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Mangroves: Biodiversity, Livelihoods and Conservation

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Part I
General Aspects

Chapter 1
Mangroves: A Unique Ecosystem and Its Significance

Sudhir Chandra Das, Pullaiah Thammineni, and Elizabeth C. Ashton

Abstract Mangroves constitute a unique forest ecosystem at the land–sea interface of the estuarine region in tropical and subtropical countries. The tidal environment and waterlogged soil with often dense anaerobic mud mean that the trees have adapted to survive with a range of aerial roots. The structural complexities of the mangrove vegetation create a unique environment which provides ecological niches for a wide variety of organisms both marine and terrestrial. The productive and biologically rich ecosystem provides many goods and services which are highly valuable and contribute significantly to the livelihoods, well-being and security of coastal communities both locally and globally. Mangrove exploitation, loss and degradation make mangroves a threatened ecosystem but increasing recognition of the importance of mangrove ecosystems for both biodiversity and human well-being is driving efforts around the world to conserve, better manage and restore these ecosystems.

Keywords Adaptations · Goods · Services · Value · Importance

1.1 Introduction

Why mangroves? A question often been asked. However, the once thought of muddy smelly dangerous mosquito-ridden place is now being appreciated for its beautiful diverse habitat and unique species, its many important ecosystem services supporting local communities and also having a global level of importance in combatting climate change. We have all worked in these ecosystems and have diverse experiences that we wanted to bring together in one book with other experts

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from around the world to learn and appreciate the mangroves of the world, their biodiversity, livelihoods and conservation strategies.

In this chapter, we introduce mangroves, their ecosystem and local and global significance briefly. Further chapters will go into more detail about the mangrove plant species and their silviculture (Chap. 2), reproductive ecology (Chap. 3), ethnobotany (Chap. 5), ecosystem services (Chap. 6) and how they support livelihoods (Chap. 7). Advances in remote sensing (Chap. 4) give an idea of losses and gains in mangrove area over time and the effects of climate change (Chap. 8) predict possible future scenarios. Threats to mangroves and conservation strategies (Chap. 10) and rehabilitation and restoration of mangroves (Chap. 9) are some of the general topics covered in this book. Part II gives the country case studies from around the world. We start from India (Chaps. 11 and 12 for Sundarbans) and travel around Asia to Sri Lanka (Chap. 13), Myanmar (Chap. 14), Malaysia (Chap. 15), Indonesia (Chap. 16), Philippines (Chap. 17), Japan (Chap. 18) to South America Ecuador (Chap. 19), Brazil (Chap. 20) and Africa Cameroon (Chap. 21).

1.2 Mangrove Definition

Several mangrove experts have recognised and defined the term "Mangrove" differently:

Davis Jr (1940) defined mangroves as "Plants which live in muddy, loose, wet-soils in tropical tidewater." MacNae (1968) defined mangroves as "Trees or bushes growing between the levels of high water of spring tide and level close to, but above the mean sea level." He also used the term "Mangal" for referring to the mangrove forest community, while the term "Mangrove" refers to the individual kind of trees. Aubreville (1970) defined mangroves as "the coastal tropical formations, found along the border of the sea and lagoons, reaching up to the edges of the river to the point where the water is saline, growing in swampy soil and covered by sea water during high tides." Geriech (1973) defined mangroves as "trees of various species of several families which grow only where they come into permanent contact with sea water or brackish water." Blasco (1975) said "The Mangrove is a type of coastal woody vegetation that fringes muddy saline shores and estuaries in tropical and sub-tropical regions." Arroyo (1977) defined the mangroves as "A small group of tree mangrove plants and associated species belonging to systematically unrelated families, possessing similar physiological characteristics and structural adaptations with common preference to the intertidal habitat." Clough (1982) defined mangroves as "Mangroves are the only trees amongst relatively small group of higher plants those have been remarkably successful in colonising the intertidal zone at the interphase between land and sea." Naskar and Guha Bakshi (1987) defined mangroves as "Coastal tropical forest formations encircled or spread by the tidal rivers and/sea water, flooded frequently by the tidal water."

Mangroves are assemblages of salt-tolerant trees and shrubs that grow in the intertidal regions of tropical and subtropical coastlines. They grow luxuriantly in the intertidal silted up deltaic regions, estuarine mouth sheltered shallow coasts, edges of the island and saline mud flats where freshwater mixes with seawater and where sediment is composed of accumulated deposits of mud.

1.3 Global Distribution of Mangroves

Mangroves are distributed around the equator in tropical and subtropical regions largely between 5°N and 5°S (Giri et al. 2011), although there are some exceptions in Bermuda (32°N), Japan (31°N), South Africa (32°S), Australia and New Zealand (38°S) (Fig. 1.1). Mangroves are mostly distributed over 124 countries and territories in the tropical and subtropical regions (Fig. 1.1). Asia has the largest extent of the world's mangroves. About 40% of the world's mangrove cover is found in Southeast Asia and South Asia followed by South America, North Central America and West and Central Africa. India has about 3% of the total mangrove cover in the world comprising 4975 km^2 (FSI 2019).

The actual coverage of world mangroves is debated with different mangrove experts projecting different mangrove forest areas. Global coverage has been variously estimated at ten million ha (Bunt et al. 1982), 14–15 million hectares (FAO 2007; Finlayson and Moser 1971; Schwamborn and Saint-Paul 1996) and 24 million ha (Twilley et al. 1992). Spalding et al. (2010) pegged mangrove area at 152,361 km^2, slightly less than the FAO estimate. Based on the first full assessment of all mangrove forests of the world, Giri et al. (2011) estimated that the total mangrove forest area of the world in 2000 (corrections added by them in September 2010 after first online publication) was 137,760 km^2 in 118 countries and territories, whereas Hamilton and Casey (2016) using a higher spatial scale gave a total of 83,495 km^2 in 105 countries.

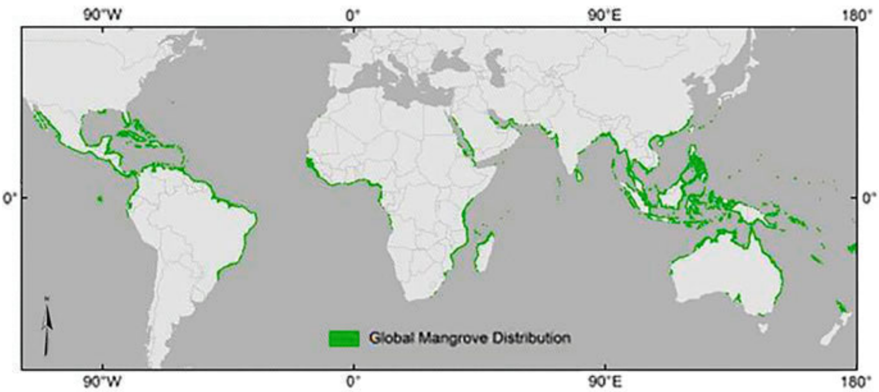

Fig. 1.1 Global Distribution of Mangrove. (Source: Cárdenas et al. 2017)

Table 1.1 Worldwide Area of Mangroves by Region (Source: Spalding et al. 2010)

Region	Area (km^2)	Percentage of total
North and Central America	22,402	14.7
South America	23,882	15.7
East and South Africa	7917	5.2
Central and West Africa	20,040	13.2
Middle East	624	0.4
East Asia	215	0.1
Southeast Asia	51,049	33.5
South Asia	10,344	6.8
Australasia	10,171	6.7
Pacific Ocean	5717	3.7
Total	**152,361**	**100**

However, there is consensus that the most extensive and highly developed mangrove forests and where the flora is rich both in quantity and in quality are found in the Indo-Malayan region and particularly in the islands of Kalimantan where the configuration of the country favours the formation of mangrove swamps over large areas in the coastal region. Indonesia contains the largest area of mangrove forest in the world. More than three million hectares of mangrove forests grow along Indonesia's 95,000 km coastline, 20% of all mangrove ecosystems in the world (Giri et al. 2011). The largest extent of mangroves occurred in Asia (42%) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%) with approximately 75% of mangroves concentrated in 15 countries (Giri et al. 2011), with 50% in Indonesia, Brazil, Malaysia and Papua New Guinea (Hamilton and Casey 2016) (Tables 1.1 and 1.2).

1.4 Mangroves: A Unique Ecosystem

Mangrove is a unique ecosystem. It is formed in the inter-tidal areas at the confluence of rivers and seas. The tidal environment and waterlogged soil with often dense anaerobic mud mean the trees have adapted to survive and the most striking is the development of superficial rooting systems (Fig. 1.2). The rooting system aids in anchoring and aiding in respiration in the largely anoxic surroundings. The laterally spreading subsurface cable and anchor roots give mechanical support to the tree, while the nutritive fine roots serve for nutrition and for the assimilation of oxygen from the uppermost silt layer. The rooting adaptations of mangroves include surface roots, stilt roots, various types of pneumatophores and various types of aerial roots. Mangrove species usually possess numerous lenticels covering the stem and the roots, aiding in respiration. When the lenticels are covered by the tide, root pressure begins to drop. When the tide goes down, air is again sucked into the aerenchyma. The thick and succulent leaves also enable the plant to withstand water stress, and

Table 1.2 Recent Area of Mangroves in the 15 Most Mangrove-Rich Countries

Region	Country	Area (km^2) Giri et al. (2011)	Area (km^2) Spalding et al. (2010)	(%)
Palaeotropics	Indonesia	31,139	31,894	20.9
	Australia	9780	9910	6.5
	Malaysia	5054	7097	4.7
	Myanmar	4946	5029	3.3
	Papua New Guinea	4801	4265	2.6
	Bangladesh	4366	4951	3.2
	India	3683	4326	2.8
	Madagascar	2781	–	–
	Philippines	2631	–	–
	Nigeria	6537	7356	4.8
	Guinea Bissau	3387	–	–
	Mozambique	3189	–	–
Neotropics	Brazil	9627	13,000	8.5
	Mexico	7419	7701	5.0
	Cuba	4215	4944	3.3
	Columbia	–	4079	2.7

Source: Giri et al. (2011) and Spalding et al. (2010). Percent of total area is derived from Spalding et al. (2010)

through the transpiration process, excess salt is released as epidermal secretions which in turn are washed out by rain or evaporated into the humid atmosphere.

The structural complexities of the mangrove vegetation create a unique environment which provides ecological niches for a wide variety of organisms both marine and terrestrial. Mangroves form the foundation of a highly productive and biologically rich ecosystem which provides a home and feeding ground for a wide range of species, many of which are endangered (Duke et al. 2014) species such as the Royal Bengal Tiger (*Panthera tigris*), Saltwater Crocodile (*Crocodylus porosus*), Fishing Cat (*Prionailurus viverrinus*), Gangetic Dolphin (*Platanista gangetica*), Irrawaddy Dolphin (*Orcaella brevirostris),* Goliath Heron (*Ardea goliath*) and Water monitor lizard (*Varanus salvator*). The mangroves also serve as nurseries to shellfish and finfishes that sustain coastal commercial fisheries and local communities.

1.5 Significance of Mangroves

Mangroves only make up less than 1% of all tropical forests worldwide, but they are highly valuable ecosystems, providing an array of essential goods and services which contribute significantly to the livelihoods, well-being and security of coastal communities. The complex network of mangrove roots can help reduce wave energy, limiting erosion and shielding coastal communities from the destructive

Fig. 1.2 *Rhizophora mucronata* with its unique stilt roots in tidal ecosystem

forces of tropical storms. Mangrove ecosystems are often an essential source of seafood for both subsistence consumption and the local and national seafood trade, in addition to providing other materials such as firewood and timber, which support the livelihoods of thousands of coastal communities. Beyond their direct benefits, mangroves also play an important role in global climate regulation. On average, they store around 1000 tonnes of carbon per hectare in their biomass and underlying soil, making them some of the most carbon-rich ecosystems on the planet.

Despite its value, the mangrove ecosystem is one of the most threatened on the planet. Mangroves are being destroyed at rates 3–5 times greater than average rates of forest loss, and over a quarter of the original mangrove cover has already disappeared, driven by land conversion for aquaculture and agriculture, coastal development, pollution and overexploitation of mangrove resources (Duke et al. 2014). As mangroves become smaller and more fragmented, important ecosystem goods and services will be diminished or lost. The consequences of further mangrove degradation will be particularly severe for the well-being of coastal communities in developing countries, especially where people rely heavily on mangrove goods and services for their daily subsistence and livelihoods.

However, the future of mangroves does not have to be bleak. Increasing recognition of the importance of mangrove ecosystems for both biodiversity and human well-being is driving efforts around the world to conserve, better manage and restore these ecosystems. Many of these have been successful at a local scale, often supported by national policies that recognise the significant long-term benefits of mangroves over short-term financial gains. Mangroves need to be understood for the valuable socio-economic and ecological resource they are, and conserved and managed sustainably. This will take a commitment by governments to make policy decisions and enforce existing protection measures to curb the widespread losses from human activities. This global synthesis document serves as a call to action to decision-makers and highlights the unique range of values of mangroves to people around the world. It aims to provide a science-based synthesis of the different types of goods and services provided by mangroves and the associated risks in losing these services in the face of ongoing global habitat loss and degradation. The document provides management and policy options at the local, regional and global level with the aim of preventing further losses through effective conservation measures, sustainable management and successful restoration of previously damaged mangrove areas. Our hope is that this call to action will generate renewed interest in mangroves for policymakers, helping to safeguard the future for these essential yet undervalued ecosystems (Table 1.3).

Table 1.3 Summary of significance of Mangroves

Local level	Global level
It is the interface between terrestrial forests and aquatic marine ecosystems, an important ecosystem supporting local biodiversity and livelihoods	Unique ecosystem of estuarine forests, wetland and waterbodies providing habitat for wide biodiversity of flora and fauna some globally endangered and threatened
Mangroves provide fuelwood and firewood, charcoal, and medicinal and other uses for local communities	Important socio-economic and cultural goods and services provided by mangroves
Mangroves serve as nurseries to shellfish and finfishes and sustain the coastal fisheries and coastal livelihoods	Mangroves serve as breeding, feeding and nursery grounds for most of the commercial fishes and crustaceans on which thousands of people depend for their livelihood
Mangrove forests act as natural "bio-shield;" the presence of dense mangrove forests reduces the speed of cyclonic storms coming from seas and thereby protects villages from extreme damage, tidal surges and seawater intrusion	Mangroves act as shock absorbers. They provide protection to the coastline and minimise disasters due to cyclones and tsunamis
Roots bind silts and soils, hence reducing soil erosion and loss of important local land	Roots reduce high tides and waves and help prevent soil erosion by trapping debris and silt and stabilise the near-shore environment. This will become more important with global climate change and increasing sea-level rises

(continued)

Table 1.3 (continued)

Local level	Global level
Maintains "Bio-geo-chemical" cycles, thereby increasing planktonic population (phytoplanktons and zooplanktons)	Mangroves perform important ecological functions like nutrient cycling
Certain mangrove species act as bio-filters as they have been found to bio-accumulate heavy metals and help with pollution in coastal waters	Mangroves perform important hydrological functions and services. They filter groundwater and storm water run-off which often contains harmful pesticides. They recharge the groundwater by collecting rainwater and slowly releasing it to the underground reservoir
	Mangroves are an important global carbon sink by absorbing CO_2 (carbon sequestration @0.06 to 0.12 g carbon/m^2/day); they can help with climate change

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Chapter 2
Mangrove Forests and Silviculture

Sudhir Chandra Das

Abstract Mangroves are threatened coastal, intertidal, halophytic plants that play very important roles in the sea–land interface areas and deltaic ecosystems of both tropical and subtropical zones. Mangroves are especially significant in the highly populated Southeast Asian countries, several Pacific Islands, and Australian coasts constituting Old-World Tropics. They are also found in South America, Mexico, and West African Coasts constituting New World Tropics. All the genera of mangroves have closely related characteristics but belong to distantly related families. Most of the species possess remarkable and highly specialized adaptations like stilt roots, knee roots, ribbon roots, pneumatophores, vivipary, and xerophyllous foliage. The silviculture of a few important species is mentioned, which can aid identification and future mangrove restoration projects.

Keywords Mangroves · Halophytic · Pneumatophores · Stilt roots · Vivipary · Estuary

2.1 Introduction

The term "Mangrove" applies to a specially adapted vegetation of the littoral region of the world, which is confined mainly to the tropics and in favorable localities extends into the subtropical zone. Mangrove forests cover extensive tracts of swampy land along the tropical seas, always fringing muddy saltwater creeks, lagoons, and estuary of rivers and on low islands. They form a characteristic dense, evergreen, and impenetrable mass of trees with numerous arched branching roots. The mangrove belt occupies a strip of low-lying muddy ground, subject to periodical inundation by tides. These forests develop on fresh alluvial deposits between the high and low tide limits and stop sharply beyond the influence of saltwater. The mangrove vegetation is of a transitory nature and represents only a seral type, condition of growth change with the progress of siltation and elevation of

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the land from sea level. The species occurring in mangroves exhibit certain pronounced characteristics for their peculiar manner of growth and seeding and possess remarkable specialized adaptations, such as aerial roots and vivipary, which enable them to exist in such habitats.

Mangrove forests are mostly tropical, with some excursions into subtropical regions such as Florida, South Africa, Victoria Australia, and southern Japan where warm tropical currents transport propagules (Tomlinson 1986). Mangroves occur worldwide in the tropics and subtropics, mainly between latitudes 25°N and 25°S. There are two broad major mangrove regions of the world distinguishable: the Old-World Tropics, Eastern or the Indo-Pacific type consisting of eastern coast of Africa, Asia, Australia, and the islands of Indian and Pacific Oceans, and the New World Tropics, Western or Atlantic type comprising of the coasts of North and South America, Western Africa, West Indies, and other Atlantic Islands.

The species occurring in the respective areas are distinct, but the eastern area is far richer in species than the western. The Indo-West Pacific Tropical Zones and Tropical Australia have the most dominant mangroves and are important in respect of species diversity, richness of the mangroves, abundance, and unique succession features of the mangroves. The flora of the mangrove forests of the eastern type (Indo-West Pacific region) consists of about 63 species with Rhizophoraceae predominating, whereas the western type (Atlantic coasts of Americas and Africa) consists of 16 species only (Chapman 1970).

All the genera of Mangroves have closely related characteristics but belong to distantly related families. Rhizophoraceae are most typical. Shrubs are few, *Acanthus* being the commonest, while the fern *Acrostichum aureum* is very typical. Palms are similarly limited to a few species notably *Phoenix paludosa* and *Nypa fruticans*. Grasses are commonly absent, but *Oryza coarctata* is an early colonizer. The silvicultural characters of all mangrove forests are remarkably identical.

2.2 Site Factors for Mangroves

The mangrove forests develop along the sea coast on fresh alluvial deposits between low and high tide limits. As a rule, the soil is clayey of considerable depth occasionally with a small admixture of sand blown by wind or deposited by water. In consistency, it varies from a semi-fluid mud to heavy stiff clay depending upon the frequency and duration of inundation. Waterlogging with saline water is a common feature, and aeration is poor. The saline nature of the soil moisture renders the sites physiologically dry.

The natural habitat of the trees is characterized by a tropical coastal climate, moist, warm, and equable with no perceptible division into pronounced seasons. Due to proximity to sea, humidity is uniformly high (75–80%) throughout the year. The temperature varies little throughout the year; mean annual temperature is very close to 27 °C with maximum of 30 °C and minimum of 22 °C. The habitat is generally sheltered against the strong wind and sea waves.

There are some extreme distributions such as *Avicennia* occurring at 38°45′S in Australia, and this may be due to local anomalies of current and temperature (Hogarth 1999).

2.3 Species Distribution

The divergence of mangrove plant species between old and new world mangroves has been explained by geological events (Duke 1995; Spalding et al. 2010). Species richness of different mangrove regions is depicted in Table 2.1.

2.4 Classification of Mangroves

Mangroves and mangrove associates have been variously categorized by different authors. Tomlinson (1986) has categorized them into (1) major elements of mangroves, (2) minor elements of mangroves, and (3) back mangroves or mangrove associates. Mepham and Mepham (1984) pointed out that there may be some physiological races existing in these mangrove species as they have different abilities to tolerate salt upon different populations. They have suggested that based on the salinity in their habitats, mangrove should be termed as freshwater mangroves and saline water mangroves.

Blasco (1975) identified the following 5 species compositions in his classification: (1) back mangroves (euryhaline zone) found on the river bank; (2) dense mangrove consisting of many species of plants; (3) tall, dense trees of *Heritiera fomes* with primary associate *Excoecaria agallocha*; (4) brackish water of mixed *Heritiera fomes* forests with *Rhizophora* species over a very limited area; and (5) palm swamps consisting of pure *Phoenix paludosa*. Naskar and Guha Bakshi

Table 2.1 Distribution of some principal mangrove species by region

Family	Species	America and W Africa	E Africa to Asia/Australia
Avicenniaceae	*Avicennia*	3 species	5 species
Combretaceae	*Laguncularia*	1 species	0
	Lumnitzera	0	2 species
Rhizophoraceae	*Bruguiera*	0	6 species
	Ceriops	0	2 species
	Kandelia	0	1 species
	Rhizophora	3 species	6 species
Sonneratiaceae	*Sonneratia*	0	5 species
Palmae	*Nypa*	0	1 species
Plumbaginaceae	*Aegialitis*	0	2 species
Myrsinaceae	*Aegiceras*	0	2 species

(1982) grouped mangrove forest into five major zones as follows: (1) sea face of beach forest; (2) formative island flora; (3) flora of reclaimed land and low-lying area; (4) flora of river banks; and (5) swamp forest.

The total plant species are grouped into 59 families, 101 genera, and 140 species. These comprise true mangroves or major elements, minor elements of mangroves or/and mangrove associates, back mangrove trees and shrubs, non-halophytic non-mangrove associates in the area, halophytic herbs, shrubs, and weeds and epiphytic and parasitic plants.

2.5 Characteristic Features of Mangrove Flora

Mangrove plants are salt-loving or halophytic plants, which show numerous modifications and adaptations in order to survive in the anoxic, waterlogged saline soils:

- Extensive lateral root systems for a proper anchorage against diurnal tidal inundation/scouring, e.g., *Excoecaria* sp.
- Supporting roots like stilt roots or prop roots. Root buttresses are formed in species like *Rhizophora* and *Xylocarpus.* Vertical knee roots from horizontal lateral roots are given out by species like *Lumnitzera, Bruguiera gymnorrhiza*, and *Kandelia candel.*
- To facilitate gaseous exchange as the lateral roots get submerged due to tidal movement, breathing roots or "pneumataphores" have been developed. These roots grow above the earth surface and contain pores called lenticels through which gaseous exchange occurs. In addition to pneumatophores, even the stilt roots contain lenticels as seen in the case of *Rhizophora mucronata*.
- To counter the excess saline conditions outside the plant cells, very high osmotic pressure is exerted in order to draw water from outside salt solution. It has been seen that the cell sap is rich in organic electrolytes in case of *Rhizophora* sp. and inorganic electrolytes in case of *Suaeda* sp.
- The leaves are normally thick and often contain salt excretory channels to deposit crystals and waxes of various compositions on leaves. Salt hairs on leaves of *Porteresia coarctata* burst to excrete salt. *Avicennia alba*, *Acanthus ilicifolius*, *Aegialitis rotundifolia*, and *Aegiceras corniculatum* also show salt excretory mechanisms.
- Mangrove leaves have sunken stomata to prevent water loss.
- The fruits of *Rhizophora, Bruguiera,* etc., germinate right on the tree and fall like a dart on the mudflats to get anchored against tidal inundation. This phenomenon is called as "Vivipary" and is an adaptation unique to mangrove plants.

Mangroves have also started manifesting quaint adaptations (being out of normal domain), as is the case of *Avicennia* species, which never throw stilt roots and are an outer estuarine species, but, when found in the mid-estuarine creeks at the foreshore, give rise to stilt pneumatophores in order to combat the higher velocity and undermining effect of water. Both stilt roots and normal pneumatophores of

Avicennia are histologically alike and contain chlorophyll unlike other stilt-rooted mangroves. Some species like *Excoecaria agallocha* (an inner estuarine species), which normally does not have pneumatophores or stilt roots, give rise to perforated "Burr" formations on the lower stem in order to ensure gaseous exchanges at places where tidal amplitude is more severe, i.e., the mid-estuarine environment. Thus, the mangroves exhibit a unique pattern of species movement. The species of the tidal forests are endowed by nature with a number of highly specialized adaptations**,** to withstand the very exacting combination of site factors they have to contend with.

2.5.1 Root Systems

The root system of the mangroves is highly specialized due to defective soil aeration they have developed devices to combat this. In the case of *Rhizophora*, the lower part of the stem dies early and the stem is supported by numerous stilt roots that rise above the mud, while aerial roots are sent down from the roots and branches and anchor themselves firmly in the soft tidal mud. This ensures stability and protection against the considerable force of sea waves and wind. These stilt roots are covered by water at high tide and exposed at low tide and prevent soil erosion by trapping sediments in the roots. *Rhizophora* is usually characteristic of the outer edge of the mangrove swamp, and the mass of stilt roots (Fig. 2.1) is a conspicuous site on approaching the shore. These peculiar stilt roots are not conspicuously developed in other species of mangroves. In other species, the roots are superficial, twisted above on the surface of the mud as in case of *Xylocarpus granatum* and sometimes bending out of the mud in the form of knees (knee roots) as in *Heritiera*, *Bruguiera*, *Kandelia*, and *Lumnitzera*. Some species produce lateral branches, known as pneumatophores, which arise from the superficial horizontal roots and emerge above the mud here and there resembling inverted tent pegs as in *Sonneratia*, *Xylocarpus*, *Avicennia,* and *Ceriops*. The ribbon roots, knee roots, and vertical pneumatophores are all adaptations for supplying the roots with oxygen and are covered with lenticels for breathing purposes (Fig. 2.1).

2.5.2 Leaf Structure

The habitat of the mangroves, namely swampy grounds impregnated with salts, is a physiologically dry one and the leaves of the trees possess a marked xerophilous structure, which helps them against the conditions of physiological droughts created by saline soil and the factors favoring rapid transpiration. The leaf structure is marked by a thick cuticle, large mucilage cells, sunken stomata, and a large-celled, thin-walled aqueous tissue, the dimension of which increases with the age of the leaves and with corresponding rise in salt content. Old leaves serve essentially as

Fig. 2.1 Different root system of Mangroves (Top left—Pneumatophores of *Xylocarpus*, Top right—Pencil roots of *Avicennia*, Bottom left—Stilt roots of *Rhizophora*, Bottom right—Knee-roots of *Bruguiera*)

water reservoirs for the young leaves. They are also characterized by high osmotic value relations.

2.5.3 Germination

Nearly all the mangrove species exhibit the most interesting characteristics of vivipary or semi-vivipary (Joshi 1984). The germination of the seeds and partial development of the embryo take place, while the fruit is still upon the tree and thus makes considerable growth before the fruits fall vertically so that on falling the radicle gets embedded into the mud. Vivipary is more pronouncedly exhibited in Rhizophoraceae and some other genera belonging to Myrsinaceae and Verbenaceae. The fruit is indehiscent, and there is no resting stage for the embryo as is the case of normal seeds. As soon as the fruit is fully developed, the embryo commences to grow inside it; the radicle soon pierces its apex and the hypocotyl elongates and protrudes hanging vertically from the fruit. After it has reached a length varying from a few centimeters to 45–60 cm or more as in the case of *Rhizophora mucronata*, the embryo plant falls leaving the cotyledons inside the fruit that remains on the tree.

The lower part of the hypocotyl is thicker than the upper part, and in some cases, the lower extremity (radicle) comes to a sharp point; when the embryo falls into the mud, it therefore becomes firmly planted in a more or less vertical position. Within a short time of falling, the young seedling produces rootlets from its lower extremity, thus further establishing itself. The embryos are buoyant, and if they do not obtain an immediate footing under the parent tree or they are uprooted, they are carried away by water and find a resting place in the mud, eventually establishing themselves in an upright position through the positive geotropism of the lower extremity and the negative geotropic nature in the upper extremity (shoot).

In silviculture term, sowing or dibbling of mangrove seeds is strictly speaking incorrectly; it is the embryo or young seedlings, which are planted in the ground. Rapid rooting and growth of pre-seedling in the early stages are common to all tidal viviparous and non-viviparous species. The mangrove species generally have a strong gregarious habit and tend to occur in more or less pure patches. They are a strong light demander, although they are shade-tolerant in the early stages.

2.6 Silviculture of Some Important Mangroves

Silviculture is the practice of controlling the regeneration, growth, composition, and quality of forests to meet values and needs. Forest management involves the integration of silvicultural practices with the concepts of social and political aspects of sustainable forestry. In this section, we will discuss ten (10) important mangrove Genera belonging to the families—Sterculiaceae (*Heritiera*), Verbenaceae (*Avicennia*), Rhizophoraceae (*Rhizophora, Ceriops, Bruguiera,* and *Kandelia*), Sonneratiaceae (*Sonneratia*), Euphorbiaceae (*Exoecaria*), Myrsinaceae (*Aegiceras*), and Arecaceae (*Nypa fruticans*), which have characteristic features and prevalent in many regions. Rhizophoraceae is the largest family of mangroves so more than one important genus is selected to highlight their silvicultural characteristics. The details of fruiting and flowering are from authors' own experiences in India and may differ in some other regions.

2.6.1 Heritiera fomes *Buch. Ham. Syn.* Heritiera minor *Lam. Family: Sterculiaceae*

Heritiera is known as Sundari in the Sundarbans and in Orissa, India. It is abundant in the deltaic regions of the Ganges, Brahmaputra, and Mahanadi ascending up the rivers within tidal limits and along the coast of eastern peninsula. It reaches its best development in Myanmar in the tidal forests from Arakan to Tenasserim. Though its habitat is situated south of the Tropic of Cancer, the temperature is equable due to its proximity to the sea with high rainfall. The tree is found growing from the sea and extends inland but not far; a certain amount of salt is indispensable for its growth, but excess is harmful. It does not flourish on high ground where salt concentration is very high. It thrives well on a low-lying, moist, clayey loam, with a slight admixture of salt. However, on very wet soils and on saline high banks its growth is stunted. *Heritiera fomes* is a characteristic species of Tidal Swamp forests in saltwater mixed *Heritiera* forests and in brackishwater mixed *Heritiera* forests. In saltwater mixed *Heritiera* forests, it occurs in association with *Exoecaria agallocha, Ceriops roxburghiana, Bruguiera conjugata, Avicennia officinalis,* and *Xylocarpus moluccensis*. In brackishwater mixed *Heritiera* forests, it occurs in association with *Bruguiera conjugata, Avicennia officinalis, Xylocarpus moluccensis, Sonneratia apetala,* and *S. caseolaris*. The freshwater type of *Heritiera* forest is mostly found in Bangladesh, and only the saltwater type is found in Indian Sundarbans.

It is a medium-to-large evergreen tree, often grooved and buttressed, 15–20 m in height, and 1–1.8 m in girth in favorable localities. The trees grow in close crops, so it is seldom found with branches low down. The crowns of individual trees are light, but their combination forms close canopy. The root system of the species is not deep. A peculiarity of this species is that it sends up pneumatophores copiously, which serves as respiratory organs. Some have knobs and knees on the surface of the ground, but all have numerous lenticels. The species is easily recognized by these aerial roots. Bark is dark gray with longitudinal fissures. Aerial roots are flat on either side. In the estuarine areas, they are so close that it is difficult to step in. Leaves measure 10–15 × 4–5 cm, oblong, lanceolate, petiolate, and leathery with silvery scales beneath. Leaves are simple and alternate. Flowers are small, orange-colored, and unisexual in tomentose panicles. Fruits are 3–4 cm in diameter, woody, indehiscent shining capsules, keeled, and capable of floating on the sea water (Fig. 2.2).

The trees flower from April to June and fruits are available from August to September. Both flowering and fruiting take place later in the saltwater areas than in the freshwater areas. Flowers are much more numerous on the trees growing on the river banks projecting over the streams so that seed dispersal by water will be easier. Seeds being buoyant are borne along in quantities on the surface by tidal currents until stranded. Germination is hypogeous and takes place very soon after the carpels fall. The thick fleshy cotyledons remain within the fibrous wall of the carpel; the stout radicle appears first, the petioles of the cotyledons meanwhile elongating so as to enable the plumule to emerge; latter soon appears the young shoot elongating and arching until stationed.

The tree is a moderate light demander. It can withstand fairly heavy shade in early stage, but once it is established, it responds well to a partial removal of shade. The distribution of the species in the Gangetic Delta clearly bears out its preference for supply of freshwater. The coppicing power of the species varies considerably, and it is usually a poor coppicer. For successful coppice growth, abundance light is required. It pollards well.

Natural regeneration is excellent in most localities in its habitat. The species bears fruit annually but plentiful seeds occur only at intervals. Germination begins while the seeds are floating on the water. Natural regeneration is satisfactory where fresh

Fig. 2.2 *Heritiera fomes* tree, flowering stage and fruiting stage

deposits of silt are observed. In the area where natural regeneration fails, artificial regeneration is attempted. For artificial regeneration, seed sowing in situ would have to be secured to prevent its floating away at high tide. Judicious thinning in increasing the rate of growth of the trees is found successful. The selection system is the suitable silvicultural system for the management of *Heritiera* forests. Felling cycle may be fixed at 20 years, and exploitable diameter may be 7.5 cm. It is very hard due to interlocked grains, elastic, strong, and heavy. It is excellent firewood. It yields charcoal of good quality and is suitable for gun powder. A transparent gum obtained from the bark is used medicinally and also as an adhesive.

2.6.2 **Heritiera littoralis** *Dry. Family: Sterculiaceae*

It is called Sundari in Bengali, Sundrichand in Marathi, and Sundari in Andaman also. It is also called looking-glass tree, the Red Mangrove of Queensland. It is a small- to medium-sized evergreen ornamental tree. It exhibits characteristic thin curving buttresses. It grows gregariously in the tidal forests all along the seashore in Andaman, Sundarbans, and east and west coasts of peninsular India. It is also widely distributed along the sea coasts in the Malayan region, Philippines, and Java. It occurs in the Littoral and swamp forests (sub-group 4A and sub-type 4A/L1 as per Champion and Seth 1968) in association with *Barringtonia asiatica, Erythrina variegata, Pongamia pinnata, Casuarina equisetifolia, Calophyllum inophyllum*, and *Terminalia catappa* and in brackish water mixed *Heritiera* forest (sub-type 4B/TS4) in association with *Barringtonia racemosa* and *B. asiatica*.

It's bark gray or discolored, and longitudinally furrowed. Leaves are elliptic-oblong, acute, or obtuse, glabrous above, and lower portion is covered with minute, silvery scales; base is rounded or acute, petiolate. Flowers are small, orange, or greenish pink in tomentose drooping axillary panicles in the upper axils. Fruits are ripe carpels, thick, and woody having sharp keel or wing. Seeds are 2.5 cm long. Both flowering and fruiting take place in the rainy season. The wood is hard, tough, elastic, strong and heavy, knotty, and twisted. It is mainly used in building boats, posts, poles, joists, tool handles, etc. The seeds are edible and used as adulterants for cola nuts. The bark contains 15% tannins and is used in Philippines for toughening fishing nets.

2.6.3 Avicennia officinalis *L. Syn.* A. tomentosa *Wall. Family: Verbenaceae*

Avicennia officinalis is commonly known as white Mangrove or Bain in Sundarbans and is found from India across Asia to Papua New Guinea. It is a large evergreen shrub or small tree of the mangrove swamps (Fig. 2.3). It is one of the commonest of the Indian mangrove swamp species, especially in east and west coasts of Indian Peninsula growing gregariously and often forming an extensive bushy growth, conspicuous from its gray foliage, and bright yellow inflorescences when in flowering condition. Its lateral roots spread in all direction through the soft mud and send up slender vertical pneumatophores. In the Sundarbans, it occurs in the inland parts of the littoral forest and is characteristic of moist depressions.

Fig. 2.3 *Avicennia officinalis* tree with its flowering stage

The wood has a peculiar structure consisting of alternate layers of pore-bearing tissue and loose large-celled tissue without pores. It is brittle and is used only as fuel, but in some localities, it is an important fuel species. The panicle heads of yellow flowers appear from March to June, and the fruits ripen from August to October. The fruit is a compressed ovoid one-seeded capsule, 2.5–3.5 cm long, dehiscing into two thick valves. The large fleshy cotyledons fill the fruit. The seeds often germinate on the tree or immediately after falling. Thick, densely hairy hypocotyls elongate from the lower end and of which a number of rootlets appear and the shoot is produced from its upper end. The seeds are buoyant and are thus able to spread by the agency of water; about October, the tidal creeks are often full of large seeds floating on the surface of the water and most of the seeds will be found to be germinating. The best method to collect the seeds for artificial regeneration is to drag with a small net and throw the seeds into a boat partly filled with water, which should then proceed straight to where the seed is to be sown. The seeds should be sown immediately after collection without delay. Usually, the seeds are broadcasted between new moon and full moon when the tides are lowest; the sowing is done when the tide has run out, and there is no water on the ground; otherwise, there is danger of the seeds floating away (Wood 1902).

Under favorable conditions, the saplings regenerate freely from seeds. The necessary conditions appear to be frequent flooding and absence of dense low cover, which the seedlings do not tolerate. Thus, a lowering of the water level results in a cessation of reproduction, while a dense growth of *Acanthus ilicifolius* tends to kill out the seedlings. The tree does not coppice well. Its lateral roots spread in all directions through the mud in which it grows and sends up plentiful pneumatophores. *Avicennia* plants are the pioneer species of the muddy flats and pave the way for other species depending upon the silting activities and rise in the level of the mudflat by further accretion.

2.6.4 **Rhizophora mucronata** ***Lam. Family: Rhizophoraceae***

It occurs on the East Coast of Africa and Madagascar to the Indian Peninsula, Andaman Islands across Asia and North Coast of Australia. It is a small- to moderate-sized evergreen tree, with many branches attaining a height of 7.5 to 12 m and a girth of 0.5–1.0 m with elliptical mucronate leaves 10–15 cm long, and the young branches are thick and prominently marked with the scars of fallen leaves and stipules. Bark is fairly smooth and brown. This tree produces characteristic stilt roots, the lower portion of the stem dying early, and the tree remaining propped up on numerous roots, which are submerged at high tide and stand out of the mud at low tide. Aerial roots are also produced from the branches, and these fix themselves in the mud. This tree is most commonly found on the outer fringes of the mangrove swamp where water is salty, and the action of the tides and waves is most strongly felt; its peculiar root system is therefore of special advantage in forming an anchorage to withstand this action.

The conspicuous white flowers appear in the hot season and the rainy season from April to September, and the fruits ripen in late rainy season from July to October. The fruit is 4–5 cm long, conical-ovoid, pendulous, coriaceous, rough, and dark brown. The hypocotyl, which emerges through the apex of the fruit, is sharp-pointed and rough with lenticels. Before dropping, it attains a considerable length (up to 45–60 cm) but sometimes longer and the seedling is thus able to establish itself in water of some little depth, the sharp point of the hypocotyl penetrating the mud, and the young plant being kept upright while the roots are rapidly developed and the first pair of leaves appear at the apex of the shoot. Seedlings that have established themselves in this way may often be found in quantity in the mud and shallow water round the parent trees. The tree commences to produce fruits at an early age. It is a poor coppicer. Natural regeneration of the species comes up fairly well throughout its habitat, and the trees are not known to have been raised artificially. The sapwood is light red, and the heartwood is dark red and hard but splits in seasoning. It is a good fuel. The bark is used for tanning.

2.6.5 Rhizophora apiculata *Blume Syn.* R. conjugata *L. Family: Rhizophoraceae*

This is a tree as large as *R. mucronata* with similar habits and is commonly associated with it in its habitat. Bark is gray, smooth, with shallow vertical furrows or short horizontal fissures. Leaves are lanceolate, cymes are two-flowered, and petals are thin and glabrous. The leaves are narrower and darker than in *R. mucronata,* and it can be easily distinguished by its calyx–lobes, which are pale yellow within (Fig. 2.4). The fruit is about 2.5 cm long; hypocotyl is smaller, about 30 cm long. It produces seeds abundantly with germination capacity of about 70–75%.

2.6.6 Ceriops decandra *Griff. Syn,* C. roxburghiana *Arn., and* Ceriops tagal *(Perr.) C.B. Robs. Family: Rhizophoraceae*

Ceriops spp. are small evergreen trees, and the 2 species resemble each other in appearance and habit and are distinguished mainly by the inflorescence, which is more compact in the later than in the former (Fig. 2.5). The bark of both species contains a great deal of coloring matter. The stem is not supported by stilt roots as in *Rhizophora,* but aerial roots are sent down from the branches and small or inconspicuous pneumatophores are produced. The fruits (2.5–3 cm long) ripen in August–September, and the hypocotyl, when it falls, is 10–15 cm long by 0.5–0.7 cm in