Cover photo and illustrations:
Front cover (centre): Fruits (propagules) of \textit{Rhizophora apiculata}
Front and back cover background: \textit{Rhizophora x lamarkii} tree

October 2004

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Preface

The present publication on the Ecology and Biology of Mangroves written by Drs V Selvam & V M Karunagaran is a timely publication, since there is growing public and political awareness of the importance of mangrove wetlands in preserving the ecological security of coastal areas and the livelihood security of coastal communities. The publication has been prepared in a user-friendly manner, particularly for the benefit of scholars and extension workers. An understanding of the facts mentioned in the publication will facilitate effective joint mangrove forest management by forest departments and local communities. The book will help to sensitize all concerned about the rich biodiversity associated with mangrove ecosystems. I hope it will be widely used by members of forest departments, scholars and students and by all interested in the conservation and sustainable and equitable management of mangrove bio-resources.

M S Swaminathan
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1. ECOLOGY OF MANGROVES

1.1 Mangrove forests and mangrove wetlands

Ecologically, mangroves are defined as assemblages of trees and shrubs that grow in the intertidal region of tropical and subtropical coastlines, in the areas where river water mixes with sea water. Mangroves have two components, mangrove forests and associated water bodies. A group of woody trees and shrubs that can grow well in saline water and water logged condition constitute the forest component. Tidal channels and canals that intersect mangrove forests and divide them into small islands and shallow lagoons and bays found associated with the mangroves constitute the water bodies. The mangrove forest and associated water bodies are together called mangrove wetland (Fig.1). Most of the mangrove wetlands are inundated by low saline water and sometimes by fresh water during the monsoons seasons and brackish water or sea water during other periods.

**Figure 1. Schematic diagram of a mangrove wetland**

<table>
<thead>
<tr>
<th>Wetlands are transitional lands between aquatic and terrestrial systems where the water table is at or near the surface of the land. To be classified as a wetland, an area must have one or more of the following three features:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The land supports plants, which are adapted to wet soil conditions. These plants are also known as hydrophytes.</td>
</tr>
<tr>
<td>2. The base land is predominantly undrained hydric soil.</td>
</tr>
<tr>
<td>3. The soil is saturated with water or covered by shallow water at some time during the growing season of every year</td>
</tr>
</tbody>
</table>
1.2 Characteristic features of mangrove wetlands

A distinctive character of mangrove wetlands is diversity in appearance of vegetation. Some plants like the banyan have looping stilt roots while some plants have needle-like aerial roots. Some plants are evergreen with shiny leaves while others have rough and pale leaves. The soil is firm in some places and muddy and slushy in other places, so that walking is difficult, if not impossible. In the muddy and slushy substrate a disturbance produces a strong smell of hydrogen sulfide (a gas that smells like rotten eggs), indicating the completely anaerobic property of waterlogged soils. Canopy height of mangroves depends on climate, topography and extant of human disturbance. The mature, undisturbed, mangrove forest develops a high, dense canopy and the trees have tall boles. The canopy looks monotonous because of almost uniform size, shape and texture of leaves. In a disturbed environment, mangrove plants are stunted and scrubby. To force a way through continuous mangrove scrub is difficult but fortunately there are a few spiny species.

1.3 Distribution of mangrove wetlands

Mangroves are almost entirely tropical (Fig. 2). Tall, dense and floristically diverse mangrove wetlands are found exclusively either in the equatorial zone (i.e. Malaysia, Indonesia, Columbia etc.) or in the tropical summer rainfall zone (i.e. in most of the coastal areas of India, Burma, Thailand, Vietnam, etc.). Only low thickets or sporadic mangrove vegetation is found in the sub-tropical dry zone (north-western India, Pakistan, Red Sea coast etc.) and in warm temperate climates (Australia, New Zealand, etc.).

The above pattern clearly indicates that mangrove distribution is limited by temperature. Although mangroves can survive air temperatures as low as 5°C, they cannot withstand freezing conditions. Physiological constraints seem to be another important factor that restricts the distribution of mangroves to a tropical climate. Mangrove plants grow in waterlogged soils and also tolerate salinity and for this, they have to spend a lot of energy. In cold coastal environments like that of Canada, Europe etc., the temperature is low and the day length of the day is also short. In this situation, if mangrove plants to grow, they will have to spend a lot of energy to tolerate the low temperature as well as to increase the rate of photosynthesis to compensate for the short duration of day light. Such physiological
strains might have prevented mangrove species from penetrating temperate coasts. In addition, dispersal of the water-buoyant propagules of mangrove plants is constrained by both wide bodies of water (seas) and land masses (continents) blocking the flow of ocean waters.

1.4 Ecological factors influencing the mangrove wetland

Though it is often mentioned that mangrove wetlands are a dominant feature in the tropical and sub-tropical coastline, all the coastal areas do not have mangrove wetlands. Similarly, all the mangrove wetlands in a given coast are not similar in area, species diversity, biomass etc. For example, the area of Sunderban mangrove wetland, which is located in the northernmost end of the east coast of India, is about 4 lakh ha (forested area 2.12 lakh ha) and the number of true mangrove species present in this mangrove wetland is about 26. The canopy height of the Sunderbans mangrove is also very high. On the other hand, the Pichavaram mangrove, which is located in the southernmost end of the same coast, is smaller in size (about 1400 ha), has less species diversity (12 true mangrove species) and less

**Tropical area:** The area between the Tropic of Cancer (23.5° N) in the north and Tropic of Capricorn (23.5° N) in the south is called tropical area, where the mean atmospheric temperature is above 18°C during all the twelve months. Tropical areas experience hot and humid weather. These areas receive abundant rainfall and considerable sunshine and thus provide ideal growing conditions for luxuriant vegetation.

**Temperate areas:** In general, the area between the Tropic of Cancer and the North Pole and area between the south of Tropic of Capricorn and the South Pole are called temperate regions. These areas have cold winters and warm summers.
forest height (about 5m in average). These differences in mangrove wetlands that are located in the same coast are mainly due to variations in the magnitude of the ecological factors that act upon and within the mangrove wetlands. An understanding of how ecological factors operate in a mangrove wetland would provide needed inputs to

a. develop and implement science-based mangrove conservation and management plans

b. identify causes of degradation and develop suitable mangrove restoration techniques and strategies and

c. develop and implement methodologies for sustainable utilization of mangrove wetland resources

The wealth (area, biodiversity and biomass) and health (hydrological and soil conditions and nutrients status) of the mangrove wetlands of a given area are determined by

- Protection against high waves
- Periodicity and quantity of fresh water inflow.
- Tidal amplitude and free exchange of water with the sea
- Topography of the coasts
- Continuous sediment supply

1.5 Protection against wave action

Seedlings of mangroves settle and grow only in coastal areas where wave energy is low or in places where the mangrove wetlands are protected by a sand barrier against high waves. The coastline of the Muthupet region of Tamil Nadu and that of the Sunderbans in West Bengal of the east coast of India are the best examples of low wave energy coasts where mangroves grow luxuriantly. In the Pichavaram mangrove wetland of Tamil Nadu, wave energy along the coast is high but a sandy beach, located between the mangroves and the sea protect the mangrove wetland, allowing the propagules (propagules are seedlings growing out of fruit) to settle and grow.

Wave energy: Waves in the oceans are created by winds. In general, the energy of a wave is related to its amplitude or “height”. If the height of the waves is low and these waves displace only small amounts of water, they transmit only low energy and the coast that has such waves is called low wave energy coasts. If the height of the waves and amount of water displaced is high, the waves contain high wave energy and the coast that has such waves is called high wave energy coasts.
**1.6 Periodicity and quantity of fresh water inflow**

*Influence of fresh water flow on mangrove growth and productivity*

Mangrove plants are capable of tolerating salinity ranging from 2‰ to 90‰. However, field observations and laboratory experiments show that mangrove plants attain maximum growth only in low saline condition (Fig. 3). These experiments also showed that for most of the mangrove species the optimal soil salinity ranges between 10 and 20‰. Some authors consider that optimal salinity for most mangroves lies between 4‰ and 15‰. In an experiment conducted, it was found that *Avicennia marina* and *Aegiceras corniculatum* grew at salinities from 0 to 35‰, but maximum growth occurred in salinity between 7 and 14‰. In general, the growth rate of mangrove trees falls by at least 50% with an increase in salinity from 20 to 35‰, with a further significant decrease in growth rate at higher salinities. Similarly, the rate of photosynthesis also reduces drastically in high salinity.

**Salinity** indicates the amount of dissolved salts present in water. It is normally expressed in parts per thousand (‰, ppt). It can also be expressed in terms of gram per litre. Sea water salinity is normally around 35 ppt or grams per litre. It means if one litre of sea water is evaporated completely, it would contain 35 grams of salt.

The growth rate of mangrove plants is affected at higher salinity mainly because the rate of ion transport to the shoot of the mangrove plant saturates and as a result shoot growth continues only with a reduction in growth rate. In addition, the photosynthetic capacity of the mangrove plants is reduced drastically due to high water loss through leaves, which create water imbalances in the leaves. Thirdly, in high saline conditions, mangrove plants have to spend a lot of energy for maintenance process, which in turn affects the growth, and to some extent, the rate of photosynthesis.

All these indicate that growth and productivity of mangrove plants are high in low saline conditions and such low saline conditions can be found only when estuarine water, where mangrove plants grow, is diluted with large amounts of fresh water for longer periods of time.
Influence of fresh water flow on mangrove reproduction

Almost all mangrove species produce propagules and seeds only in low saline conditions. This can be considered as a natural phenomenon of the mangrove species and is related to their evolution. According to mangrove ecologists, all the mangrove plant species originally evolved in a terrestrial environment. But they gradually migrated to coastal saline areas to avoid competition from other plant species. During evolution these mangrove species developed morphological characters and physiological mechanism to live in saline conditions but they produce propagules only during the monsoon season when water and soil salinity is low or fresh water condition may exist, which provides a suitable condition for the propagules to establish and grow fast. Hence, alteration of the periodicity of fresh water flow into mangrove wetlands would severely affect reproduction of mangrove plant species.

Influence of fresh water flow on mangrove plant diversity

On the basis of salinity distribution, theoretically five salinity zones can be identified horizontally in mangrove wetlands. They are euhaline, polyhaline, mesohaline, oligohaline and limnatic zones (Fig. 4). The range of salinity in these zones is given below.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Range of salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euhaline zone</td>
<td>30 to 40‰ and more</td>
</tr>
<tr>
<td>Polyhaline zone</td>
<td>18 to 30‰</td>
</tr>
<tr>
<td>Mesohaline zone</td>
<td>5 to 18‰</td>
</tr>
<tr>
<td>Oligohaline zone</td>
<td>0.5 to 5‰</td>
</tr>
<tr>
<td>Limnatic zone</td>
<td>0.5‰ (Fresh water)</td>
</tr>
</tbody>
</table>

It is observed that most of the mangrove species are absent in the euhaline condition, due to higher annual average salinity and in the limnatic zone, because of its pure fresh water nature. The other three salinity zones have their own group of mangrove species and dominance of species in each of these three zones depends on the value of the average salinity (Fig. 5). The species commonly found in the polyhaline zone belong to the genus *Rhizophora, Bruguiera, Ceriops, Avicennia* and *Sonneratia*. Species belonging to *Acanthus, Aegiceras* and *Kandelia* are common in the mesohaline zone. Fresh water loving species such as *Hertiera, Nypa fruticans* etc dominate the oligohaline zone. Some species of mangroves such as *Avicennia marina*, which tolerate a wide range of salinity, may be present in many of these zones.
All the five zones described, can be found only in mangrove wetlands which receive a copious inflow of fresh water for long periods of time in a year. In these mangrove wetlands the number of mangrove plant species present or diversity of mangrove species will be high. The best example is the Sunderbans of West Bengal and Bhitarkanika of Orissa of the east coast of India. On the other hand, such zonation may not be present conspicuously in mangrove wetlands such as Pichavaram and Muthupet of Tamil Nadu of the same coast where the amount of fresh water discharged is very low. In these kinds of mangrove wetlands diversity of mangrove plants will also be less.

**Reduction in fresh water flow and reduction in species diversity in the Pichavaram mangrove wetland**

The Pichavaram mangrove wetland is located in the northern part of the Cauvery delta. The river discharge data of the Public Works Department, Government of Tamil Nadu, shows that till 1924 the Pichavaram mangrove received fresh water for nearly 6 months in a year, from July to December. After 1924, a number of major and minor dams were constructed on the river Cauvery and its tributaries...
and distributaries. Consequently, ayacut area has increased manifold and to meet irrigation requirements, a large quantity of fresh water was diverted. This resulted in a gradual decline in the amount as well as periodicity of fresh water flowing into the Pichavaram mangroves. For example, in the 1930s, 74 TMC (thousand million cubic feet) of water was let into the Coleroon River, which supplies fresh water to the Pichavaram mangroves. It reduced to 31 TMC in 1930s and further to 3 to 4 TMC in the 1990s.

Available literature shows that salinity-sensitive species such as *Cynometra ramiflora*, *Xylocarpus granatum*, *Kandelia candel*, *Bruguiera gymnorrhiza* and *Sonneratia apetala* were once present in large numbers in the Pichavaram mangroves. The first three species where collected from the Pichavaram mangrove wetlands by the Botanical Survey of India and French Institute of Pondicherry and preserved in their herbarium. A large number of tall trees of *Sonneratia apetala* were noticed even during the early 1970s but now it is no more available. The distribution pattern of these species in different mangrove wetlands of India in relation to fresh water flow indicates that these species might have totally disappeared as the annual average salinity of Pichavaram mangroves increased due to reduction in fresh water flow.

The above discussion indicates that the quantity and periodicity of fresh water flow play a critical role in determining the diversity, biomass and productivity of mangrove wetlands. Fresh water flow may not directly influence these attributes of the mangrove wetland, but it may be through influencing the salinity condition of the soil, pore water, ground water and running water. Hence, preparation of mangrove restoration, management and conservation plans for any mangrove wetlands requires the following information:

a. Present status of the quantity and periodicity of fresh water discharged and changes over a period of time.

b. Identification of different salinity zones (either from available information or by direct observation)

c. Identification of species predominantly associated with each salinity zone and their community structure

d. Variation of soil salinity during the monsoon season and peak summer period.

1.7 Tidal range and free exchange with the sea

Another important factor that influences the ecology of mangrove wetlands is the tide. In simple term, a tide is nothing but the temporary rise and fall of sea water
due to the gravitational forces of the moon and sun. The following are the basic terms used to describe tides in mangrove ecology:

**High tide and low tide:** Rise in the water level due to the gravitational pull of the moon and sun is called high tide and fall in the water level is called low tide (Fig. 6a).

**Tidal amplitude:** The difference between the high and low tides is called tidal amplitude or tidal range (Fig. 6a).

**Spring tide:** On full moon and new moon days, the sun and moon are in the same line. As a result, the combined gravitational forces of these celestial bodies pull the ocean water more strongly than during any other period and due to this, tidal amplitude during these periods are larger. These larger tides are called spring tides (Fig. 6b).

**Neap tide:** During the first quarter (i.e. 7 days after new moon) and last quarter (i.e. 7 days after full moon) the sun and moon are at right angles to each other. As a result, there is no combined gravitational pull. This results in smaller tides and they are called neap tides. In the Pichavaram mangrove wetland, tidal amplitude during the spring tide is about 64 cm whereas it is only 35 cm during neap tide (Fig. 6b).

**Intertidal region:** The area which is flushed by tidal water is commonly called intertidal area. It has many parts such as high tidal region, mid-tidal region, low-tidal region and sub-tidal region (Fig. 6b).

**Micro tides** Tides with less than 1 m tidal amplitude are called micro tides.

**Macro tides** Tides with more than 1 m tidal amplitude are called macro tides.
During high tide, seawater rushes into the mangrove wetland through the mouth of the estuary and then it is taken to various parts of the mangrove forest by tidal creeks and channels. During low tide, water from the mangrove forest drains off and moves out of the mangrove wetland through tidal creeks. This is called as tidal flushing or tidal inundation. Tides influence the ecology of the mangrove wetlands in the following manner:

- Tides bring saline water into mangrove wetlands, which is necessary for mangrove species to exclude other terrestrial species.
- During high tide, nitrogenous and phosphorus nutrients are imported into mangrove wetlands from the sea and during low tide, nutrients are exported to the sea.
- Tides play an important role in the dispersal of mangrove propagules and seeds.
- Along with topography and other factors, tides play a critical role in determining the vertical zonation and area of the mangrove wetland.
- Tides play an important role in the migration of fish, prawn and crab in and out of the mangrove wetlands and thereby decide the quantity and quality of the fishery resources of the mangrove wetland.

**Tides and vertical zonation of true mangrove plant species**

Vertical zonation of mangrove plant species is one of the classical features of the mangrove wetlands. Although mangrove plants share a common ability to grow in saline and waterlogged soil, they frequently appear as mono-specific zones parallel to shorelines, tidal channels and canals. A number of theories have been put forward to explain the zonation of plant species in mangrove wetlands. However, it has been proved by many ecologists that zonation occurs mainly due to physiological adaptation of mangrove species to varying physical and chemical features of the mangrove forest floor. Frequency of tidal flushing along with topography determines these variations in physical and chemical properties.

For example, the lower intertidal portion of mangroves is inundated daily by tidal water and as a result soil moisture in this region is always high and soil salinity is low. This creates a microhabitat which is preferred by a group of true mangrove species, which require high soil moisture and low salinity. On the other hand, high tidal regions are inundated by tidal water only during the spring or high tide (which occurs once in 15 days) and in these regions soil salinity is high (due to evaporation of water between the two tidal inundations which take place once in 15 days) and soil moisture is low. In between the high tidal and low tidal regions, various soil zones are present, depending upon the frequency of tidal inundation.
and each zone is occupied by a different species. The above situation is a hypothetical one, whereas and in the actual mangrove environment, complexities are found in the vertical zonation due to the combined effect of tidal amplitude, microtopography, soil texture and microclimatic condition. The simple zonation observed in Pichavaram mangroves of India is shown in Fig. 7 and a complex zonation of an Australian mangrove wetland is given in Fig. 8.

Apart from these physical factors, propagule size, shape and density have also been implicated in mangrove zonation. The larger and more irregularly shaped propagules are less likely to be transported by wave action through complex root structures and mud to the landward side of a mangrove community. For example, the large propagules produced by *Rhizophora* are rarely transported to the landward edge of a community and it is only large propagules that are capable of withstanding the wave action, which prevents smaller, lighter propagules from establishing in tidal areas. Smaller propagules such as those of *Bruguiera* are more likely to be landward, where the reduced levels of inundation allow root establishment.

**The larger the tidal range, the larger the area of the mangroves**

Tidal amplitude in combination with topography plays an important role in determining the size of the mangrove wetlands. In the Sunderbans mangroves of West Bengal, tidal amplitude is about 4 to 5 m (macro tide) during the spring tide and the topography is smooth. As a result, tidal water penetrates up to 90 km from the shoreline and because of this (along with long periodicity and large inflow of fresh water) the area of the Sunderbans is very large. On the other hand, the tidal amplitude in the Pichavaram mangroves is only 64 cm during the spring tide. The coastal topography is flat only for a limited distance from the sea (beyond which small sand dunes are present. Tidal water penetrates only to a limited length inland due to low tidal amplitude and hence, the size of the Pichavaram mangrove is less. Thus, a large area of mangroves can be seen only in places where tidal range is very high (but the slope of the topography should be gradual).
Figure 8. Complex pattern of species zonation in an Australian mangrove wetland
Siltation in the mouth region of the mangrove estuary and tidal water exchange

Though tides play a significant role in determining the ecological functions of the mangrove wetlands, in recent times, seasonal closure of the mouths of mangrove estuaries due to siltation has affected the free flow of tidal water in and out of mangrove wetlands. This has many negative implications. Due to poor exchange with the sea due to mouth closure, water in the mangrove environment becomes stagnant and evaporation of stagnant water increases salinity to a very high level in a short period of time, posing an acute salinity problem to both aquatic animals and plants. This has been observed in the Pichavaram mangrove wetland of India in recent times. In the Pichavaram mangrove wetland, the mouth of the estuary is almost closed or becomes very narrow during June to October, due to the deposition of sand in the mouth region. The sand is brought from the sea by waves (Fig. 9). As a result, the amount of water exchanged between the mangroves and the adjacent sea is restricted, which in turn increases the temperature and salinity of the water, causing death of fish, crabs and prawns. In addition, leaves of mangrove plants become very pale and a large amount of salt is seen secreted by leaves, which in turn affects the photosynthetic capacity of the mangrove plants.

The reason for mouth closure in the Pichavaram mangrove wetland is also related to fresh water inflow. In the coastal waters near the Pichavaram mangrove wetland, wave pattern changes during June and as a result a large amount of sand is churned from the bottom of the coastal water and carried and deposited in the mouth

Figure 9. Schematic diagram showing past and present conditions of the mouth of the Pichavaram mangrove wetland
region by waves. It is a phenomenon occurring every year. However, in the past, the mouth of the estuary was never closed since there was sufficient flow of fresh water into the mangrove wetland from June onwards which pushed back the sand deposited by waves. As described earlier, fresh water flow into the Pichavaram mangrove has been drastically reduced in recent years and fresh water is discharged only during October to December. As a result, sand brought from the sea is not pushed back but allowed to be deposited in the mouth region, leading to the closure of the mouth.

1.8 Macro topography
Macro topography along with tidal amplitude and sediment supply play an important role in determining size of the mangrove wetland. For example, larger mangroves are present along the east coast of India because the topography along the east coast is almost flat and as a result, tidal water penetrates deep inside the land. Along the west coast of India, the slope is very steep (except in Gujarat) due to the presence of the Western Ghats. This prevents penetration of tidal water deep inland along the west coast. Because of this, the mangrove wetlands of the west coast are small in size though annual rainfall and tidal amplitude are high in most of the areas.

1.9 Sediment supply
The mangrove wetland receives sediment mainly from the fresh water inflow. Regular supply of fresh sediment (soil, sand, and minerals washed from land), usually after rain into the mangrove wetland, is necessary for many purposes.

Supply of nutrients: Fine sediment supplied by the fresh water is rich in nutrients because a large amount of dissolved inorganic nutrients such as ammonia, nitrate, nitrite and inorganic phosphate adsorb (attach) themselves onto the sediment particle. When these sediment particles settle in the mangrove environments, the nutrients are gradually released due to physical and chemical processes and become available to mangrove plants. In recent times, fresh sediment supply to mangrove wetlands has reduced greatly due to reduction in fresh water flow, which in turn reduces the supply of nutrients that are essential for mangrove plant growth.

Extension of mangrove areas: The rate and quantity of sediment supply also play an important role in increasing the area of mangrove wetlands. When river water meets sea water, coagulation of sediment takes place, leading to deposition of sediment in the mangrove environment. Continues deposition of sediment leads to the formation of islands, which are then colonized by the mangrove plants.
Figure 10. Ecological factors influencing health and wealth of mangrove wetlands
Figure 10 shows how fresh water flow, tidal water, topography and other ecological factors interact and create conditions for mangrove growth. Human-induced stresses in the upstream, for example, diversion of fresh water, or within the mangroves, for example, clear felling, or a combination of these stresses, cause changes in any one or all the above mentioned factors, which in turn change the edaphic condition, leading eventually to degradation of mangrove wetlands.

1.10 Classification of mangrove wetlands

Currently two major systems, developed by Lugo and Snedaker (1974) and Thom (1984) respectively, are commonly followed to classify mangrove wetlands.

Classification of mangroves at the regional scale

Thom’s (1984) classification system can be used to group mangrove wetlands on the regional scale. It is based on three groups of dynamic factors namely, geophysical (changes in sea level, climatic conditions and tidal properties of a region), geomorphological (character of sedimentation, dominance of particular processes-wave, tidal or river and micro topography of the wetland) and biological. On the basis of these factors, Thom (1984) identified 5 different environmental settings for mangrove wetlands that occur on coasts dominated by terrigenous sediments (shallow marine sediments consisting of material derived from the land surface) and another setting for mangroves occurring on carbonate platforms.

i) River-dominated mangrove wetlands

River-dominated mangrove wetlands are characterized by high inflow of fresh water and sediment discharge, but low tidal range. The deposition of these river-borne sediments leads to the formation of deltas. The deltas build seawards over flat offshore slopes, and dampen wave energy. Deltas can be divided into active deltaic plain and abandoned deltaic plain. The active deltaic plain is an area of high fresh water discharge, which normally does not allow salt-tolerant plants such as mangroves to grow. On the other hand, the abandoned delta, where the flow of the river water is

<table>
<thead>
<tr>
<th>Geophysics</th>
<th>Geophysics is the study of the physics or nature of the earth and its environment. It deals with the composition and physical phenomena of the earth and its liquid and gaseous envelopes. Areas of studies include the atmospheric sciences and meteorology, geology, seismology and volcanology and oceanography and related marine sciences, such as hydrology.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Geomorphology is the study of present-day landforms, including their classification, description, nature, origin, development and relationship to underlying structures and also, the history of geologic changes are recorded by these surface features. The term is sometimes restricted to features produced only by erosion and deposition.</td>
</tr>
</tbody>
</table>
not very strong, supports extensive mangroves. Within the abandoned delta, mangroves are distributed in response to microtopography (minor differences in land elevation) and frequency of tidal inundation. In river-dominated mangroves, large quantities of sediment are continuously deposited and thus, new areas are always available for mangroves to grow. Some examples are Krishna and Godavari mangroves of Andhra Pradesh and Pichavaram and Muthupet mangroves of Tamil Nadu.

**ii) Tide-dominated mangrove wetlands**

In this type of mangrove wetlands, the dominant physical forces are high tidal range and strong bi-directional tidal currents (during the high tide, large amounts of sea water rush into the mangroves with high velocity, which create a water current towards the mangroves from the sea; similarly, during the low tide, sea water comes out of the mangroves very strongly, creating strong current towards the sea from the mangroves). These currents are responsible for the dispersion of sediments brought by rivers and in this process elongated islands and shoals are formed in the offshore zone. Wave energy is often quite low in this mangrove setting because of the friction of waves with islands or shoals. Typically, the main river channels are funnel-shaped and are fed by numerous tidal creeks. These creeks are separated by large tidal flats. Extensive mangroves are found in these tidal flats and islands and shoals. Some examples are the Sunderbans and Mahanadi mangrove wetlands.
iii) **Wave-dominated mangrove wetlands**

Wave-dominated mangrove wetlands are characterized by higher wave energy at the shoreline and relatively low amount of river discharge. The high wave energy reworks the sand supplied by rivers and sand settled along the sea floor. This reworking of sand leads to the formation of sandy ridges parallel to the shoreline and barrier islands. These barrier islands enclose broad, elongated lagoons. Mangroves are found around the margin of the lagoon, in a variety of habitats. Wave dominated mangrove wetlands are common along the coasts of Mexico, Brazil and other middle and South American countries.

iv) **Composite river and wave dominated mangrove wetlands**

This type of mangrove wetland is characterized by high wave energy and high river discharge. Sand discharged by the rivers is rapidly redistributed by waves along the shore to form extensive sand sheets. Much of the sand deposited in the coastal waters is also reworked landward and as a result, a complex of landforms develops, within which extensive mangrove forests grow, for example, the Grijalva delta of Mexico.

v) **Drowned bedrock valley**

The setting of this kind of mangrove wetland is defined by a bedrock valley system, which has been drowned by a rising sea level. Neither marine nor river deposition
has been sufficient to fill this open estuarine system. However, the heads of the valley may contain relatively small river deltas, which are little modified by waves. At the mouth of the drowned valley bordering the open sea, a tidal delta may occur, composed of marine sand reworked landward during a rise in sea level. Mangroves may flourish in fine sediments found at the heads of drowned tributary valleys, as for example in the Gulf of Kutch mangroves of Gujarat.

**vi) Carbonate settings**

Carbonate settings are those in which terrestrial sediment supply is low or absent but calcareous sediment or lime mud (marl) production dominates. Examples are oceanic islands, coral reefs and carbonate banks. In these cases, thick mangrove-derived peat accumulates over the carbonate platform (which supports extensive mangroves). An example is the Mangroves of Andaman and Nicobar islands.

As explained above, different geophysical and geomorphological factors combine together and produce an array of physical settings in which mangroves grow. Environmental conditions in these physical settings differ widely, which in turn control distribution of mangrove species through ecophysiological factors.

**Classification of mangroves at the micro level**

According to Lugo and Snedaker (1974) each mangrove wetland can be further classified into a number of ecotypes on the basis of topography and hydrology. According to this system, six types namely, overwash, fringe, riverine, basin, scrub and hammock mangroves can be identified. Each ecotype of mangroves has its own set of environmental variables such as soil type and depth, soil salinity, tidal flushing rates etc. Each of these types also has its own range of primary production, litter decomposition, and carbon export along with differences in nutrient cycling rates, and factors that determine the role of mangroves on the bioproduction of adjacent water bodies.

**i) Overwash mangroves**

In a mangrove wetland, the overwash mangrove forest occurs in and adjacent to the bays on small islands, newly formed shoals and finger-like projections. In most instances overwash mangrove forests are situated almost perpendicular to tidal flow patterns and are overwashed with each high tide. The velocities of tidal currents are large enough to carry all loose debris into the inner bays. As these materials are not redeposited by these retreating tides, there is an observable paucity of detritus in these forests.

**ii) Fringe mangroves**

This type of mangroves are situated as thin fringes along the slightly sloping shorelines of waterways and are for the most part, exposed to the open bays. Tides
are the primary physical factor in fringe forests. However, tidal waters do not overwash these forests. Tides export buoyant materials such as leaves, twigs and propagules from mangrove areas to adjacent shallow water areas. This export of organic material provides nutrition to a wide variety of organisms and provides nutrients for the continued growth of the fringing forests.

iii) Riverine mangroves

The riverine mangrove forests occur along the major river drainage, emptying into mangrove wetlands. Salinity drops during the wet season, when rains cause extensive fresh water runoff; however, during the dry season, estuarine waters are able to intrude more deeply into river systems, and salinity increases as a result. This high seasonal salinity may aid primary production by excluding space competition from terrestrial plants. Further, nutrient availability in these systems becomes highest during periods when salinity is lowest, thus promoting optimal conditions for mangrove growth. This alternating cycle of high runoff/low salinity followed by low runoff/high salinity suggests that riverine mangrove forests are the most highly productive of the mangrove communities.

iv) Basin mangroves

Basin mangrove forests occur on the landward side of a mangrove wetland. They are also called interior mangroves. These mangrove forests are protected against waves and often inundated only infrequently by the tides. Salinity varies greatly, depending on the circumstances. In areas of high rainfall or of substantial groundwater flow, salinity may be quite low. On the other hand, evaporation and removal of water by the mangrove trees may combine to raise salinity and in some areas soil may be distinctly hypersaline. Because currents, both riverine and tidal, are low, a basin type of mangroves is likely to represent a sink for nutrients and sediments.

v) Scrub mangroves

These are usually found in extreme environments where nutrients are limited or little fresh water is available. Trees are stunted and frequently no more than 1 m in height.

vi) Hammock mangroves

These mangroves are special forms of basin mangroves and found only in the Florida region of North America. In this type, mangrove forest grows over a peat which infill a depression in the underlying limestone substrate.

One or more of these functional types of mangroves could be recognized in a given mangrove wetland and demarcating and mapping these ecotypes in a
mangrove wetland would be very helpful in identifying interventions for mangrove management and conservation.

1.11 Habitat and economic value of mangrove wetlands

Shoreline stabilization

As they are located along the coastline, mangroves play an important role in shoreline stabilization. The extensive aboveground root systems of the mangrove vegetation act as a sieve, thereby reducing current velocities and shear. These root systems also enhance sedimentation and sediment retention and thereby stabilize soils, which reduces the risk of erosion, especially under high-energy conditions such as tropical storms.

Shoreline Protection

Mangrove forests are able to absorb and reduce the impact of strong winds, tidal waves and floods that accompany tropical storms, thereby protecting uplands from more severe damage. Even though some of these forces can devastate the mangrove forest, mangroves in general have a great capacity to recover after major disturbances. Mangroves produce abundant propagules, their seedlings grow quickly and they reach sexual maturity early, characteristics that accelerate their natural ability to regenerate. The speed of recovery, however, depends on the type of forest affected, the nature, persistence and recurrence of the disturbance and the availability of propagules.

Detritus based food web

Detritus is defined as fine particulate organic matter derived from decomposed of dead plant and animal tissues. In the mangrove ecosystem, dropped leaves, broken twigs and branches, fallen fruits and other parts of plants constitute litter. After falling on to the mangrove forest floor they are taken to nearby water bodies by tides. In the water, first some chemicals from these vegetative parts are first leached out. After leaching of most of the chemicals, fungi attach to the decomposing leaves and other plant parts and break them down into small pieces. Shortly after fungal invasion, bacteria begin to grow on the decomposing matter. The finely decomposed matter along with fungi and bacteria is defined as detritus. The fungi and bacteria convert the nitrogen present in the decomposing vegetative parts into protein. In addition, a variety of enzymes are also produced during the process of decomposition by fungi and bacteria. The presence of nitrogen, carbon, various enzymes and fungi and bacteria increase the nutritive value of the detritus.

In the mangrove waters, primary production by algae and phytoplankton is low and in this situation detritus, derived from decomposing plant materials become an important
source of food for animals. The animals that feed on detritus are called detritivores or detritus consumers. They include a variety of fish, crabs, shrimps, clams, snails, nematodes etc., and their juveniles. All these animals derive their nourishments primarily from a diet of vascular plant detritus. Small carnivores such as minnows and other fish consume these detritivores and larger carnivores, including birds, eat these small carnivores. Shellfish like mullets, prawns and crabs are available in large quantities in the mangrove environment mainly because of the presence of large quantities of detritus (Fig. 16).

**Figure 16. Detritus–based food web**

**Nursery ground for aquatic animals**

Mangrove wetlands provide both habitat and a source of food for a diverse animal community that inhabits both the mangroves and the adjacent coastal waters. Some animals depend on the mangrove environment during their entire lives, while others utilize mangroves only during specific life stages, usually reproductive and juvenile stages. Mangrove wetlands act as nursery grounds for the juveniles of prawns, crabs and some fish, which constitute the fishery resources of the mangrove environment. Apart from these, commercially important bivalves such as oysters, mussels and clams are commonly found in and around mangrove roots.
From an economic point of view, mangroves are often far more important for the aquatic life they support than for the wood production potential. It has been estimated that the average yield of fish and shellfish in mangrove areas is about 90 kg per hectare, with the maximum yield being up to 225 kg per hectare. In the part of the Sundarban mangroves in Bangladesh, an average of 9,000 tons of fish and shellfish are harvested annually which corresponds to approximately 53 kg per hectare whereas in the Pichavaram mangroves in India, an amount of 60 kg per hectare has been recorded. An indication of the strong relationship between fish resources and the extent of mangroves is shown in Table 2.

Table 2. Relationship between fishery resources and extent of mangroves in Malaysia

<table>
<thead>
<tr>
<th>Peninsular Malaysia</th>
<th>Area of mangrove</th>
<th>Total</th>
<th>Contribution by mangrove sp.</th>
<th>Contribution by non-mangrove species</th>
</tr>
</thead>
<tbody>
<tr>
<td>West coast</td>
<td>96,000</td>
<td>433000</td>
<td>184000</td>
<td>249000</td>
</tr>
<tr>
<td>East Coast</td>
<td>17,000</td>
<td>216000</td>
<td>5000</td>
<td>191000</td>
</tr>
<tr>
<td>Total</td>
<td>113,000</td>
<td>649000</td>
<td>209000</td>
<td>440000</td>
</tr>
</tbody>
</table>

However, to assess the economic status of a mangrove fishery and to formulate appropriate management measures, accurate fishing effort data are necessary.

**Habitat for wildlife**

Mangrove wetlands provide a habitat for a wide variety of wildlife such as saltwater crocodiles, monitors etc. Both residential and migratory birds use mangroves for refuge, nesting and feeding. Otters are commonly found in many mangrove wetlands. Some mangrove wetlands such as the Sunderbans of West Bengal provide a habitat for tigers. Other mammals such as wild pigs, rodents, deer, monkeys and bats are also found inhabiting many mangrove wetlands.

**Economic value**

Mangrove products can be obtained directly from the forest (wood) or from derivatives such as prawn, crabs and fish. The most common uses of mangrove wood are as a source of fuel, either as charcoal or firewood and as the primary material for the construction of boats, houses, furniture etc. *Rhizophora* trees are commercially cultivated in many countries such as Malaysia, Thailand etc., for charcoal production. Besides wood, many other mangrove products have also been exploited commercially. Mangrove bark has traditionally been used as a source of tannins, which are used as a dye and to preserve leather. The pneumatorphores of different mangrove species are used in making corks and
fishing floats. Mangroves are also used as a source of food (mangrove derived-honey, vinegar and salt). In some parts of the world, the tender leaves, fruits, seeds and seedlings of *Avicennia marina* and vegetative parts of other species are traded and consumed as vegetables. Many of the mangrove species are a good source of food for cattle and camels.

Mangroves have great potential for medicinal uses. Materials from different species can treat toothache, sore throat, constipation, fungal infection, bleeding, fever, and kidney stone. Mangroves also contain toxic substances that have been used for their antifungal, antibacterial and pesticidal properties.

Mangrove wetlands have been widely recognized for their role in maintaining commercial fisheries by providing nursery ground, refuge from predators and food to important fish, prawn and crabs, which ensure livelihood security to hundreds of thousands of fishing families.

1.12 Natural and human-induced threats to mangroves

i) Storms and hurricanes

Mangroves are particularly sensitive to storms and hurricanes because of their exposed location within the intertidal zone, their shallow root systems, and loose nature of the forest soils. The effect of storms and hurricanes varies, depending on factors such as wind speed and water levels. Small storms generally kill a few trees by lightning or wind-induced tree falling, creating forest gaps. It is considered as an important mechanism for natural forest regeneration.

In contrast, high-energy storms (hurricanes and typhoons) devastate mangrove forests. Entire mangrove populations can be destroyed, with significant long-term effects to the ecosystem. Mangrove forests affected by hurricanes show uniform tree height, reduced structural development and sometimes, changes in species composition. However, mangrove forests can recover easily, but the rate of recovery depends on the severity of mangrove damage and mortality, mangrove species composition, the degree of sediment disturbance and propagules availability.

ii) Sedimentation

Even though mangroves colonize sedimentary environments, excessive sediment deposits can damage them. Moderate sedimentation is beneficial to mangroves as a source of nutrients and to keep up with predicted increases in sea level. But excessive, sudden sedimentation can reduce growth or even kill mangroves.
Complete burial of mangrove root structures interrupts gas exchange, killing root tissues and trees. For example, *Avicennia* trees will die with 10 cm of root burial. Seedlings are especially sensitive to excessive sedimentation. Excessive sedimentation can result from natural phenomena such as river floods and hurricanes. In the Krishna mangroves of Andhra Pradesh of the east coast of India, large amounts of sand was brought into the mangroves during the 1972 cyclone, which completely buried the root system of all mangrove species and killed mangrove forests in thousands of hectares. These mangroves have still not recovered fully. Excessive sedimentation can also result from human activities such as road construction in and around mangroves, dam construction, mining etc.

**iii) Reduction in fresh water flow**

Another factor that severely affects mangroves is reduction in fresh water flow. In recent years, many of the mangrove wetlands receive very limited amounts of fresh water due to the construction of dams upstream. This increases the salinity of the water and soil, leading to the disappearance of salt-sensitive mangrove species, reduction in growth and reproduction in other species. In addition, reduction in fresh water flow also causes seasonal closure of the mouth of the mangrove estuaries, leading to limited exchange of tidal waters. This increases water temperature and salinity in shallow mangrove waters. Closure of the estuarine mouth and poor of exchange of sea water not only affect the mangrove plant community but also cause reduction in fishery resources by preventing recruitment of young fish, prawn and other marine organisms into the mangrove wetlands, thereby endangering the livelihood security of the coastal community.

**iv) Conversion of mangrove wetlands**

Despite the ecological and economic importance of mangroves, deforestation of mangrove forests has been widespread. Deforestation has been mostly related to the conversion of mangrove forest for agriculture, aquaculture, human settlement and salt-production. Despite laws established for mangrove protection in many different countries, unregulated exploitation and deforestation of mangroves continues. In the Philippines, approximately 60% of the original mangrove area has disappeared due to conversion into various other land uses. Similarly, in Thailand 55% of the mangrove forest cover has been lost over a period of 25 years, mainly due to prawn farming. Conversion of mangrove wetlands leads to loss of habitat, increase in shoreline erosion, damage to fisheries and loss of services derived from these ecosystems.
v) **Clear felling on rotation – unscientific management practice**

Clear felling is another cause of mangrove degradation. Many of the mangrove forests are clear felled for timber and firewood. In many of the Indian mangrove forests, trees were clear felled in large areas by government agencies on rotation basis under coupe system of management. Since nearly 80% of the mangrove soil is water, clear felling in large scale exposed the mangrove wetlands to sunlight, which caused evaporation of soil water. Evaporation of soil water caused subsidence of sediment, changing the flat topography of the mangrove wetland into a trough shape. Tidal water, entering into the trough, became stagnant and evaporation of stagnant water increased soil and ground water salinity to a level which is lethal to mangrove plants. Hence, no natural regeneration is noticed in the clear felled area. It has been estimated that clear felling by government management agencies was responsible for nearly 60 to 80% of degradation of the mangrove wetlands of India. Fortunately, clear felling under coupe system of management was abandoned a long time ago and now these degraded areas are being restored.
2. BIOLOGY OF MANGROVES

2.1 Floristics

The most noteworthy feature of the mangrove forests, apart from their unique habitat, is the relative paucity of the species comprising them. The paucity of species is mainly due to the peculiar conditions of the mangrove wetlands, where only a few plants are able to survive and flourish in saline muddy areas and to withstand frequent inundation by saline water. In general, the flora of the mangrove wetlands is divided into two groups namely, a) true or exclusive mangrove species and b) associate mangrove species. The following are the characteristic features of true mangrove species:

- they grow only in mangrove environment
- they play a major role in determining the structure of the plant community
- they have the capability to form pure stands
- they are morphologically adapted to living in waterlogged condition – e.g. aerial roots
- they are physiologically adapted to living in saline environment
- they have viviparous reproduction
- they are taxonomically isolated from terrestrial relatives

True mangrove species comprise 69 species in 27 genera, belonging to 20 families from two plant divisions, including the fern family in the Polyodiophyta and the reminder in the Magnoliophyta, also known as the angiosperms (Annexure 1).

Some of the terrestrial plant species and pure halophytes (that grow only in saline areas) and are also found within or in the peripheral areas of mangrove wetlands. These species are called associate mangroves. The terrestrial species that are found to associate with mangroves are unable to tolerate high salts and therefore do not penetrate deep into the mangrove wetlands. They are normally found in elevated lands present within the mangrove ecosystem. On the other hand, halophytes such as *Suaeda* and *Salicornia* are able to grow along with mangroves in hypersaline areas.

Taxonomic uncertainties still exist with mangrove plants despite their familiarity. This is mainly because they have wide distributions and few fieldworkers have the opportunity to explore species throughout their range. Often the characters that
separate species are not very obvious. The geographical limits of several of *Avicennia* taxa are still uncertain, even though this is the most constant genus in mangrove wetlands and the names for its species are not always reliable. Knowledge of the geographic range of mangrove species is often incomplete, so checklists of mangrove species for given areas are constantly in need of revision.

### 2.2 Morphology and anatomy

**Roots and adaptation to waterlogged conditions**

The underground tissues of any plant require oxygen for respiration. In dry soils, diffusion of gas between soil particles can supply the oxygen required by the roots. In waterlogged soils as in mangrove wetlands, the spaces between soil particles, otherwise called pores, are filled with water and oxygen concentration in the pore water is very low. When oxygen movement into soil is severely limited due to water logging, the oxygen that is present in pore water is soon depleted by the respiration of soil microbes. This results in soil with no oxygen and these soils are called anoxic soils. Anoxic soils are very common in mangrove environment and mangrove plants are adapted to survive in such a harsh environment. The most striking adaptation to overcome the problem of anoxic soil is various forms of aerial roots.

**Stilt roots:** In growing *Rhizophora* species roots diverge from the tree as much as 2 m above ground and penetrate the soil some distance away from the main stem. Because of their appearance and because they provide the main physical support of the trunk, the aerial roots of *Rhizophora* are often called stilt roots. On reaching the soil, absorptive roots grow from the stilt roots vertically downwards into the soil. A secondary aerial root may loop off and penetrate the soil still further away from the main trunk. The aerial roots of neighbouring trees often cross, and the result is the development of an impenetrable mesh of stilt roots. Stilt roots, more or less similar to that of *Rhizophora*, develop in *Bruguiera* and *Ceriops* (close to the stem base) during the sapling stage, becoming shallow buttresses in old trees.

**Pneumatophores:** In species like *Avicennia*, shallow horizontal roots radiate outwards, often for a distance of many metres. At intervals of 15 to 30 cm, vertical structures known as pneumatophores emerge as lateral branches from horizontal roots and stand erect, up to 30 cm above the soil. A single *Avicennia* tree of 2 to 3 m height may have more than 10000 pneumatophores. In *Sonneratia*, the height of the pneumatophores may reach more than 3m. In *Avicennia*, pneumatophores may develop secondary thickening but secondary thickening is very common in
Figure 17a. Stilt roots of *Rhizophora*

Figure 17b. Pneumatophores of *Avicennia*
the aerial roots of *Sonneratia*. The surface texture of the aerial roots of *Avicennia* is smooth and spongy whereas flaky bark develops in the younger aerial roots of *Sonneratia*. Both in *Avicennia* and *Sonneratia* the roots include chlorophyll in the subsurface layers. Pneumatophores remain unbranched, but are capable of branching when damaged.

*Knee roots*: In *Bruguiera* and *Ceriops* the horizontal roots reorient upwards through the soil as they grow away from the parent tree. The tip of the upward extension forms a pronounced loop. At the site of the loop, secondary thickening occurs, mainly on the upper side, so that a blunt, knoblike structure is raised above the soil surface and these roots are called knee roots. By the repeated development of loops, a single horizontal root develops a series of “knee roots” at regular intervals. Branching of the root system is largely restricted to these “knees”; from these branches new horizontal roots develop and form anchoring roots. The size, shape and frequency of knee roots are characteristic for each species but vary according to soil conditions. Knee roots are also present in *Lumnitzera* but are seemingly inconspicuous and develop little secondary growth.

Localized erect outgrowths of the upper surface of the horizontal roots can be seen in *Xylocarpus mekongensis*. These structures are secondary and produced entirely by localized cambial activity on the upper surface of the horizontal roots and in this respect, knee roots of *Xylocarpus mekongensis* are entirely different from that of *Bruguiera* and *Ceriops* where the knee roots are initiated as the result of primary growth.

*Buttress roots*: In *Xylocarpus granatum*, the horizontal roots become extended vertically by eccentric cambial activity throughout their length. These roots are laterally sinuous in their course, so the result in the mature tree is a series of wavy, plank-like structures, growing away from the base of the trunk. Similar buttress roots can also be seen in *Heritiera* as narrow surface outgrowths of the base of the trunks.

Elaborate aerial roots are absent in *Aegiceras*, *Aegialitis*, *Excoecaria agallocha*, *Nypa* etc. However, certain structures may be developed to aerate the root system. The base of the stem in *Aegialitis* is enlarged with a spongy texture. In *Nypa*, the individual leaves function like a giant pneumatophore. Like aquatic plants, mangrove roots have no root hairs.

*Aerating underground roots*: The method of aerial roots aerating the underground roots can be explained with the help of the stilt roots of *Rhizophora*. The stilt roots
of *Rhizophora* can divided into two components namely, a) more or less horizontal arches and b) vertical columns. The columns have the role of supplying oxygen to the underground roots. Air passes into the column roots through numerous tiny pores or lenticels, which are particularly abundant close to the point at which the column roots enter the surface soil. Roots entering the soil are largely composed of aerenchyma tissue, honeycombed with air spaces, which run longitudinally down the root axis. Oxygen enters into the underground roots through the lenticels. If the lenticels are closed, oxygen in the underground system will decrease continuously and carbon dioxide concentration will increase.

There is another interesting way in which gas exchange takes place in the mangrove roots. Lenticels or tiny pores in the aerial roots are hydrophobic, so that while a root is covered with water during the high tide, these lenticels remain closed, and neither air nor water can enter. At the same time respiration in roots removes the oxygen found in the air spaces of the roots and carbon dioxide is produced. Because of the high solubility of carbon dioxide in water it does not replace the volume of oxygen removed. This results in reduction of gas pressure within the roots. When the tide recedes, lenticels open again and because of the reduced gas pressure within the roots, air is sucked in. Along with air, oxygen also enters into the roots.

**Anchorage:** The rooting system of mangroves also has the function of anchorage. Because of anoxic condition, mangrove roots do not penetrate deep into the soil and tend to remain close to the surface. Therefore, there are no deeply anchored taproots. Secondly, mangrove soil is often fluid and unstable. In such a situation, aerial roots provide effective anchorage and the presence of aerial roots is one of the reasons for mangrove forests to function as an effective wall against strong winds and cyclones.

**Wood**

Datable growth rings do not exist in mangrove woods and this causes severe constraints on ecological analysis because no indirect measure of the age of a tree is possible. Superficial examination of mangrove woods might suggest the presence of growth rings, but these rings seem related to variations in the density of chemical wall deposits.

Mangrove woods have special features that enable the tree to overcome the high osmotic potential of sea water and to the high temperature, which promotes transpiration. There are numerous vessels running through the wood. These range in density from 32 to 270 per sq.mm. The diameter of these vessels is also very
narrow, ranging from less than 100 µm to 150 µm. The high density of narrow vessels creates high tension (negative pressures) in the xylem and a slight decrease in diameter of the vessels therefore brings about a proportionally much greater increase in resistance to flow of water. The narrowness of vessels in mangrove woods is therefore compensated by an increase in their numbers, hence their density. The vessel elements, which form the vessels, normally have simple perforation plates except in mangrove Rhizophoraceae, which have scalariform perforation plates. The wood of most mangroves is diffuse porous, which aids in the slow movement of water through wood.

Wound repair in mangrove wood has also been well studied. In *Rhizophora* species, a closing layer isolates wounded tissue within 17 days and it is completely enclosed by periderm by 52 days. Isolation of the wounded site and development of wound periderm may prevent spread of pathogens to undamaged tissues.

**Leaf**

Leaf shape and texture in most of the mangroves is uniform, generally ovate to elliptic outline with blunt to pointed apex and usually with entire margins or with unclear crenations (Fig. 18). Leaf morphology is particularly uniform in *Rhizophora*, *Ceriops*, *Bruguiera*, and *Kandelia* although there are differences in texture and average size. In *Rhizophora* species the mucronate versus nonmucronate shape of the leaf apex segregates species on a broad geographical basis. A hybrid between two species of *Rhizophora* has an intermediate leaf tip morphology showing that leaf apex morphology is genetically controlled. Leaf texture is firm to almost coriaceaous but never rigid. The veins are obscure and never prominent; this is related to the absence of vein sheath. Conspicuous waxy deposits do not occur but the cuticle is thick and smooth with small hairs, which gives a glossy appearance to mangrove plants.

The leaves are of moderate size and are arranged in a modified decussate arrangement (Fig. 19) with a pair at an angle less than 180° to the preceding pair. This arrangement reduces shading and produces branch systems with greater diversity that fill space in the most photosynthetically efficient way. The leaves are generally dorsiventral, with thicker cuticle on the lower leaf surface. Isolateral leaves are also found in some mangroves such as *Sonneratia apetala* and *Kandelia candel*.

Three different types of stomata namely, anomocytic, paracytic and diacytic are identified in mangrove leaves and they do not show any high degree of specialization. These types differ in their arrangements of guard cells and subsidiary cells. Guard cells are somewhat thick walled, often with prominent or even elaborate ledges.
Figure 18. Mangrove leaves are almost uniform in size, shape and texture (A. Rhizophora apiculata  B. Rhizophora mucronata  C. Rhizophora x lamarkii  D. Ceriops decandra  E. Bruguiera cylindrica  F. Avicennia marina  G. Avicennia officinalis  H. Aegiceras corniculatum)
Figure 19. Leaves of mangrove plants are arranged in a modified decussate (bijugate) pattern
a) Bruguiera cylindrica  b) Lumnitzera racemosa
The horn or beak like cuticular outgrowth covers the outer side of the stomatal pore or both the inner and outer sides. These structures provide resistance to stomatal transpiration (Fig. 20).

Figure 20. Types of stomata found in mangrove plants

a) Anomocytic - no subsidiary cells (*Lumnitzera, Xylocarpus, Heritiera*)

b) Panacytic - subsidiary cells parallel with the long axes of the guard cells (*Rhizophora Ceriops, Bruguiera, Excoecaria, Sonneratia*)

c) Diacytic - common wall of subsidiary cells is at right angles to the guard cells (*Avicennia*)
A common feature of most mangrove leaves is the frequent development of groups of enlarged terminal tracheids at vein endings. Branched sclereids are a regular feature in the mesophyll of most mangrove leaves. In many species, two or more kinds of sclereids can be distinguished on the basis of size, shape, and location. Both sclereids and tracheids are involved in water storage, and sclereids may provide mechanical support to leaves or discourage herbivores. Limited development of bundle sheath fibers and the absence of bundle sheath extensions give a firm texture to mangrove leaves. Apart from these, mangrove leaves contain many specialized cells such as tannin cells, oil cells, mucous cells, lacticifers, etc.

In general, the epidermal and stomatal characters of mangroves resemble those of xeric trees and shrubs. The presence of thick cuticle, sunken stomata, and distribution of cutinized and sclerenchymatous cells through the leaf tissue, including the epidermis, are xeric characters. Probably these characters had developed in response to the physiological dryness of the mangrove habitat. In comparison, the root structure in most mangrove species resembles those of hydrophytes. A unique combination of xeric and hydrophytic components in one organism in mangrove species enables these species to flourish in a wet, yet physiologically dry, habitat.

2.3 Physiology

Salt regulation

The salinity of the mangrove environment ranges from fresh water to sea water. Sea water salinity is about 35 grams per litre, which means an osmotic potential of –2.5 MPa (-25 atmospheres) and water must be taken up by the plants against this pressure. In some areas, mangrove plants have to grow in hypersaline conditions and uptake of water under this condition is much more difficult. The problem may be further aggravated by fluctuation in salinity. Variation in salinity may be more difficult to cope with than high salinity itself. Mangrove plants have a variety of mechanisms to cope with the problem of salinity. On the basis of the method adapted, mangrove plants are divided into three types:

i) Salt excreting type: this type of mangrove plants take saline water as such through roots and only water molecules and essential salts are retained in the tissues and excess salts are excreted through salt glands.

ii) Salt excluding type: the roots of these mangrove plants possess an ultra-filtration mechanism called reverse osmosis by which water and salts in sea water are separated in the root zone itself and only water is taken inside while salts are rejected.

iii) Salt accumulating type: this type of mangrove plants possess neither salt glands nor an ultra-filtration system, but these species have the capacity to accumulate a large amount of salts in their leaves and develop succulence.
However, interplay between salt exclusion by roots, elimination of excess salt by secretion and tolerance of high salt concentration in tissues are common, but not well understood.

Salt exclusion by mangrove plants seems to be a simple physical mechanism. Negative hydrostatic pressure is generated within the plant, largely due to transpiration processes. This is sufficient to overcome the negative osmotic pressure found in the root zone. Because of the differences in pressure, water is drawn into the plants and unwanted ions are excluded. The physical nature of this desalination process was demonstrated in Ceriops species. Seedlings of Ceriops with shoots removed were kept in a ‘pressure bomb’. A pressure bomb is nothing but a container containing sea water, which is subjected to changes in pressure by introducing compressed nitrogen. Ceriops seedlings without shoots were kept in this container and the roots were immersed in sea water while the cut stem was exposed to the atmosphere. With a positive pressure on the roots of 4 to 4.5 MPa (40 to 45 atmospheres), the cut stem exuded about 4 ml of water per minute. This was continued for a number of hours and the total amount of water exuded by the seedling was found to be greater in volume than the total water capacity of the seedling. This indicates that water must have came largely from the environment (here it was from the pressure bomb) and not from within the seedling itself. In the water surrounding the roots, the salt concentration increased ten-fold, showing that salt was being excluded. When the Ceriops seedlings were poisoned with either carbon monoxide or the metabolic inhibitor dinitrophenol, the rate of desalination was the same, indicating that the ultra filtration is a physical process that does not depend on metabolic processes.

On the other hand, a number of mangrove species such as Avicennia and Aegiceras possess salt glands in the leaves (Fig. 21). These species take some salt along with water but excrete the excess salt through salt glands. The secretary cells of the salt glands are packed with mitochondria, suggesting intense metabolic activity. Metabolic inhibitors can prevent secretion of salts by the salt gland. Salt secretion requires a lot of energy. Salt glands resemble each other closely across a range of species, presumably as the result of convergent evolution. They also closely resemble glands that secrete other materials, such as nectar, suggesting a possible evolutionary origin.

Even with the exclusion of most of the salt, concentration of sodium and chloride ions within the plant tissues is higher than in non-mangrove species. High salt concentrations are known to inhibit many enzymes. Intracellular mangrove enzymes are protected partly by being more resistant to this inhibition, and partly by partitioning of solutes within different cellular components. Sodium and chloride ions are at high concentration within cell vacuoles, but are largely excluded from
Figure 21. Salt glands in mangrove plants (after Tomilnson, 1986)
the cytoplasm itself. To avoid the consequences of an osmotic imbalance within the cell, high cation concentrations in the vacuole are balanced by high concentrations of non-ionic solutes in the cytoplasm. Various substances (particularly glycinebetaine, proline and manitol), probably contribute to maintain osmotic balance.

Exclusion, tolerance and secretion are used with different emphasis by different species and within a species under different environmental conditions. Table 3 summarizes the known occurrence of these mechanisms in a range of species. Given the range of methods adapted by different mangrove plants for salt regulation, it is not surprising the mangrove species differ in their extent of salt tolerance.

**Table 3. Types of salt regulating mechanism operating in different mangrove species**

<table>
<thead>
<tr>
<th>Species</th>
<th>Mechanism of salt regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Salt exclusion</td>
</tr>
<tr>
<td>Acanthus</td>
<td>✓</td>
</tr>
<tr>
<td>Aegialitis</td>
<td>✓</td>
</tr>
<tr>
<td>Aegiceras</td>
<td>✓</td>
</tr>
<tr>
<td>Bruguiera</td>
<td>✓</td>
</tr>
<tr>
<td>Ceriops</td>
<td>✓</td>
</tr>
<tr>
<td>Excoecaria</td>
<td>✓</td>
</tr>
<tr>
<td>Rhizophora</td>
<td>✓</td>
</tr>
<tr>
<td>Sonneratia</td>
<td>✓</td>
</tr>
<tr>
<td>Xylocarpus</td>
<td></td>
</tr>
</tbody>
</table>

✓ Prevailing salt regulation mechanism

**Photosynthesis and growth**

Mangrove plants, like other higher plants, depend on the photosynthetic reduction of carbon dioxide to form carbohydrates and other organic materials necessary for growth and maintenance. Mangroves, in common with other plants, show characteristic C3 photosynthesis. Mangrove plants experience the following difficulties in maximizing the rate of photosynthesis:

- Carbon dioxide enters, and water is transpired, through mangrove leaf stomata. At high soil salinities, stomatal conductance (the passage of gas through the stomata) is reduced. This conserves water by reducing transpiration but also reduces uptake of carbon dioxide, which in turn affects the rate of photosynthesis.
• The assimilation of carbon during the photosynthesis cannot be done without spending water. In a mangrove wetland, water is not in short supply, but as described earlier, uptake is difficult because of salinity. Hence, in mangroves, just sufficient water is expended to maintain the carbon assimilation rate very near the photosynthetic capacity of the leaf.

• Minimum use of water leads to another problem. To maximize photosynthesis, a leaf must position itself horizontally to sunrays to get maximum light. But in this position, the temperature of a leaf increases rapidly, sometimes 10ºC above air temperature. High leaf temperature may reduce the biochemical capacity to fix carbon. One way of reducing leaf temperature would be to increase the transpiration rate and lose heat by evaporation. Mangroves cannot afford to do this because of the problem in taking water from the saline environment. Instead, mangrove plants tend to keep their leaves at an angle to the horizontal to minimize increase in leaf temperature. Such positioning of leaves prevents mangrove leaves getting maximum light, which in turn affects the rate of photosynthesis.

These ecophysiological responses to environmental conditions and the high water efficiency of mangroves help to explain why they grow better in wet equatorial climates such as in Malaysia, Indonesia, Columbia etc., than in seasonally monsoonal or arid climates. In wet equatorial climates, persistent cloud cover prevents exposure of the mangrove forest canopy to high levels of sunlight and keeps the leaves relatively cool. This, coupled with high relative humidity and inflow of fresh water, places less stress on water. The net result is increase in photosynthesis, less expenditure of energy for maintenance and high growth rate. That is why mangrove plants growing in wet and humid and less saline environments are always tall and luxuriant. In contrast, mangroves growing in arid climate are exposed to high solar radiation and in consequence, experience high leaf temperatures and low ambient relative humidity; soil salinity in this environment is also high due to poor rainfall. All these lead to high rate of water loss, partial stomatal closure and low photosynthetic rate. All these take place at the expense of growth rate and that is why mangrove plants growing in an arid climate are poorly grown or stunted in growth. Mangroves growing in seasonally monsoonal climate, such as in India, often experience similar environmental conditions during the dry season and in this season growth rate is very low or almost nil.

In general, beautiful mangrove forests exist in areas where soil salinity is between 5 and 25‰. The size of mangrove trees and the number of species decrease if the soil salinity ranges between 40 and 80‰. If the soil salinity exceeds 90‰, no mangroves can be seen in that area.
2.4 Reproduction

Pollination

Most of the mangrove plants are hermaphrodite. Mangroves have both self-pollinating and cross-pollinating mechanisms that vary with species. For example, *Aegiceras corniculatum* and *Lumnitzera racemosa* are self-pollinated. *Avicennia officinalis* is self-fertile but can also cross-fertilize. In *Avicennia marina*, protandry makes self-pollination of an individual flower unlikely. In many of the mangrove species there is limited evidence for self-compatibility.

Mangroves are almost exclusively pollinated by animals, except *Rhizophora*, which is wind pollinated. The identity of pollinators differs from species to species. Insects pollinate *Lumnitzera racemosa*, whereas birds pollinate *Lumnitzera littorea*. Birds are particularly important pollinators in the dry season when the absence of terrestrial plant flowers causes them to turn to mangroves as a food source. Bees are the common visitors to mangroves and have been observed to pollinate *Avicennia, Acanthus, Aegiceras, Excoecaria, Scyphiphora* and *Xylocarpus*. Wasps and flies are important pollinators of *Ceriops decandra, Kandelia candel* and *Lumnitzera racemosa*. Bats are the major pollinators of *Sonneratia*.

Vivipary

Mangroves plants display a unique reproductive mechanism known as vivipary. A distinctive feature of the majority of mangrove species is that they produce unusually large propagating structures called propagules. This term is used because in most mangrove species, what leaves the parent tree is a seedling, not a seed or fruit. After pollination the growing embryo remains attached to the parent tree and grows into a propagule (Fig. 22). This phenomenon is known as vivipary. *Rhizophora* and other members of the *Rhizophora* family such as *Bruguiera, Ceriops* and *Kandelia* show the most advanced form of vivipary. In these species, after fertilization, the embryo develops within a small fruit. As the embryonic axis or hypocotyls, elongates, it bursts through the seed coat and develops into a spindle-shaped structure. Unlike seeds of terrestrial plants, there is no period of dormancy and growth of the propagules continues. While still attached to the parent, the developing seedling (propagule) develops chlorophyll and actively photosynthesizes. The parent tree supplies the water and necessary nutrients. Eventually the hypocotyl detaches from the residual fruit, leaving behind its cotyledons, and falls from the parent tree. Three pairs of leaves and associated stipule pairs are produced while the propagule is still attached to the parent tree. The first pair of leaves aborts and persists only as minute vestiges on the detached propagule so that the plumule is actually protected by well-developed stipules. Lateral roots, visible on older seedlings
Figure 22a. Viviparous propagules

a. Rhizophora mucronata  b. Rhizophora apiculata
c. Bruguiera cylindrica  d. Ceriops decandra

Figure 22b. Cryptoviviparous propagules

a. Avicennia marina  b. Avicennia officinalis  c. Aegiceras corniculatum

Figure 22c. Normal Seeds

a. Excoecaria agallocha  b. Xylocarpus granatum
as apical protuberances, arise early in seedling development and delineate the morphological root at the end of the hypocotyl.

Salt concentration declines between the pedicel and the cotyledons, and then again between cotyledons and hypocotyl and declines still further towards the tip of the hypocotyl. Tissues of the propagules are thus preserved from premature exposure to high salt levels.

*Aegiceras, Avicennia, Nypa* and a number of other mangrove species show a more or less similar form of reproduction, known as cryptovivipary. In cryptovivipary, germination and embryonic development take place on the parent tree, but the developing hypocotyl emerges from the seed coat and but not the fruit, before it detaches from the parent tree.

The final group of mangroves reproduces and disperses by more or less conventional seeds, ranging in size from a few millimeters in length to the massive fruits of *Xylocarpus granatum*. The following table shows viviparous, cryptoviviparous and non-viviparous mangrove species (Table 4).

**Table 4. Viviparous, cryptoviviparous and non-viviparous species**

<table>
<thead>
<tr>
<th>Viviparous species</th>
<th>Cryptoviviparous species</th>
<th>Non-viviparous species</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Rhizophora</em> species</td>
<td><em>Avicennia</em> species</td>
<td><em>Sonneratia</em> species</td>
</tr>
<tr>
<td><em>Kandelia</em> species</td>
<td><em>Aegiceras</em> species</td>
<td><em>Excoecaria</em> species</td>
</tr>
<tr>
<td><em>Bruguiera</em> species</td>
<td><em>Aegialitis</em> species</td>
<td><em>Scyphiphora</em> species</td>
</tr>
<tr>
<td><em>Ceriops</em> species</td>
<td><em>Nypa</em> species</td>
<td><em>Lumnitzera</em> species</td>
</tr>
<tr>
<td><em>Pelliciera</em> species</td>
<td><em>Xylocarpus</em> species and others</td>
<td></td>
</tr>
</tbody>
</table>

**Dispersal**

Mangrove plants usually produce a large number of propagules. It has been estimated that *Avicennia* can produce about 20 lakhs propagules per hectare. It is probable that vivipary and the production of large number of propagules is an adaptation to the local habitat. On leaving the parental tree, a mangrove propagule must be physically able to withstand a certain amount of rattling around in the tide and currents. Size may be an advantage here. A large propagule which sinks after a few days is likely to have travelled only a short distance, which means that it is still within the area in which its parent flourished, which must therefore be reasonably favorable for its own survival. Secondly, the accumulated stores of starch within the hypocotyl mean that rooting, erection of the propagule into
Figure 23. Rooting and erection of seedings of *Rhizophora* sp

Figure 24. Rooting and erection of seedings of *Avicennia*
vertical position and respiration to grow can take place initially without being limited by the rate of photosynthesis. Not all mangrove species show vivipary, and not all have large propagules. Presumably different strategies have been adopted. Perhaps a species with large numbers of small, short-lived propagules exploits gaps (that already exist) in the mangrove forest, while the objective of large and long-lived propagules of Rhizophoraceae is to be around when a new gap appears.

*Rhizophora* propagules generally float for some time before rooting themselves (Fig.23A). Initially floating is horizontal. Over a period of about 30 days they shift to a vertical position (Fig.23B). Roots first appear after 10 days or so, and many of the propagules lose buoyancy and sink. By 40 days, virtually all propagules show root growth (Fig.23C). Most propagules will strand in horizontal position and erect themselves after rooting in the mud. Propagules which do not successfully root after 30 days or so, may regain buoyancy and float off again in a horizontal position. They may remain viable for a year or more. Other mangrove species show more or less similar patterns with a period of flotation, followed by sinking, rooting, stranding and establishment of seedlings. *Avicennia marina* propagule sinks after shedding its pericarp, which may happen within a few days after falling from the trees. In this species initial root growth raises the body of the seedling, thereby minimizing contact with mud (Fig.24).

Salinity also affects dispersal. In several species, floating is prolonged in salt water compared with fresh water. For example, *Avicennia marina* propagules shed their pericarp more readily in brackish water (about 18‰) than in either sea water or fresh water. Immediately after establishment, mangrove seedlings are tolerant of high salinity levels (6 to 18‰). A direct relationship has been established between the size of the propagules and seedling survival.

### 2.5 Biomass

A normal dense mangrove type in Asia constitutes above-ground biomass of about 100 to 200 tons of dry matter per hectare. In an Australian mangrove, above ground and below ground biomass of *Aegiceras corniculatum* is estimated to be 40 and 50 tons per hectare respectively; the above and below ground biomass of *Avicennia marina* is found to be 150 and 80 tons per hectare respectively. In luxuriantly grown mangroves it may reach up to 700 tons per hectare. It clearly indicates that mangrove forests act as an important sink for carbon dioxide. Biomass of the different parts of *Rhizophora apiculata* measured in a plot in Thailand is shown in Table 5.
Table 5. Biomass of different parts of *Rhizophora apiculata*

<table>
<thead>
<tr>
<th>Parts of the tree</th>
<th>Dry matter (tons per ha)</th>
<th>Ash free dry matter (tons per ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>74.4</td>
<td>7.07</td>
</tr>
<tr>
<td>Branches</td>
<td>15.8</td>
<td>1.46</td>
</tr>
<tr>
<td>Prop roots</td>
<td>61.2</td>
<td>5.82</td>
</tr>
<tr>
<td>Leaves</td>
<td>7.4</td>
<td>0.63</td>
</tr>
<tr>
<td>Buds, flowers &amp; fruits</td>
<td>0.3</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>159.0</strong></td>
<td><strong>15.0</strong></td>
</tr>
</tbody>
</table>

2.6. Fauna

Mangrove animal communities can be divided into two categories: a) resident fauna, comprising those species that live entirely within the mangroves and b) non-resident or visiting fauna, consisting of animals that come into mangroves seeking food or shelter but live elsewhere at other times. The list of non-resident mangrove fauna can be very large and diverse. This includes terrestrial animals such as tigers, wild bear, deer, shrews, otters, civet cats, monkeys, eagles, kites, herons, kingfishers, waders, monitors, spiders, insects etc. At high tide animals from the aquatic zone including fish and prawns invade mangroves.

Like plant communities, mangrove animals also show zonation, vertically in the vegetation and horizontally over the shore. Factors such as tree height, salinity, soil type, tidal inundation pattern, topography, plant cover and presence of other animal species determine the distribution of mangrove fauna. However, using tidal height, a generalized pattern can be developed and six different zones characterized by burrowers, bivalves, fiddler crabs, sesarma crabs and littorinid and neritid snails could observed. In addition, to tree and forest floor, there are special habitats within the mangrove swamps, which are inhabited by distinctive animal communities of their own. These special habitats include decaying trees, eroded creeks and gullies. In many of the mangrove forests, sand dunes of small elevation are found inside the mangrove wetlands and various terrestrial animals inhabit these sand dunes. These small sand dunes, which do not get tidal water, can also be consider as a special habitat within the mangroves wetlands.

Tree communities

Animals in the canopy

Insects are abundant in the mangrove canopy. The herbivore insects feed on leaves, flowers, seeds or mangrove propagules. In fact, the process of mangrove leave
detritus formation, the principal source of energy in the mangrove ecosystem, actually begins with the tree canopy. Various insects chew holes in growing mangrove leaves, which exposes the leaves to fungal attack and speeds their death and decay once on the ground. It has been estimated that nearly 10% of the mangrove leaves are consumed by insects. However, not all leaves are equally susceptible to insect attack. For example, leaves of Rhizophora are tough, even leathery and contain tannins; hence, insects do not generally attack these leaves. On the other hand, leaves of Avicennia are softer and more succulent and thus, become easily attacked by insects. It has been observed that younger leaves are probably physically easier to eat than older ones of the same species. Many other factors also determine the magnitude of insect attack. For example, leaves with low carbon and nitrogen ratio (C:N ratio) are richer in nitrogen and of greater value to a herbivore. Insects relish Avicennia leaves since they have relatively low C:N ratio than that of Rhizophora. The species with lowest level of insect attack is Excoecaria. When the leaves of this species are damaged, they produce a toxic latex which strongly irritates even human skin and is sometimes lethal to many animals. Hence, insects avoid grazing on such leaves.

If plants evolve defences against insects, insects in turn can evolve tolerance of defensive chemicals. This is probably why the insect fauna differs between different mangrove species. An estimate indicates that 276 insects are living in the mangrove vegetation of Andaman and Nicobar islands, of which 197 are herbivores, 43 are parasites and 36 are predators.

Ants are also abundant in the mangrove tree canopy, as they are in other tropical forest vegetation. The tailor or weaver ant is famous for stitching folded leaves together using sticky secretions from a larva. It is also famous for its savage bite. Ants are essentially terrestrial animals and therefore, many of them found in mangroves are arboreal and construct their nests above the highest point reached by tides. The mangrove ecosystem is also famous for mosquitoes and other biting insects. To breed mosquitoes require shallow and fairly stagnant pools of water. These occur in abundance in mangroves. Rot holes in trees, tidal pools and the water retained in crab burrows all provide suitable environments for egg laying and larval development. The role of these mosquitoes, acting as vector to many of the human pathogens, has not been established well, except in mangroves which are located very close to large cities and receive contaminants through sewage discharge. Finally, in many mangrove environments, where Sonneratia is present abundantly, the tree will be lit up with the lights of thousands of tiny flashes of light. The firefly Pteroptyx is responsible for this!
**Animals on the trunk**

Snails of various genera such as *Dostia, Littorina, Cassidula, Pythia, Melampus* etc are found on the trunks and lower branches of mangrove trees. These snails move up above the water level during the high tide and down to the moistened parts of the trees after the tide has receded. These snails may retreat to ground level during dry neap tide periods and feed on detritus. Low down on the trunk and many times on the surface of the stilt roots lives a group of encrusting fauna dominated by bivalve molluscs. Chief among them are oysters (*Crassostrea*). There may also be heavy infestations of barnacles. These are filter feeding animals that can only feed when they are covered by tidal waters. This explains why they are restricted to the lower trunk and roots.

**Ground dwellers**

Molluscs along with crabs dominate the mangrove soil surface. As mentioned earlier, many of the snails can move freely between the trees and the ground. Many other animals also show the same flexibility. The mudskippers, *Periophthalmus* and *Boleophthalmus*, hop over the mangrove floor in search of prey, but if necessary will jump onto mangrove branches and roots in chase of insects or to escape predators. Sesarmid crabs will also do this, but only as an escape response.

In terms of numbers and ecological importance, it is the faunal community living in the mangrove soil that is most significant. Crabs and mudskippers dominate the soil towards water. The crabs are zoned across the shore in distinct species groups according to their ability to tolerate high temperature and desiccation. Lowest on the shore, well below the mangrove tree zone, occur *Macrophthalmus*. Higher up, but still in front of the mangrove trees are found fiddler crabs. From about mid-tide level and upwards through the main mangrove forest zone fiddler crabs dominate, with one species replacing another at each tidal level. However, the population of fiddler crabs is high only in the areas which have soft mud and are continuously bathed by tidal water. If the soil of the forest floor is firm due to continuous exposure to the sun, fiddler crab population reduces and sometimes these crabs cannot be seen. The landward mangrove forest zone is the domain of the sesarmid crab and the very landward edge and into the terrestrial zone there may be land crabs such as *Cardisoma*.

As indicated earlier, many of the crabs show a tendency to live in brackish water, or even completely fresh water, some are amphibious, capable of living both in brackish and fresh water, and a few are virtually terrestrial. Because of this, crab
diversity and population are high in the mangrove environment, where they forage at low tide on the exposed mud or on mangrove roots and trunks. At high tide, they avoid predators such as fish by retreating into burrows in the mud. Some are active by day, others by night.

Most of the mangrove crabs are detritivores. They scoop up a claw full of mangrove soil and with their mouth select out particulate organic materials such as decaying mangrove leaves and other plant parts. Some of the sesarmid crabs may drag entire decaying leaves into their burrow, tear and devour portions of leaves. The leaves are then broken into smaller pieces with the mandibles and passed into the stomach. A crab’s stomach contains an array of ridges and hooked teeth, which act against each other and grind the leaves into smaller particles, which are then passed back down the gut for digestion and absorption. In this way, crabs further the process of leaf detritus formation begun by insects. Many of the crabs such as fiddler crabs, spend several hours per day turning over and sifting the mangrove soil surface for organic materials. By simply handling the soils, crabs expose the soil to air, thus aerating the soil and helping in oxygen diffusion and also exposing the organic matter more freely to attack by microorganisms. Because of this, crabs are called “engineers of the mangrove environment”.

Soil in-fauna

The permanent soil macro fauna or in-fauna is very important to the functioning of the mangrove ecosystem. Polycheate worms, peanut worms and bivalves such as blood cockle and clams dominate the soil in-fauna. *Nereis, Lumbriconereis, Leiochrides* and *Glycera* are common mangrove polycheates. These animals play an intermediate role in the process of detritus formation.

Meio-fauna

The semi-microscopic fauna living in the mangrove soil constitute meio-fauna. The main constituents of meio-fauna are nematode worms and harpacticoid copepods, although many other animals are also present. There can be 100 meiofauna per sq.cm in mangrove mud. The meiofauna, together with soil fungi and bacteria, are important for two main reasons. Firstly, they are key agents in breaking down mangrove organic materials into detritus and secondly, they are food for the larger mangrove animals. Mention must be made of a unique fauna of the mangrove wetlands, the mangrove frog, *Rana cancrivora*, which lives in disused crab burrows. It is the only frog known to tolerate and even breed in brackish water environment.
Fauna of mangrove gullies and dead wood

Low-lying mangrove gullies are a special biotope, characterized by continuously wet conditions: the mud in these areas is usually semi-fluid. Here two snails, namely, *Telecopium telescopium* and the tiny red snail, *Assiminea* are found in large numbers. Dead mangrove wood is an even more specialized habitat. A dead tree trunk will be riddled with the burrows of Teredo, a wood-boring bivalve called the shipworm. As the dead wood becomes eaten away, it becomes a moist and secluded environment for delicate animals like nemertine worms and sea anemones. Other typically marine animals, such as isopods and amphipods may also invade it, and even insect larvae. Crabs too find the inside of a dead mangrove tree a perfect hideaway. Within a few months, a freshly fallen tree can be almost completely eroded by these animals.

Aquatic fauna

At high tides, the mangrove environment is transformed in terms of faunal activity. Crabs and other animals active on the mangrove floor at low tide conceal themselves in their burrows or move up on the trunk of the trees. The incoming water brings a temporary population of fish, prawn and crabs, mainly mud crab *Scylla serrata* and *Scylla oceanica*. Some species of fish such as mullets are known to feed directly on mangrove detritus. Many other species feed on other small animals like *Acetes*, a small shrimp, which occurs in large numbers in the mangroves. Many other fish consume isopods, nematodes, insects etc living in the mangrove environment. Larger fishes such as seabass and catfish feed on various mangrove fauna, particularly mangrove snails and crabs. Other commercially important species with a strong affinity for mangroves include snappers, groupers and anchovies. Prawns of the family penaeids enter mangroves in large numbers as postlarvae or juveniles. Their diet includes zooplankton, algae and mangrove detritus. But equally important is the protection that these animals get from the root system of the mangroves. Prawns may stay in the mangroves for several months and when they mature, they have a strong urge to return to the sea for spawning. Thus, a population of typical prawn species such as *Penaeus indicus, P.monodon* etc., shows a distinctive division of subpopulations: the juveniles occur entirely in the mangrove waters and the sub adult population lives in the coastal waters, while the adult population lives offshore. An estimate indicates that about 166000000000 juveniles of *Penaeus indicus* passed through the Straits of Singapore in one month to nearby mangroves. It has been proved by many studies that a clear relationship exists between the abundance of prawn and the area of mangroves. For example, in Indonesia it was found that the commercial landings
of prawns were significantly correlated to the amount of mangrove adjacent to
the prawn fishing grounds.

It has been estimated that for every hectare of mangroves grown, fish catch would increase
by about 1.08 tons per hectare per year, provided other conditions such as free exchange
of water between mangrove environment and adjacent sea is maintained properly and no
pollutants are discharged into the mangrove

Wildlife

Mammals

Many mammals frequent mangroves but only a few live there permanently
and fewer are restricted to them. In many countries, mangroves represent
the last refuge for a number of rare and endangered mammals. In the Sunderban
mangroves groups of rhesus macaque (Macaca mullata) are very common,
particularly in the Sonneratia apetala patches. They are also common in
Bhitarkanika mangroves of Orissa. In the Malaysian mangroves, monkeys are
commonly seen foraging for shell-fish and crabs during the low tide. The Malaysian
proboscis monkey (Nasalis larvatus) is endemic to the mangroves of Borneo, where
it feeds on the foliage of Sonneratia caseolaris and Nipa fruticans as well as
Rhizophora propagules. The Sunderban mangroves is the habitat for the
Bengal Tiger (Panthera tigris tigris) and contains about 300 to 500 tigers, which
is the largest single surviving population of tigers. Heriteira and Phoenix formations,
which are rarely inundated or inundated only for a short period, form ideal tiger
habitat. Another notable feature of the tiger habitat is that there is a complete
absence of ground flora. During extreme high tides, when the Phoenix areas are
inundated with water, the tigers are compelled to lead an amphibious life.
The tigers have adapted to drinking saline water even though they prefer fresh
water. Other mammals such as the spotted deer (Axis axis) and wild boar
(Sus acrofa) are common in the Sunderbans. The leopard (Panthera pardus)
is also found in the Sunderbans. Mousedeer and small carnivores like
fishing cat, civets and mongooses and otters are also common in many of the
mangroves of South and Southeast Asia. Many mangroves are also habitat for
a variety of bats. The Indian flying fox, short-nosed fruit bat, the greater
false vampire, the Indian pigmy pipistrelle, the lesser yellow bat etc are found in
the Sunderbans.

Reptiles

The salt water crocodile or estuarine crocodile, Crocodilus porosus is found in large
numbers in the mangroves of Sunderbans and Bhitarkanika. Two species of
crocodiles namely, *Corcodilus acutus* and *Caimen crocodiles* are found in the mangroves of Coasta Rica, where they are listed as endangered species. The American alligator *Alligator mississippiensis*, found in the Florida mangroves has also been listed as endangered. Efforts are being made in India, Bangladesh, Papua New Guinea and Australia to conserve the estuarine crocodile through breeding programmes.

Another reptile commonly found in large mangroves is monitors. The Bengal monitor (*Varanus bengalensis*), Water monitor (*Varanus salvator*) and Yellow monitor are found in the mangroves of Sunderbans and Bhitarkanika of Orissa. The large lizards, *Iguana iguana* and *Cetenosaura similis* are commonly found in the mangroves of Latin America.

Marine Turtles are known to lay their eggs on the sandy beaches found in many mangrove areas throughout the world. The Gahimatha beach, located close to Bhitarkanika mangroves is famous for mass nesting or *aaribada* (a Spanish term for mass arrival) of Olive Ridley turtles. A minimum of 50000 to a maximum of 740000 female visits this beach for nesting every year.

**Avifauna**

The mangrove swamps are ideal sanctuary for avifauna, many of which are migratory. In the Muthupet mangroves of Tamil Nadu, nearly 100 migratory bird species have been recorded including, the pelican, flamingo, cormorant, teals etc. In a Colombian mangrove 77 bird species have been recorded, of which 43% are permanent residents, 22% are regular visitors and 18% are temporary winter residents. A number of threatened species such as spoonbills, large snowy egrets, scarlet ibis, fish hawks are found in the mangrove environment. Birds like the heron, egrets and kingfishers catch fish in the shallow waters of the mangrove creeks and also prey on mudskippers. Waders probe for buried invertebrates on the mud surface, either among mangrove trees or on adjacent mudflats. Larger fish eaters such as pelicans, storks and cormorants may feed within the mangroves or move to far away places and return to mangroves to roost or breed. During feeding, roosting and breeding the birds deposit large amounts of fecal matter or guano, which enrich the mangrove environment with nitrate and phosphate.
Further readings


## Appendix 1:
Flora found exclusively in the mangrove environment
(true mangrove species)

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