functional groups, whereas in terrestrial humic compounds it is mainly due to free and methylated phenolic functional groups (derived from lignin breakdown and amino acids) (Ertel et al., 1986). Compared with fulvic acids, the humic acids have considerably higher molecular weights, less oxygen-containing functional groups, and are less abundant in terrestrial organic matter and in oxic marine sediments (Rashid, 1985). An association with lipids is strongest for high molecular weight (> 100 000) humic acids (Poutanen and Morris, 1983) and may be related to the fixation of unsaturated fatty acids as aliphatic esters (Tyson, 1994). Some alkanes, pigments and fatty acids are also probably adsorbed onto the surface of the humic macromolecules (Tyson, 1994). Marine humic compounds are characterized by predominance of (highly branched) aliphatic structures, low phenol content, high sulphur content low aromaticity, relatively low molecular weights (mostly <700), lower total acidity, and higher nitrogen and hydrogen contents than terrestrial humic compounds (Tyson, 1994; Libes, 1992). Specific biochemical residues such as amino acids, sugars etc. have also been detected at the molecular level in aquatic humic substances.

Humic substances are considered as playing an important role in chemical and microbiological processes aquatic systems. However, only 10-30% of this dissolved organic substance has been characterized (Hayase & Shinozuka, 1995). Condensation reactions are said to occur within the top few metres of the sediment (Tyson, 1994). It is thought that simple compounds such as carbohydrates and proteins are condensed into complexes that are associated with hydrophobic compounds such as lipids and pigments, leading to the formation of humic and fulvic acids (Poutanen and Morris, 1983). The most common mechanism proposed for humic compounds is the ‘Maillard reaction’, a series of condensation reactions between reducing sugars and amines that produces melanoidins (high molecular weight, brown, acidic polymers. However, the evidence for such a mechanism occurring in nature is meagre and ambiguous (Hatcher et al., 1985); such reactions
also normally proceed at rates too slow to realistically compete with microbial consumption of the metabolizable precursors (Tyson, 1994), and the concentrations of the precursor monomeric units are also too low (Whelan and Emeis, 1992).

A common assumption in aquatic biogeochemistry is that photochemical reactivity of dissolved organic carbon (DOC) in natural waters is mainly due to the abundant humic- and fulvic acids. The high aromaticity and resulting light- and UV-absorbing properties of these compounds have been stressed as important features promoting this activity (Bertilsson & Bergh, 1999).

1.5.2 Organic carbon dynamics

Mineralization

Although real system is complex, three relatively distinct consecutive phases can be identified during breakdown of organic matter under experimental conditions (Valiela et al., 1984, 1985). These are referred to as the 'leaching phase', the 'decomposer' phase and the 'refractory phase' (Valiela et al., 1984; Kristensen, 1994). The duration and relative magnitude of each phase may primarily depend on the origin and age of the litter material, the temperature, and the redox environment (e.g. aerobic vs. anaerobic).

The leaching phase is the first change to occur in organic matter following death or senescence of the organism, and results from autolysis, the breakdown of 'cell materials' by intracellular (lysosomal) hydrolytic enzymes. Significant amounts of soluble organic compounds, mostly amino acids, mono- and disaccharides and long-chain fatty acids, are produced and then leached, resulting in the maximum rate of observed weight loss (Valiela et al., 1985). These compounds are, as a result of their dissolved state, readily available for uptake by bacteria (Benner and Hodson, 1985). Most of the leaching occurs within hours, then becomes progressively slower and is generally complete within a few days. The leaching phase is not mediated by microbes (Valiela et al., 1984).

The decomposer phase takes place after 3-20 days following bacterial colonization of the detritus and lasts for about 0.75-2.0 years (Benner et al., 1992). The decomposer phase of degradation is significantly slower than its predecessor. The most important control on the rate of degradation during this
phase is the rate of dissolved organic matter release, which is dependent upon the hydrolytic activity of the fermenting bacteria (Nedwell et al., 1994 a, b). The rates of degradation during both leaching and decomposer phases are strongly influenced by temperature and dissolved oxygen content, and are greatest under warm and oxic conditions (Valiela et al., 1985). Degradation during the decomposer phase may be stimulated by bioturbation (Kristensen et al., 1992).

The final 'refractory' phase of degradation represents the slow breakdown of the least digestible fraction. The rate of decay during this phase does not appear to show any significant correlation with temperature, nitrogen supply, or detritus feeders (Valiela et al., 1985). Formation of refractory humic compounds and geopolymers occur during this phase (Valiela et al., 1984; Kristensen, 1994).

Mangrove sediments are extremely complex and affected by both physical and biological processes. Plants and animals interact with the sediments causing binding, bioturbation and pelletization. Physical processes such as rainfall, wind wave erosion and tidal current resuspension act as major factors contributing to mineralization (Lallier-Verges et al., 1998). Out of the microbiological processes occurring in mangrove areas, the role of fungi, algae and other macrosystems is well-recognised.

Mangrove soils are rich in organic matter, but the detritus is relatively nutrient poor and refractory resulting in low net mineralization rates (Kristensen et al., 1992, 1995). Decomposition rates of mangrove litter depend on the degree and frequency of tidal inundation, nutrient quality, climatic and edaphic factors, the presence or absence of litter-consuming fauna within forests (Robertson, 1988 and Chale, 1993; Robertson & Daniel, 1989, Kristensen et al., 1995) and substrate characteristics, such as, redox potential, temperature and moisture, climatic parameters such as precipitation, wind and solar radiation (Holmer et al., 1999) and micro-organism diversity (Hutchings and Saenger, 1987). Thus, the dynamics of litter breakdown will vary geographically. The availability of molecular oxygen (Benner et al. 1985), anatomy and intrinsic properties relating to chemical composition such as initial nitrogen and lignin contents (Benner et al. 1985, 1990a) strongly influence the transformations and fate of detritus. Mangrove detritus has high C:N ratios and a significant fraction of the organic matter is considered to be refractory humic compounds and geopolymers (Benner et al., 1990; Kristensen et
al., 1994). This is probably an important cause of the observed low rates of mineralization in mangrove ecosystems despite the ambient high temperatures (Kristensen et al., 1992, 1995). Furthermore, the fragmentation and consumption of mangrove leaves by crabs may increase the decay rates by up to 2 orders of magnitude (Kristensen & Pilgaard, 1999). The interaction of organic matter (OM) with solid surfaces is an important process in the biogeochemical cycling of carbon in aquatic systems (Ding & Henrichs, 2002). Adsorption of OM to sediment particles can decrease its availability to microbial degradation (Sugai and Henrichs, 1992; Mayer, 1994; Hedges and Keil, 1995). The progressive alterations of organic matter that occur during diagenesis in the water column and sediments efficiently remove the readily identifiable organic constituents and leave behind a large fraction that cannot be characterized.

- *Aerobic vs Anaerobic (Oxic vs Anoxic)*

Aerobic decay, decay in the presence of ample free oxygen, can be symbolised as the reverse of photosynthesis. Anaerobic processes by nature are incomplete and much less efficient energetically than aerobic processes because of the inefficiency of electron transfer in either anaerobic respiration or fermentation. Anaerobic rates of mineralization of the leachable and lignocellulosic components of mangrove leaves and wood are 10-30 times lower than the respective aerobic rates. This suggests a very long residence time for mangrove detritus in anaerobic sediments (Benner & Hodson, 1985). In mangrove environments, the decay of organic matter is mainly mediated by anaerobic degradation: sulphate reduction and methanogenesis (by disproportionation). Chemoheterotrophic respiration results in the oxidation of reduced (fixed) forms of carbon. There is also a much higher energy return when this can be done in an aerobic environment. Many compartments of mangrove ecosystems, however, are anaerobic and utilize other, more available, terminal electron acceptors (i.e. NO₃, SO₄²⁻, and even CO₂). Therefore, the availability of organic carbon and electron acceptors determine the chemical pathways that are dominating a given environment at a given time. In slightly reducing situations, nitrate is used as a terminal electron acceptor. As systems become more reducing, sulfate is used as a terminal electron acceptor. This process, called sulfate reduction, is believed to be the dominant pathway of anaerobic respiration in mangrove systems. Finally, under the most reducing
conditions, carbon dioxide is used as the terminal electron acceptor. This process, fermentation, is inhibited by sulfide production (a by-product of sulfate reduction) so it is of little importance to mangroves over a large spatial scale. Low molecular weight substrates, such as lactate, acetate, and \( \text{H}_2 \) serve as electron donors in sulphate reduction and methanogenesis, and \( \text{H}_2\text{S}, \text{CO}_2, \text{H}_2\text{O} \) and \( \text{CH}_4 \) are products.

Biogeochemical studies (Nedwell et al., 1994a,b and Kristensen et al., 1995) suggest that aerobic respiration (decomposition) and sulfate reduction (anaerobic decomposition) are the major pathways of organic matter diagenesis in mangrove sediments (Alongi et al., 1998). It was earlier thought that aerobic decomposition is much more important than anaerobic decay in mangrove sediments. More recently, it was shown that this is not always true, and that sulphate reduction may be an important electron acceptor in organic-rich deposits typical of mangrove forests (Kristensen et al., 1994; Alongi et al., 1998). A number of recent studies have revealed that the contribution of sulphate reduction varies with a number of factors such as season, benthic community activity and physical transport conditions (Kristensen et al., 2000). Sulphate reduction has been found to be responsible for upto 100% of the total benthic metabolism in highly productive and undisturbed coastal environments (Mackin and Swider, 1989), whereas values lower than 10% have been found in less productive and disturbed (currents, bioturbation and rooted plants; Kristensen et al., 1994, 2000; Banta et al., 1999) sediments.

The tidal regime has a major influence on the organic matter mineralisation. In high inter-tidal areas the sediment is only inundated for a short period during spring tides and the benthic community appears semi-terrestrial. Aerobic processes dominate due to the penetration of crab burrows and tree roots deep into the sediments (Eshky et al., 1998). Sulphate reduction may therefore be of minor importance in the mineralization of organic matter (Kristensen et al., 1995; Holmer et al., 1999). The duration of inundation is longer in low intertidal mangrove forest areas. The benthic community is of more marine origin, but faunal diversity and abundance are low in the unpredictable environment. Surface sediments are usually oxidized, but due to the sparse benthic fauna, anaerobic processes may dominate mineralization in the deeper layers with sulphate reduction being responsible for more than half of the total benthic metabolism (Kristensen et al., 1992, 1995; Holmer et al., 1999).
- **Export vs Import**

Mangrove swamps export mangrove litter and this enhances bacterial productivity in adjacent coastal waters (Alongi et al., 1989). The extent of outwelling is related to the geomorphology of the tidal basin, tidal amplitude and water motion, and the ratio of the areal extent of the vegetation to the receiving open ocean area (Alongi, 1990a,b).

However, the information available on this phenomenon is confined to few regions in the world and often controversially (Dittmar & Lara, 2001a,c). Adjacent mangrove areas in Hinchinbrook Island (Australia) were source and also effective sink for dissolved nutrients and organic carbon (Alongi, 1996; Alongi et al., 1998; Ayukai et al., 1998). Twilley (1985) determined net-export of dissolved and suspended organic carbon from mangroves in Rookery Bay (Florida, U.S.A.). Wattayakorn et al. (1990) reported outwelling of inorganic nutrients from mangroves in Klong Ngao (Thailand). In Terminos Lagoon (Mexico), the mangrove seems to be rather an importing system for dissolved nitrogen species (Rivera Monroy et al., 1995). Simpson et al. (1997) found an almost balanced net exchange for nitrate between Malaysian mangroves and adjacent coastal waters, whereas other inorganic nutrients showed large variability in their fluxes. In Braganca (North Brazil), strong outwelling of nutrients and organic matter was measured, exceeding that of other mangroves in the world (Dittmar & Lara, 2001a,c). The reasons for this large variability are hitherto poorly understood. Ayukai et al. (1998) found differences between two adjacent mangroves with different freshwater inputs, and put forward variations in tidal-range, topography, sediment chemistry or community structure as other possible reasons for the inconsistencies among export balances.

The export of organic matter, like primary productivity, seems to be dependent upon the hydrologic characteristics. It is important to note, however, that not all mangrove systems are net exporters of organic carbon. Systems that have little or no hydrologic energy may be net importers of organic carbon.
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1.6 METALS IN MANGROVE SEDIMENTS

Anthropogenic activity has introduced significant amount of heavy metals into aquatic environment in a non-conservative manner (Bethoux et al., 1990; Campbell et al., 1988). The behaviour of these elements in the aquatic system must be addressed, both to assess and understand the nature and extent of man’s influence, and because most of them are potentially toxic.

The coastal habitats of Kochi is deteriorating rapidly due to urbanization, recreational development, and industrial installations which are now underway near many of the mangrove areas, representing a direct threat to these forests. In order to protect and conserve these fragile mangrove ecosystems, this study which would help in the preservation of biodiversity of this area was undertaken to investigate the potential of their alteration by existing inputs from anthropogenic waste disposal and other activities. Pollutants like oil, solid wastes and industrial wastes reaching mangrove environments can cause damage to mangrove roots that may affect the respiratory and osmoregulatory capabilities of the plant leading to death (Getter et al., 1981) and/or exert acute and chronic effects on aquatic organisms. Among pollutants, heavy metals have been of interest because of their toxicity, persistence, and prevalence on the environment (Cosma et al., 1979).

Analysis of pollutants in sediments has become an important tool for tracing anthropogenic pollution of water (Senten, 1989), because some pollutants are adsorbed by material in suspension and by fine-grained particles. After flocculation and sedimentation they are enriched in bottom deposits by a factor of 1000 or more (Forstner, 1979). The present study attempts to provide the first baseline information concerning the levels of numerous heavy metals in surface and core sediments of three-selected mangrove ecosystems of Kochi.

1.7 SCOPE OF THE PRESENT STUDY

A perusal of available literature indicates that work done hitherto on coastal habitats, particularly mangrove ecosystems in Kerala focus predominantly on biological and geological aspects. No significant attempt for a systematic chemical investigation on mangrove ecosystem in Kerala has been reported.
Mangrove environment is an aquatic zone capable of trapping large quantity of pollutants, particular heavy metals, nutrients, organics etc. Mangrove forest sediments can provide a sink for these materials that are derived from marine and terrestrial sources. Direct adsorption, complexation with organic matter and the formation of insoluble sulphides all contribute to the trapping mechanism. The concentration and chemical speciation of these materials are influenced by the distribution of geochemically distinct zones within the sediment. A major part of organic matter in natural waters and sediments is composed of amino acids, proteins, carbohydrates, lipids, phenolic compounds, humic substances, etc. Most of these substances are derived from decaying vegetation and play a significant role in the productivity and biological cycle in the aquatic environment, either inhibitory or stimulatory. The type of flora in the watershed, the distribution and abundance of wetland and littoral plants, and the pathways of release of detrital organic material into the water body have different effects on overall rates of eutrophication and development of aquatic ecosystem. There is little information on the chemical import of these compounds vis-à-vis the sustainable development of estuarine / wetland habitats. Rigorous, long term studies on biogeochemical status, temperature, pH, oxygen content, alkalinity, salinity, soil texture, etc., it is hoped, would be required to generate a holistic appreciation of the biogeochemical interactions that regulate the mangrove environment. Therefore, it was considered desirable to attempt a characterization of these compounds with a view to ascertaining their role in effective management of this ecosystem. It is possible that some of the above mentioned compounds could be used as biomarkers, by means of which, the origin and transport of organic matter across a water system can be evaluated. The present study aims at investigating variations, the relative proportion of dissolved, particulate and sedimentary fractions of these materials, as well as nutritional quality and the pollution extent so as to be able to comment on the role of wetland ecosystems, particularly with regard to their contribution to coastal nutrient budget, food chain, and hydrochemistry etc. This study, it is hoped, will not only increase the knowledge on the stability and resilience of coastal ecotones subjected to natural or anthropogenic perturbations but will also contribute to the generation of scientifically-based information on coastal management and protection.
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