ECOANATOMICAL CHARACTERISATION AND DEVELOPMENT OF ANATOMICAL KEY OF SELECTED MANGROVE SPECIES OF WEST COAST OF INDIA

By

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(2013-27-101)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

Doctor of Philosophy in Forestry

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VELLANIKKARA, THRISSUR-680656
KERALA, INDIA
2017

DECLARATION

I, hereby declare that this thesis entitled "**Ecoanatomical characterisation and development of anatomical key of selected mangrove species of West Coast of India**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled "**Ecoanatomical characterisation and development of anatomical key of selected mangrove species of West Coast of India**" is a record of research work done independently by Ms. Anju S. Vijayan (2013-27-101) under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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ACKNOWLEDGEMENT

With deep admiration I evince my heartfelt gratitude and unforgettable owe to my major advisor ***Dr. E. V. Anoop,*** *Professor and Head, Department of Woodscience, College of Forestry for his valuable guidance, support, inspiration, critical advise, encouragement and friendly cooperation throughout the course of my research work. Words are not enough to express my gratitude and respect for him. I consider myself lucky to have him as my advisor.*

I owe my sincere thanks to my advisory committee members ***Dr. K. Vidyasagaran,*** *Dean, College of Forestry;* ***Dr. T. K. Kunhamu,*** *Professor and Head, Department of Silviculture and Agroforestry, College of Forestry,* ***Dr. A. V. Santhoshkumar,*** *Professor and Head, Department of Plant Physiology and Tree Breeding, College of Forestry and* ***Dr. P.O. Nameer,*** *Professor and Head, Department of Wildlife Sciences, College of Forestry for their timely interventions, valuable advice, co-operation and constant encouragement during the study. I take this opportunity to recognise* ***Dr. K. Sudhakara,*** *Former Dean, College of Forestry for his support during the study.*

My deep sense of gratitude goes to ***Mr. N. Vasudevan,*** *Principal Chief Conservator of Forest, Mangrove cell, Maharashtra and* ***Ms. Neenu Somaraj,*** *D F O, Amaravati, Maharshtra for arranging permission to collect samples from Maharashtra. I extend my cordial thanks to* ***Mr. Abdul Azeez A. Shaikh*** *, ACF, Social Forestry, Karwar and* ***Mr. Manjunath,*** *RFO for arranging permission to collect samples from Karnataka.*

My deep sense of gratitude goes to ***Dr. S. Gopakumar,*** *Professor, Department of Forest Management and Utilization, College of Forestry and* ***Mr. Srinivassan, K*** *for kindly providing me various facilities for the conduct of the study. My sincere thanks to* ***Dr. C. Sunanda,*** *and* ***Mrs. Jayasree*** *for their valuable guidance.*

*I express my venerable thanks to **Mr. Reneesh, Mr. Kiran, Mr. Toji,** Teaching Assistants, **Dr. Sreejith Babu, Ms. Swadhi** and **Mr. Alex** for their suggestions and co-operation in executing the research work. I extend my sincere thanks to for their valuable help in time of need.*

*I am grateful to all members for their ever willing help, great support, field practical's and kind co-operation rendered through all my works. My special thanks to **Mr. Reghu Raj, Mr. Mahusoodhanan, Dr. Jyothi Krishnan, Mr. Salman Shaikh, Mr. Parashuram, Dr. Merwin Fernandas, Ms. Sini, Mr. Rahees, Ms. Anshee, Mr. Niyas, Mr. Subu , Ms Swagathika, , Mr. Deepak Kumar, Mr. Ashish, Mr. Nithin Mohan** and **Mr. Raj.***

*I am grateful to all members of Woodscience department for their ever willing help, great support, field practical's and kind co-operation rendered through all my works. My special thanks to **Mr. Vishnu, R, Ms. Lekshmi, Ms Sophia, Ms. Divya, Ms. Jeeshma, Vishnu, H** and **Mr. Bill** for their patience in helping me during field and lab work. The help rendered by **Mrs. Mini, Mrs Jyothi, Mrs. Seena, Mrs. Sheeja** and **Mrs. Sindhu** will be always remembered. I can hardly overlook the co-operation, timely help and moral support rendered by my juniors and seniors **Ms. Parvathy, Ms. Vinu, Ms. Delphy, Ms. Anu. Ms. Devi, Ms. Sukanya, Ms. Ashwathy, Ms. Devipriya, Ms. Neenu, Ms. Lakshmy, Ms. Jilna, Ms. Dipti, Mr. Sachin, Ms. Kavya** and **Ms. Reshma** .*

*I place on record my deep sense of gratitude to the **Kerala Agricultural University**, my alma mater for providing the financial and technical support for pursuing my studies and research.*

*The unfailing support and unstinted encouragements extended by my parents, **Mr. Vijayan, P. N.** and **Mrs. Sobhana Vijayan** and my sister **Ms. Athira** are gratefully acknowledged with deep sense of gratitude. Lastly, I thank one and all who have directly or indirectly helped me during the study and during various stages of my work.*

*Lastly, I bow my head before **The Almighty God** for helping me through the thick and thin of life, protecting me and giving me the ability to complete my research successfully.*

Anju S. Vijayan

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1. INTRODUCTION

Mangroves are the taxonomically diverse endangered angiosperms that form dominant vegetation in the interface of land and sea along the tropical and subtropical coast. Though most of the mangrove genera and families have highly diversified, they have developed certain morphological, anatomical, physiological, physiognomical adaptations and succession mechanisms which are governed by climatic, edaphic and salinity factors of both soil and water phases (Naskar and Mandal, 1999). These ecosystems are extended mainly between 24°N and 38°S latitudes that receive rainfall between 1000 and 3000 mm and temperature ranging from 26 to 35°C (FSI, 2015). The specific environmental conditions of the mangrove communities make them taxonomically and anatomically unrelated from their terrestrial relatives. Neverthless, they have a number of similarities with respect to physiognomy, physiology, anatomical characteristics and structural adaptations to the habitats that show the phenomenon of convergent evolution.

Though these are considered as one of the most productive, protective and biologically important ecosystems of the world, this unique ecosystem is in continuous jeopardy and in recent decades is facing unimaginable threat due to continuous human intervention throughout the world and faces a profound emergency. The mangrove forests of India which spreads across nine States and three Union Territories, occupies 4,662.56 km^2 (FSI, 2015) representing about 3% of the global and 8% of Asian mangrove forest areas. Mangrove areas are larger in the East Coast of India comprising around 80% compared to 20% in the West Coast owing to the terrain and due to the river deltas. Based upon the degree to which they are restricted to these habitats and their importance in these communities, Tomlinson (1986) grouped mangroves into three categories viz. major, minor and associates. True mangroves play a predominant role in community structure and have the ability to form pure stands (Tomlinson, 1986).

Out of the 32 true mangroves (FAO, 2007), 20 were reported in West Coast of India by several workers (Untawale, 1986; Naskar and Mandal, 1999; Kathiresan and Bingham, 2001). However, the species richness and mangrove area in India is getting reduced drastically at an alarming rate during the last few decades due to natural as well as anthropogenic causes which has even led to the extinction of some rare species (Swain and Rao, 2013). Knowledge on occurrence and distribution of mangrove species is also inadequate. Systematic studies on the wood anatomical details of coastal mangroves has not been attempted hitherto for facilitating identification of various genera and species from their wood structure. Hence, an anatomical key for the identification of the mangroves species of the West Coast is a need of the hour. The effect of ecological parameters on wood anatomical features is defined as the 'ecoanatomy' of wood (Baas and Carlquist 1985; Lindorf, 1994). This relation between wood structure and ecological factors has been acknowledged by pioneer wood anatomists (Van vliet, 1979; Carlquist, 2001; Hacke and Sperry 2001) and was in recent decades confirmed by several authors (Lens *et al.*, 2011; Pace and Angyalossy, 2013).

The concepts given by Carlquist (1988a) that the adaptation to particular environmental conditions drives the evolutionary trends in the wood anatomical features. Many anatomist since then started gathering and interpreting the anatomical data from the angle of ecological adaptability, either floristically or familywise. Carlquist has attempted to analyse factors underlying the selective forces which have guided evolution of conductive tissue in vascular plants. The ecophysiological activities of plants will be influenced by environmental factors, biological and ecological factors. Most of the investigations carried out along these lines are restricted to ecophysiology of mangrove vegetation and limited studies were carried out in wood anatomy of this vegetation and ecoanatomy in particular. Thus there is a paucity of information relating to ecoanatomical wood features of mangrove species. The ecoanatomical wood features such as vessel diameter, vessel frequency, and vessel length affect the hydraulic efficiency and safety of a tree in its habitat, in interaction with temperature, drought, and seasonality. Because of saline environmental conditions prevailing in mangrove ecosystem, the xylem sap is at negative absolute pressures. This increase in xylem sap tension induced cavitation, which result in the formation of gas bubbles (embolism). Embolism reduces hydraulic transport efficiency and causes branch die back and finally leads to the death of the plant. Mangrove woods have been found to have specialized ecoanatomical features to localize air embolism to a greater extent and maintain hydrological safety and balance (Tomilinson, 1986; Anoop *et al.*, 2013).

The present work is aimed at preparing a wood anatomical key of mangrove species of West Coast of India and to investigate their ecoanatomical features and to unravel their evolutionary trend, to better understand mangrove evolution.

In this background the objectives of the study were

1. To prepare an IAWA (International Association of Wood Anatomists) based wood anatomical key of the selected mangrove species
2. To elucidate the ecoanatomical wood features such as vessel length, vessel diameter and vessel frequency, nature of vessels and vessel grouping of selected mangrove species of the West Coast of India
3. To find out the evolutionary trend of wood anatomy of mangroves

2. REVIEW OF LITERATURE

2.1. Historical account of mangrove ecosystem

Mangrove species have been known and studied since ancient times. Schneider (2011) reported that twenty-four centuries ago, the ancient Greeks, discovered mangroves from the Indian Ocean and Red sea and it is even less well known that they observed them not only with wonder but also with scientific curiosity. Descriptions of *Rhizophora* mangroves in Red sea and Persian Gulf are the earliest known evidences by Theophrastus (305 BC) and Nearchus (325 BC). There were records on *Rhizophora* by Aboul Abbas (1230) and Plutarch (70 AD) according to Chapman (1976). The bibliography of mangrove research (Rollet, 1981) shows fourteen references of mangroves before 1600 AD, twenty five from 17th century, forty eight from eighteenth century and four hundred and twenty seven from the nineteenth century. In contrast, there were 1500 mangrove references during the period from 1900 to 1975 and about 3000 between 1978 and 1997. It is estimated that mangrove vegetation cover extended roughly 170,000 square kilometers of the earth's surface (Spalding *et al.*, 1997; Valiela *et al.*, 2001), usually on soft sediments protected from extreme wave action, such as in the deltas of large rivers and estuaries and on the leeward side of barrier Islands. Woodroffe and Grindrod (1991) addressed that Pleistocene events did affect global climate and sea levels, ultimately modifying present mangrove distributions in different regions of the world. During Pleistocene dry periods, mangrove species were more restricted to wet climatic equator area than they are today. Additionally, the drop in sea level associated with Pleistocene glacial events created broad land connections among the Malay Peninsula, Sumatra, Borneo, and Java, as well as a bridge between Australia and Papua

New Guinea (Woodroffe *et al.*, 1985; Clark and Guppy, 1988; Woodroffe, and Grindrod, 1991), which created a large extent of suitable habitat for mangroves. Thus, while the latitudinal ranges of many mangrove species contracted during this period of maximum glaciation, newly exposed land from lower sea levels offered suitable sites for mangrove expansion along the equator. During the Pleistocene, wet climates in Southeast Asia and northern Australia, and arid climates which are less favorable for mangrove diversity in Africa and the New World tropics could have affected the distribution of mangrove species: patterns of aridity along American and African coasts might have contributed to range contraction of mangrove species in the Atlantic–Caribbean–East Pacific region, whereas increased mangrove area in Southeast Asia and Australia might have created opportunities for mangrove species expansion in the Indo–West Pacific. It is widely believed that mangrove forests developed first in the Indo-Malaysian region and then spread to other regions of the tropics. This region is, therefore, considered as the cradle of evolution for mangrove vegetation (Krishnamurthy, 1993). Anyway, mangroves are quite old, possibly arising just after the first angiosperms, around 114 million years ago (Duke, 1990).

2.2 Definition and classification of mangroves

Mangroves are the characteristic littoral plant formations of tropical and subtropical sheltered coastlines. They have been variously described as *'woodland, 'tidal forest'* and *'mangrove forest'*. Generally, mangroves are trees and bushes growing below the high-water level of spring tides (FAO, 1994). The word 'Mangrove' has been defined variously in literature. The oxford dictionary mentioned the words 'mangrove' and 'mangrowe' since 1613, indicating tropical trees or shrubs found in coastal swamps with tangled roots that grow above the ground, whereas the Americans, the Spanish, and the Portuguese used the term 'Mangle' and 'Mangue' indicating trees and shrubs of the genus *Rhizophora* (Mepham and Mepham, 1984). Later, the term 'mangrove' was referred to the individual plant or tidal forest or both, as 'Mangrove plants' and

‘Mangrove ecosystem’ (MacNae, 1968). Chapman (1976) used the term ‘mangrove’ for inter tidal plants, and considered plant communities of inter tidal forest as mangrove ecosystem called ‘mangal’. The term ‘mangal’ was also commonly used in French and in Portuguese to refer to both forest communities and to individual plants. Mangrove is an ecological term referring to a taxonomically diverse association of woody trees and shrubs that form the dominant vegetation in tidal, saline wetlands along tropical and subtropical coasts (Tomlinson, 1986).

Chapman (1976) considers 90 species representing mangrove while (UNDP, 1986) reported only 65 species. Recently FAO (2007) proposed 71 species as true mangroves. Tomlinson (1986) mentions only 48 mangrove species, out of which 40 are true mangroves from the old world of tropics and 8 true mangroves from the New World. Several workers have opined that plants growing in between the highest and the lowest tidal limits may be considered ‘mangrove’ (Blasco 1975, 1977; Clough 1982; MacNae 1968; Naskar and GuhaBakshi 1987). Mangroves form taxonomically diverse groups, the majority of which fit in to four genera: *Bruguiera*, *Sonneratia*, and mainly *Avicennia* and *Rhizophora.*

Indian workers have given varying numbers of mangrove species in a range between 30 and 60 species (Blasco, 1975; Untawale, 1986; Banerjee *et al.,* 2002; Jagtap *et al.,* 1993). This variation is due to the fact that there is a lack of clear-cut demarcation. Saenger and Bellan (1995) listed 60 mangrove species growing exclusively in the tidal zones, as ‘true mangroves’. Mepham and Mepham (1984) suggested that any arborescent species growing in the tidal zones might be referred to as “Potential mangrove” or ‘Frequent mangrove’. Tomlinson (1986) recommended that mangrove species were basically of two types, viz., (1) major element of mangals or true mangroves and (2) minor element of mangals. Later, several workers (Tomlinson, 1986 Chai, 1982; Mepham and Mepham;1984; Naskar, 1993) coined the term ‘Mangrove associate’ for the flora representing non arborescent, herbaceous, sub-woody and climber species, found growing mostly in regions bordering the tidal periphery of mangrove habitats between true mangroves and their associate species. In India, mangroves are classified into 3 categories (i) major mangroves (ii) mangrove associates and (iii) back mangroves, based on morphological and anatomical features adapted to saline habitats (Naskar and Mandal, 1999). The flora of the Indian Sundarban includes 26 true mangrove species, 29 mangrove associates, and 29 back mangrove species of 40 families and 60 genera (Naskar and Bakshi, 1995).

2.3. Geographical distribution, area and species diversity in mangroves

2.3.1 Global scenario

The global distribution of mangroves predominantly in tropical range. One hundred and twenty-four countries cover up to 75% of the tropical and subtropical shorelines located between 30°N and 30°S are home to highly productive mangrove ecosystems (FAO, 2007). The most extensive area of mangroves is found in Asia, followed by Africa and South America. The halophytic evergreen woody mangroves typically fringe the transition zone between land and sea in intertidal coastal regions, estuary, and reef environments, which are characterized by strong winds, varying inundation, high temperatures, and anaerobic muddy soil (Kathiresan and Bingham, 2001).

Mangroves growing in favorable conditions enable an optimal lush growth, with tree canopies reaching a height of 30-40 m. Mangrove distribution of the world have been divided into two distinct floristic realm namely Indo-West Pacific realm, or eastern group, which extends east from eastern Africa to the islands of the central Pacific and the other one is the Atlantic East Pacific realm, or western group, which includes the Americas and West and Central Africa (ITTO, 2012). The total mangrove area in different parts of the world is not precisely known. Finlayson and Moser (1991) opined that the total mangrove area of the world are about 14 million hectares. The world's greatest contiguous mangrove area in the Sunderbans situated in the Bay of Bengal, which covers a mangrove area of about 2,400 sq. km, which is estimated to be 62 % of the total Indian mangrove forest (Mandal *et al.*, 2010).

According to Chapman (1980), a total of 55 mangrove species in global level are known so far of which 44 are found in the Indian Ocean-Western Pacific Zone. Duke (1992) and IUCN (1983) have recognized 70 species of mangroves all over the world while Tomlinson (1986) recognized 48 true mangrove flora from the globe which distributed in six different geographical regions and structure in respect of each mangrove species. Countries such as Indonesia, Malaysia, India, Thailand and Singapore are rich in mangrove species (Kathiresan and Rajendran, 2005).

2.3.3 Indian scenario

Mangroves are widespread, though intermittent, along the extensive coastline of India. In the past, total area of the mangroves in India was around 6,740 km^2 which accounting about 7% of the world mangroves and 8% of the Indian coastline (Untawale, 1987). Currently it spreads over an area of 4,661.56 km^2 which account for about 3% of the global mangroves and 8% of Asian mangroves (FSI, 2015; FAO, 2007). The decline of mangrove in India is about 33%, which is very alarming and continuance of mangrove loss at this rate may fade away the ecosystem. These mangrove habitats (69 ° E - 89.5° E longitude and 7° N - 23° N latitude) comprise three distinct zones: East coast habitats having a coast line of about 2700 km, facing Bay of Bengal, West Coast habitats with a coast line of about 3000 km, facing Arabian sea, and Island Territories with about 1816.6 km coastline (Naskar and Mandal, 1999). Based on Thom's (1982) classification of coastal habitats, the Indian mangrove habitats are categorized as (a) deltaic mangrove habitat which includes the major estuaries of East coast and two gulfs of West Coast, Gujarat. (b) coastal mangrove habitat which includes the inter-tidal coastlines, minor river mouths, sheltered bays and backwater areas of the West Coast (c) Island mangrove habitat which includes shallow but protected inter tidal zones of 'Bay Islands' and Lakshadweep Atoll. Mangrove cover has been categorized into three classes viz. very dense (canopy density of more than 70%), moderately dense (canopy density between 40-70%) and open mangrove cover (canopy density between 10-40%). In India, the states like West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Andaman and Nicobar Islands, Kerala, Goa, Maharashtra, and Gujarat occupy vast area of Mangroves. About 60% of the mangroves occur on the East Coast bordering the Bay of Bengal, 27% on the West Coast along the Arabian Sea, and 13% on Andaman and Nicobar Islands (ITTO, 2012).

According to Naskar and Mandal (1999) mangrove area is large in the East Coast of India with 80 % compared to 20 % in the West Coast owing to the terrain and the river deltas of Ganges, Brahmaputra, Mahanadi, Godavari, Krishna and Cauvery the latter which have nutrient rich alluvial soil. Sundarbans form a major portion of mangrove forests in India, covering about 2,106 sq. km of mangrove forest and water (FSI, 2015). The Sundarban comprises essentially of numerous Islands formed by the sediments deposited by three major rivers, the Ganga, Brahmaputra and the Meghna, and a dense network of smaller rivers, channels and creeks. Mangroves are the most dominant flora in Sundarbans and 30 true mangroves occur in the Indian Sundarban. The area under mangroves in Gujarat is the second largest along the Indian coast, after Sunderbans. Gujarat has recorded about 23 percent of India's estimated mangrove cover of which the coastal district of Kutch covers almost 90 percent of mangrove area. Gradual topography along the east coast is said to have an extensive intertidal expanse which favours major formation of mangroves in the deltaic regions (Jagtap and Komarpant, 2003).

In India, deltaic and backwater-estuarine type of mangroves occurring in the West Coast (Arabian) which is characterized by typical funnel-shaped estuaries of major rivers or backwaters, creeks, and neritic inlets. Insular mangroves are present in Andaman and Nicobar islands which are formed by many tidal estuaries, small rivers, neritic islets, and lagoons (Gopal and Krishnamurthy, 1993).

2.3.4 Scenario in the West Coast of India

According to Sidhu (1963) total coverage of mangroves in the West Coast were reported to be 1140 km^2 but according to Indian State of Forest Report (2015) the area distribution of mangroves in West coast and is about 1367 km^2. The total length of coastal line in West coast of India is estimated to be about 3000 km and mostly inundate with Arabian sea water, during high tides (Naskar and Mandal, 1999). The major mangrove zones of the Indian West Coast are restricted in four Maritime States; these are the Gujarat coast, the Maharashtra coast, the Karnataka coast, the Kerala coast and the Goa coast are considered to fall under coastal mangrove habitats in the inter tidal zones along with mouths of minor rivers or minor estuaries and back waters, facing Arabian sea by North-East to West and East to West directions. The mangrove vegetation is sparse, less extended, and confined to patches due to scanty upstream freshwater supply, excessive amount of silt-clay deposition, low average rainfall and relatively low tidal fluctuation (Blasco and Aizpuru 1997; Naskar and GuhaBakshi 1987; Untawale, 1984).

The Indian mangroves comprise approximately 59 species in 41 genera and 29 families. Of these, 34 species belonging to 25 genera and 21 families are present along west coast. There are about 25 mangrove species which have restricted distribution along the east coast and are not found on the West Coast. Similarly, there are eight species of mangroves which have been reported only from the west coast. There are 21
approximately 16 mangrove species reported from the Gujarat coast, while Maharashtra

has about 20 species, 14 species from Goa and 10 species from Karnataka. There are hardly three to four species of mangrove which are rarely found along the Kerala coast.

2.3.4.1. Mangroves of Gujarat coast

Gujarat is the Western most state of India and the total length of the coastal line facing the Arabian sea is about 1600 km; situated within the longitude 68° E and 73° E and latitude 20°10' N and 23°10' N. Gujarat mangrove forest covers an area of about 1,107 km^2 out of which 174 km^2 are moderately dense and 933 km^2 are open mangroves (FSI, 2015). The mangroves are predominantly distributed over three mangrove areas viz. Gulf of Kambhat, Gulf of Kutch and Kori creek (Pandey and Pandey, 2013). A total of 15 mangrove species belonging to 10 genera and 7 families have been reported from the state (Pandey and Pandey, 2010). *Lumnitzera racemosa* was reported for the first time in Gujarat (Bhatt and Shah, 2008).

2.3.1.2 Mangroves of Maharashtra Coast

Maharashtra State has a 720 km long coastline that is roughly divisible into three types - hills with steep cliffs entering the sea, sandy beaches and mudflats. Shorelines of mixed nature are also found, e.g., rocky waterfronts and sandy beaches with interspersed rocks, mud-coloured sandy beaches, etc. According to FSI (2015), the mangrove cover in the State had remained constant at 186 km^2 since 2005 till 2013. Then a sudden jump to 222 sq. km was registered in the year 2015. Untawale (1987) reported that the Bombay coast was covered with luxuriant mangrove in its seven Islands till the year 1670. All these dense mangroves zones were cleared due to anthropogenic pressure, like urbanization, industrialisation and for exploiting fire woods and became stunted and sparse mangroves (Naskar and Mandal, 1999). The Maharashtra coastal zone extends between the latitude 15° 52' N and 20° 10' N and 72° 10' E and 73° 10' E longitude which falls under five districts from South to North viz.Thane, Sindhudurg, Ratnagiri, Raigad and Bombay. Jagtap *et al.* (1993) recognized 22 that 26% of mangroves of West Coast of India present along the creeks and estuaries. Out of 55 species of mangroves in India, Maharashtra has reported 20 species, i.e., about 11%, which is the highest on the western coast of India (Jagtap *et al.*, 1993). Since the overall salinity of the coastal waters in Maharashtra is on higher side, *Avicennia marina* is the commonest species. Especially in the polluted waters there is a greater dominance of this species, which is less susceptible to the effects of pollution. *Excoecaria* spp,, *Rhizophora* spp. and *Sonneratia alba* are also dominant, especially in the Sindhudurg and Ratnagiri districts.

2.3.1.3 Mangroves of Goa coast

The central West Coast of India, includes the State of Goa, is marked by large hills bordered by narrow alluvial plains followed by an indented coastline with bays, estuaries and sandy stretches (Wagle, 1982). The mangrove cover in Goa is estimated to be about approximately 2,000 hectares of the total mangrove cover of India (Untawale *et al.*, 1982; Jagtap and Nagle, 2007). About 61 of mangrove species have been reported in the Indian subcontinent (Krishnamurthy *et al.*, 1987; Singh and Odaki, 2004). Jagtap (1985) has reported 15 true mangrove species and 11 mangrove associates in the State of Goa.

2.3.1.4 Mangroves of Karnataka coast

Untwale and Wafar (1986) reported that the Karnataka coast line is extended about 320 km long from North to South, within the latitude 12°45'N and 15°00 N and longitude 74°00' E -75°00' E. In this coastal line, the mangroves are fringing type in the intertidal zone, covering about 50 km^2 area. Untawale and Wafar (1986) have mentioned the distribution pattern of mangrove flora and associated benthic algae along the entire State coast. Rao and Suresh (1989) have published a comprehsive account on 23 the distribution, density and floristics of mangroves of Karnataka coast and have tried to match their baseline ground truth survey with satellite telemetry and remotely sensed photographs. Menon and Neelakantan (1992) have investigated the leaf chlorophyll contents in the mangrove flora of Kali. There are 13 species from 9 genera under 7 families of mangrove found in this estuary (Achari *et al.*, 2002).

2.3.1.3 Mangroves of Kerala coast

The Kerala coast is a long and narrow coastline on the south western shore line of the main land Indian subcontinent which is also called "Malabar coast". Kerala has a coastal area of about 576 km^2, is endowed with a long stretch of backwaters and a series of lagoons running parallel to the sea, separated by a strip of land varying in width from a few hundred metres to several kilometres. All along the coast, sand bars have been formed by waves and these sand bars prevent the water of small streams from reaching the sea. As a result, backwaters or lagoons have been formed along this shore and these lagoons are connected by channels or canals. The mixing of tidal waters from the sea and freshwater inflow from 41 west flowing rivers, create a congenial environment of mangroves along the fringes of these backwaters and estuaries. It is estimated that Kerala once supported about 70,000 ha of mangroves along its coast (Ramachandran *et al.*, 1986., Ramachandran and Mohanan, 1987; Basha, 1991) which has dwindled at present to an area of about 1700 ha. According to FSI (2015) the total mangrove coverage in Kerala coast is about 9 km^2. An earlier account of the mangroves of Kerala coast is available in the works of Troup (1921) and Gamble (1915). Of the 14 Districts in Kerala, mangroves are spread over in 10 Districts. Basha (1991) reported that Kannur has the highest area under mangroves (755 ha), followed by Kozhikode (293 ha) and Ernakulum (260 ha). More than 80% of the mangroves are under the custody of private owners; therefore, they are under serious threat of destruction (Mohandas *et al.*, 2012). According to Vidyasagaran and Madhusoodanan (2014) 15 pure mangrove species and about 33 semi mangrove species were recorded in Kerala. 24

Avicennia and *Rhizophora* species are the prominent constituents of the different communities in almost all the mangrove forests in Kerala. *Ceriops tagal*, believed to be extinct in Kerala coast was being rediscovered from Vincent Island of Kollam district (Vimal *et al.*, 2014). Mohandas *et al.* (2012) addressed that *Lumnitzera racemosa* and *Ceriops tagal* were the most threatened species in the West Coast of India. One of the endangered pure mangrove species, *Bruguiera sexangula* were recorded from Pulluni, Malappuram district of Kerala (Vidyasagaran and Madhusoodanan, 2014). In Kerala maximum extent of mangrove destruction was reported from Ernakulam district. When Cochin became industrial capital of the state, there was flooding of developmental projects which took away prime areas of mangroves from Panangad, Gosree, Vallarpadam, Vypin and Puthuvypin. Thrissur district consists of low extent of mangrove in the state. Mangrove destruction is going on in Chettuva, Thrissur district by the name of ecotourism. However, mangroves of Pulluni in Malappuram face acute threat from developmental activities.

Dense stands of mangroves in Kerala exhibit a particular pattern of zonation of vegetation (Mohanan, 1997), with particular species congregated in a specific zone. Besides, zonation varies from locality to locality among the isolated patches (Vidyasagaran *et al.*, 2014). In the mangroves of Kannur District, the proximal zone that is closest to the sea comprises of the predominating species like *Avicennia marina, Sonneratia caseolaris* and *Sonneratia alba*, while the intermediate zone occupies with species like *Rhizophora apiculata* and *Bruguiera cylindrica,* whereas in the mangroves at Chettuva (Thrissur District) and Ponnani (Malappuram District), the proximal zone is characterized by the predominance of *Aegiceras corniculatum* and *Acanthus ilicifolius*, often mixed with *Avicennia officinalis* in place of *Acanthus ilicifolius*, and the intermediate zone with species like *Bruguiera cylindrica* and *Rhizophora mucronata.* According to FSI (2015) mangrove in Kerala extended over about 9 km^2 distributed in three districts. Ramchandran *et al.* (1986) reported 25 km^2 of the mangrove area in Kerala State extended to Veli estuary, Quilon, Kumarakon, Cochin, Chettuva, Calicut, Edakkad, Pappinisseri, Kungimangalam and Chittari. Distribution of pure mangroves in Kerala revealed that *Excoecaria indica, Lumnitzera racemosa* and *Ceriops tagal* are the most threatened species in the West Coast. Similarly *Bruguiera sexangula* is also confined in a few places wherein their populations are facing further decline. Mangroves of Kerala are considered as the relics of the past. Invasion of the Islands by encroachers made extensive clearing and degradation of many areas.

2.3.5 Threats to mangrove diversity and endangered mangrove species

Throughout their range, mangroves and their associated species are threatened by anthropogenic activities such as mangrove destruction and overexploitation, as well as by more indirect anthropogenic factors such as pollution and climate change. The world loss of mangrove forest areas recorded ranges between 19% and 35% of its total mangrove forest area during period between 1980–2001 (Valiela *et al.,* 2001; FAO, 2003). On average, 3000 km^2 of mangrove forest were lost each year between the early 1980s and 2001, which is about 2.1% per year. At this rate of loss, mangroves could be extinct in 100 years (Duke *et al.*, 2007). Mangroves are already critically endangered or approaching extinction in 26 of the 120 countries in which they exist (FAO, 2003). Due to growing pressures from urban and industrial development along coastlines, combined with climate change and sea level rise, there is an urgent need to conserve, protect, and restore tidal wetlands (Barbier, 2007). Mangroves are uniquely adapted coastal ecosystem of great ecological and economic significance, but their habitat continued to disappear globally at a rate of 0.66% per year during the period between 2000–2005. It is reported that sixteen percent of mangrove species in the world are at an elevated threat of extinction; of which, only two species namely *Sonneratia griffithii* (critically endangered) and *Heritiera fomes* (endangered) exist in India. Only 5% of mangroves and 3% of associates are under the category of lesser risk and the rest of them are endangered or vulnerable and/ or critically endangered (Kathiresan *et al.*, 2013).

2.3.6 Ecosystem services of mangroves

Mangrove ecosystem are considered as the most productive ecosystem of the world. Mangroves are distributed along tropical and subtropical region, and are linked to multiple ecosystem services such as carbon sequestration and nutrient cycling (Ong, 1993), act as keystone species (Duke *et al.*, 2007; Dorenbosch *et al.*, 2004) and provide direct and indirect economic benefits (Ellison, 2008; Sullivan, 2005). The roots of these ecosystem trap the rich nutrient laden soil and provide a favourable ground for the growth of many spices and prevent soil erosion (Blaber, 2000). Indian mangrove supports a unique group of fungi, microbes, plants and animal species including crustaceans, molluscs, fishes, birds and endangered mammals (Sandilyan, 2007). Overall, the ecosystem services provided by mangrove forests are estimated to be worth at least US$1.6 billion per year worldwide (Costanza, *et al.,* 1997). Mangroves offer many important goods and services to human communities. These benefits are often overlooked, however, resulting in the degradation or loss of mangrove forests, at considerable cost to society. Given these large ecological and economic benefits, the recent findings of a global trend towards a reduction of range extent across mangrove biome due to human activities (FAO, 2007) and climate change (Ellison, 2005) is of major concern. It is estimated that we are losing 1–8% of mangrove cover each year (FAO, 2007; Ellison, 2005) and that if current trends continue, the entire mangrove biome may be lost within the next 100 years (Duke, 2007). One major consequence of this reduction in mangrove extent are already experiencing is the concomitant loss of associated species diversity – today, almost 40% of mangrove dependent animal species are considered to be at higher risk of extinction (Greenburg, 2009).

2.3.7 Zonation in mangroves

Mangrove communities often exhibit distinct patterns of species distribution governed by the complexity of environmental factors and competition between individuals. The local patterns of tidal inundation influence soil characteristics that control species zonation of mangrove forests. There are more than 80 species of mangroves occurring in various parts of the world which includes herbs, shrubs or tall trees (Blaber, 2000). They can form dense forest in intertidal region subject to having favourable conditions; however, a few species form a dense canopy (Jayasurya *et al.*, 2005). They exhibit extreme variations in plant composition, structure and growth rate. Mangrove forests can vary from a narrow fringe along the banks of an estuary to dense stands covering many square kilometers. The monospecific stands of *Avicennia* spp. are characteristic of large intertidal regions of many subtropical estuaries and may also form a narrow fringe along tropical ecosystems. Some mangrove forests in the tropics have a complex zonation, may contain several tree species (Hutchings and Saenger, 1987). In many parts of the world, a conspicuous zonation of tree species into narrow monospecific bands parallel to coastline has been reported (Snedaker, 1982). Mangrove zonation patterns have been described for Indonesia (Van Steenis, 1957; Prawiroatmodjo *et al.*, 1985), Australia (Macnae, 1969; Bunt, 1982; Elsol and Saenger, 1983), East Africa (Macnae, 1968), Papua New Guinea (Johnstone, 1983), northwest coast of Sri Lanka (Amarasinghe and Balasubramaniam, 1992), Kenya (Gallin *et al.*, 1989; Beeckman *et al.*, 1990) and Kenyan open coast (Ruwa, 1993). Typical patterns from the Indo-Pacific region showed *Aegiceras, Avicennia* and *Sonneratia* in the lowest intertidal zones, various species of *Bruguiera* and *Rhizophora* occupying in the mid-intertidal areas and *Heritiera, Xylocarpus* and numerous other species in the higher intertidal regions (Smith, 1992). Bunt *et al.* (1982) noted that some species common at the seaward mouth of an estuary are not present near the regions of the estuary. The paradigm that zonation is the classical feature of mangrove forests. This is seen in most mangroves worldwide and is almost accepted (Chapman, 1976). While describing mangrove zonation patterns, several hypotheses have been advanced. Smith (1992) noted physiological adaptations to environmental gradients such as soil pore water, salinity, tidal inundation, soil texture and oxidation-reduction potential have been used in most cases to explain the observed zonation. Wells (1982) conducted extensive fieldwork in the mangroves of northern Australia noticed that seedlings of several species grow in soils with salinity over 65 (*Avicennia marina, Avicennia officinalis* and *Rhizophora stylosa*), few species, however, that appeared restricted to soil salinity low-tide level (*Aegiceras corniculatum, Sonneratia caseolaris and Avicennia officinalis*), low to mid-tide level (*Rhizophora mucronata, Sonneratia apetala and Avicennia alba*), mid-tide level (*Bruguiera cylindrica and Rhizophora apiculata*) and mid to high tide level (*Lumnitzera racemosa, Bruguiera gymnorrhiza, Ceriops decandra, Excoecaria agallocha* and *Xylocarpus granatum*). In India this zonation may be very distinctive in both East Coast and West Coast of India. A very broad and general distinction would be proximal zone (front mangroves), middle zones (mid mangroves) and distal zone. In proximal zone the mangrove species are specially adapted with stilt roots, prop roots for stability and anchorage. Main species with these features are *Rhizophora apiculata, Rhizophora mucronata, Avicennia* spp. and *Sonneratia* spp. are also found. In middle zones *Bruguiera gymnorhiza, B. cylindrica, B. parviflora, B. sexangula*, all species of *Rhizophora, Lumnitzera racemosa, H. littoralis, Ceriops tagal, Aegicerus corniculatum* and *Xylocarpus granatum* were occured. Above the *Rhizophora/ Avicennia* line luxuriant group of *Bruguiera gymnorrhiza, B. cylindrica, Lumnitzera racemosa, L. littoralis, Ceriops tagal* and *Aegiceras corniculatum* occur. The distal zone is found towards the inland forest. Towards Island area mangroves like *Excoecaria agallocha, Heritiera littoralis* and *Xylocarnus* spp occur. Both *Heritiera* and *Xylocarpus* produce buttresses. Generally the salinity is on lower side in this zone occurring towards hill sides where run off of fresh water is for a prolonged period. The duration of tidal submersion is low in this zone compared to front mangroves. Blasco (1975) reported there is three distinct zones in Pichavaram, Tamil Nadu comprising 1) the mangrove proper 2) the back mangrove and 3) the slightly or not saline soils. Mangrove proper includes *Rhizophora* zone. This stratum includes the true mangrove such as *R.mucronata, R.apiculata, Sonneratia apetala, Bruigeria cylindrica, Ceriops decandra, Aegicerus corniculatum, Lumnitzera racemosa.* The zone next to the Rhizophora zone, *Avicennia* spp. dominates. *Excoecaria agallocha* were found in back mangroves and majority of mangrove associates falls under slightly saline soils. *Excoecaria agallocha* is the mangrove species that extended most towards inland and found everywhere else in India. In Kerala also Rhizophoraceae zone present in intertidal zone. The zone very near the Rhizophora zone is the one in which *Avicennia* spp. dominates. Contrary to this Nameer *et al.*(1992) reported that *R. mucronata* and *Bruigeria cylindrica* present towards the inland of Vypin in Ernakum district.

However, the zonation in mangroves is not so simple and varies from place to place. Every species has its own level of salinity tolerance. Estuaries on east coast show distinct zonation. The high salinity range on the east coast estuaries may be the principal reason for distinct zonation there. The range and force of tidal action also play a determinant role in creation and maintenance of zones as distribution of seeds or propagules is influenced by tidal action. Also, tides do influence the salinity in an estuary.

2.3.8. Adaptations of mangroves

It is well known that mangrove species have developed a variety of adaptations to deal with salt stress and anoxic soils (Luther and Greenberg, 2009). The most typical morphological and physiological adaptations of mangrove species such as the aerial roots, stilt-roots, pneumatophores, root knees, and plank roots that have a higher proportion of gas space when waterlogged, mechanisms of salt exclusion by the roots, tolerance of high tissue salt concentrations and excretion of salt excess from leaves, vivipary and tidal dispersal of propagules makes it possible for the mangrove trees to survive these conditions in contrast to upland tree species (Baskin and Baskin, 2001;

Tomlinson, 1986; Alongi, 2009). According to Tomlinson (1986), short, narrow vessel elements resist high tensions in water columns. These are considered as the wood anatomical adaptations of plants in stressful environmental conditions to avoid reduction of hydraulic capacity after cavitation and subsequent air-filling of vessels (Baas *et al.,* 1983).

2.3.9. Taxonomical consideration of the mangrove family

Mangrove genera do not come from a single genetic group but they represent a variety of plant families that are adapted to tropical intertidal habitat. There are 19 families with mangrove representatives, but only 4 families are exclusively mangroves. There are no orders that are exclusively for mangrove genera. The plant family Rhizophoraceae has only 4 of its 16 genera that exist in mangrove habitat (Tomlinson, 1986). Taxonomy of mangrove flora is not free from confusion. There are frequent changes in nomenclature of species and genera. This is further made difficult as the same plant is identified differently by different workers in different areas. The taxonomical problems posed by some of the mangrove plants are puzzling, as certain species also produce hybrids and morphologically they show similarities to more than one species of the same genus. This difficulty, to a certain extent in, Indian species has been overcome by publishing an identification manual for the mangroves found in India by the Botanical Survey of India (Banerjee *et al*., 1989). According to this manual, Indian mangroves comprise approximately 59 species of 41 genera belonging to 29 families. Of these 34 species in 21 genera and 21 families occur in mangrove and tidal vegetation along the East Coast and about 25 mangroves along the West Coast. Several workers reported that there are 48 mangrove species out of which 20 are true mangroves and 28 are mangrove associates reported in West coast of India distributed in 21 families (Ramachandran *et al.,* 1986). The plant taxonomy of the Indian mangrove forest types has been described by different workers. The first systematic comprehensive account of the Sundarban vegetation was given by Prain (1903). Blatter (1908) divided the mangroves into four zones viz. a) coastal sea water and semifluid mud b) salt marshes of the tidal creek c) salt marshes along the coast and d) interior drier marshes. Gamble (1915) described the plant taxonomy of the Indian mangrove forest types. The mangrove forests cannot be regarded as climax or pre climax types. However it is necessary to undertake a thorough and systematic study of the successional stages (Champion, 1936). Navalkar (1956) described the plant taxonomy of the Indian mangrove forest type. Navalkar (1956), Puri and Jain (1957) and Qureshi (1957) followed similar methods based on soil salinity, tidal flow and nature of the communities. While fixing the forest type of India, placed the tidal forests under primary seral type of the moist tropical seral formations (Champion and Seth, 1968). Blasco (1975) has made studies on the tidal inundations along the Cauvery delta for different mangrove species. An attempt has been done by Blasco, (1975) showing the different successional stages of mangroves in India. Untawale (1986) reported present status of the mangroves along the West Coast of India in Kachchh mangroves comprising *Sonneratia, Rhizophora* and *Ceriops* are pushed into vulnerable and *Aegiceras* into endangered category.

A detailed study of coastal mangrove ecosystem of Karnataka state was conducted by Ananda Rao *et al.*(1998). Kulkarni (2000) reported conservation aspect of Indian mangroves. Gamble's (1915) work also record rich mangrove vegetation along the Kerala coastal line. In Kerala there was a mention of occurrence of woody species of mangroves even in the beginning of this century till 1914 in literature; Troup (1921) gave references about Mangroves of Kerala, which was cited by Waheed Khan (1957). The study of Thomas,(1962) at Veli, Mohanan,(1981) at Quilon, Ramachandran *et al.* (1986) at Kumarakom and Basha, (1991) throughout Kerala clearly reveals the existence of true mangroves and the present: nature of isolated patches of' mangroves found in the state of Kerala. Vijayan *et al.* (2015) studied the floral diversity of Ayiramthengu mangroves of Kerala estuary.

2.3.10. Wood anatomical consideration of the mangrove family

Mangrove woods proved to be different from woods belonging to species growing in upland even if those species belonged to the same family or even genus (Javan). Wood anatomy can be used to identify a wood specimen in many cases, so obviously there are wood features that correspond to the taxonomic system. The family Rhizophoraceae with 16 genera comprising 120 species of trees and shrubs has a wide range of distribution in tropics and subtropics (Tomlinson, 1986). Four genera of this family viz. *Rhizophora* L., *Bruguiera* Lam., *Ceriops* Arn. and *Kandelia* W and A., differ from other genera in their habitat and adaptations. According to Bentham and Hooker (1965) this family includes 17 genera and about 50 species and divided these genera into three tribes namely Rhizophoreae, Legnotideae and Anisophylleae. The tribe Rhizophoreae which includes exclusively mangrove genera differs from other mangroves and tidal forest species by virtue of their viviparous seeds. Tomlinson (1986) depicted this tribe as 'mangrove Rhizophoraceae' because of their adaptability to mangrove ecosystems. Almost all the members of this family have used external morphological characters only. Marco (1935), however, used wood anatomical characters; Geh and Keng (1974) studied morphological and palynological as well as anatomical characters. It is clear that the views on the position of the mangrove genera (*Bruguiera, Ceriops, Kandelia*, and *Rhizophora*) have almost always been unanimous. Only Schimper (1893) did not classify them in one group. He assumed that the remarkable structure of the fruit and the mode of germination of these mangrove trees (viviparous) were mere adaptations to the tidal habitat and thus provided artificial and systematic characters. For this reason he mixed them with the inland genera. This was not supported by wood anatomical characters, as has been previously pointed out by

Moll and Janssonius (1926) and Marco (1935). Schimper's classification has never been accepted.

A considerable amount of wood anatomical data has been published in the past, mainly concerning the mangrove genera *Bruguiera, Ceriops,* and *Rhizophora* and the inland genera *Anisophyllea, Carallia, Combretocarpus*, and *Gynotrochesthe* (Van Vlet, 1976; Howard, 1948). The woods of the mangrove genera (Rhizophoreae) are very different from all inland representatives of the family. Exclusively scalariform perforation plates were observed in the mangrove genera and in some species of Cassipourea. In the mangrove genera there were mostly 5-8 bars per perforation, rarely up to 11. The presence of exclusively scalariform perforations with a constant number of bars is characteristic for the mangrove genera, while mixed perforations with a variable number of bars is characteristic for another group of genera. The fibres have thick or very thick walls, except in two genera (*Kandelia* and *Poga*) where the walls are usually thin (Van vliet, 1976). However, Marco (1935) illustrated that *Kandelia* can have very thick-walled fibres. Fibres with septa were observed in three of the four mangrove genera, being absent in *Ceriops*. According to Karlstedt (1971), the number of septa per fibre vary within *Rhizophora* members holds little specific diagnostic value. For most of the genera the main type of parenchyma distribution (unilaterally paratracheal, paratracheal banded, paratracheal scanty) is rather constant, although some species or genera are variable in this respect. The variation is rather considerable in the genus *Ceriops* (from scanty to ± banded) and *Cassipourea* (absent to frequent, scanty unilaterally paratracheal to unilaterally paratracheal banded). The rays of the Rhizophoraceae vary from heterogeneous I to III, and are in some cases even homogeneous (mangrove genera). Solitary crystals were observed in almost all genera. Only in *Kandelia* spp. it is of diagnostic value, since silica bodies were present in the ray cells of all samples studied. The vertically unilaterally compound vessel-ray pits can be used to support the close, mutual relationship of the genera growing in the mangroves, because this typical structure is restricted to these four genera alone, Presence of silica accumulations reported to be abundant in Rhizophoraceae family (Carlquist, 2001).

Avicenniaceae are one of the families frequently segregated from Verbenaceae. But according to Angiosperm Phylogeny Group III classification, *Avicennia spp.* belongs to Acanthaceae family (APG, 2009). Avicenniaceae have successive cambia with distinctive bands of sclerenchyma in the conjunctive tissue. Vessels are in radial multiples of 4 or more common. Imperforate tracheary elements are nonseptate libriform fibers. Crystals are abundant in rays. Avicennia (about six species) is a common constituent of tropical mangrove communities and is characterized by large horizontal roots producing lateral erect aerating roots (pneumatophores). The vascular system of Avicennia contains included phloem within the xylem. The alternative "rings" of xylem and phloem are separated by parenchyma (conjunctive tissue), considering the past as annual rings (Chapman, 1947). The wood anatomy of *Avicennia* is characterized by anomalous uniform growth rings which are however not correlated with the age of the tree (Robert *et al.,* 2011). Each ring consists of a band of xylem containing vessels and a band of conjunctive phloem tissue (Tomlinson, 1986). Between the parenchyma layers, successive cambia can be found. Simple perforation plates and having intervessel pits alternate, 5-20 vessels per square millimetre for *Avicennia* sps whereas 20 - 40 vessels per square millimetre for *Avicennia marina* (Inside wood, 2014). Orange gummy infiltration abundant occluding in many cells (Panshin, 1932).

The systematic position of *Sonneratia* L. f. which forms a part of the Myrtalean complex, has been the subject of discussion. Earlier, (Bentham and Hooker, 1862) have placed its genus in Lythreae of the Lythraceae. However, Thorne (1968, 1976, 1981) and Dahlgren (1975) kept this genus in the Lythraceae, but in a separate subfamily

Sonneratioideae. But according to Angiosperm Phylogeny Group III classification *Sonneratia* L. belongs to Lythraceae family (APG, 2009). Contrary to these, many systematists accorded a family status, Sonneratiaceae to these genera (Emberger, 1960; Cronquist, 1968; Takhtajan, 1969; Hutchinson, 1973). Rao *et al.* (1987) studied the wood anatomical difference between *Sonneratia* and its upland relative *Duabanga* are treated in the same family, anatomically there are more quantitative and qualitative dissimilarities than similarities between these two genera. From the observations made, *Duabanga* and *Sonneratia* show the following similarities: diffuse porosity, radially flattened fibres delimiting growth rings, vestured intervessel pits and minute fibre pits only on the radial walls. The dissimilarities between these two genera are: low and high frequency of vessels, percentage grouping of solitary vessels and radial multiples, tangential diameter of vessels, size of intervascular pitting, size and shape of vessel-ray pitting, presence and absence of parenchyma, uni- to multiseriate heterogeneous rays to almost exclusively uniseriate homogeneous rays, variable type of crystals and normal type of crystals in the rays, absence and presence of septa in the fibres. Furthermore, there are differences in vessel perforation types and morphology of vestured pits between these two genera (Rao *et al.,* 1987).

Aegiceras belongs to the family Myrsinaceae. Aegiceras can easily be distinguished from other Myrsinaceae by the presence of relatively narrow vessels, a relatively high vessel density, short vessel elements and fibers (which are both storied), non-septate fibers, a combination of uniseriate and multiseriate rays, and multiseriate rays with exclusively procumbent body ray cells and without sheath cells (Lens, 2005). On the other hand, the characteristic breakdown areas in rays are clearly present (Moll and Janssonius, 1926; Panshin, 1932; Metcalfe and Chalk 1950). At least some of these differences are related to the mangrove habit of *Aegiceras.* Tomlinson (1986) noted that the wood of mangrove species typically has a high number of narrow vessels, which are less vulnerable to cavitation, causing a safer sap stream. Furthermore, short vessel elements could also contribute to the safety of the sap stream in mangroves, which experience strongly negative pressures in their vessels due to the saline, physiologically dry, environment (Carlquist, 1977). However, Panshin (1932) and Van vliet, (1976) reported that the vessel element length of mangrove inhabitants does not differ considerably from the inland representatives. There are also other morphological features in *Aegiceras* that are atypical of Myrsinaceae, such as the presence of versatile anthers, viviparous fruits with exal-buminous seeds, and unitegmic ovules (Stahl and Anderberg, 2004). According to some authors, it seems highly unlikely that all these differences can be explained by the mangrove habit, supporting the idea to elevate *Aegiceras* to family level (Candolle, 1844; Dahlgren, 1975). However, molecular data show that *Aegiceras* falls within a well supported clade including all other woody taxa of Myrsinaceae studied (Kallersjo *et al.*, 2000).

Heriteria belongs to the family Malvaceae (APG III, 2009). The genera of all Sterculiaceae members are storyed with short vessel member length. Thus the family as a whole is considered as specialised one. The vessels in Sterculiaceae is usually moderate size in which the range varying from 30 to 200µm in tangential diameter. The pits to other vessels are always alternate commonly hexagonal in outline. Eventhough it recorded the primitive metatracheal paranchyma, the most specialized homogeneous rays were reported in this species (Chattaway, 1937). In *Lumnitzera racemosa* numerous (22— 24/mm^2) simple perforated vessels with oblique end walls and solid amorphous contents were frequent in the vessels. Parenchyma scanty paratracheal were reported in this species (Van vliet, 1979).

2.3.11. Ecological wood adaptation of dicotyledons

Ecological trends in wood have been investigated in several studies, and can be generalized as follows: (i) vessel element length and vessel diameter decrease from wet region to dry regions and from tropical to cool temperate or arctic latitudes, while the reverse is true for vessel density; (ii) a high degree of vessel grouping and the occurrence of vasicentric tracheids are most common in arid floras; and (iii) prominent helical thickenings are most abundant in Mediterranean and temperate floras (Van der Graaff and Baas, 1974; Van den Oever *et al.*,1981; Carlquist, 2001; Baas, 1986). An attempt has also been made in the present study to correlate the wood anatomical characters with ecological factors. Carlquist (1975) attempted to analyses factors underlying the selective forces which have guided evolution of conductive tissue in vascular plants. According to (Carlquist, 1977) short, narrow vessel elements resist high tensions in water columns. The most limiting factor for trees growing in a saline environment is the risk for cavitation – that is air bubble formation inside the xylem sap (Cochard, 2006) blocking water transport. Plants especially mangroves, maintain a balance between the protection of their water transport system against cavitation and conducting capacity (Mauseth and Stevenson 2004; Hacke *et al.*, 2006). High vessel density, high vessel grouping, small vessels and short vessel members are the adaptations to avoid reduction of hydraulic capacity after cavitation and subsequent air-filling of vessels (Baas *et al.,* 1983). To some extent there is an inverse correlation between diameter of vessels and the number of vessels per square millimetre. By dividing mean vessel diameter by number of vessels per square millimetre of transection one gets a value which may vary. A low value for this ratio indicates a great redundancy of vessels. According to him the more numerous the vessels per square millimetre the less the chance that disabling of a given number of vessels by air embolisms formed under water stress would seriously impair water conduction in a plant. A low value for this ratio would therefore indicate a capacity for withstanding water stress or freezing. Carlquist termed this ratio as 'vulnerability' and this ratio when multiplied by mean vessel member length gives values which he termed 'mesomorphy'. Species showing higher values indicate the mesomorphic nature of the plant. *Sonneratia* occurs in mangrove habitats and is adapted to saline hence physiologically dry conditions. Accordingly it shows smaller vessels with higher frequencies.

Duabanga growing inland has larger vessels in lower frequencies. In keeping with its mangrove habit, *Sonneratia* has a very low vulnerability value (2.51-4.52, average 3.52) when compared to *Duabanga* which showed a value of 43.20 (range 34.80-51.60). The low values obtained for *Sonneratia* are indicative of its capacity to resist water stress. Similarly, the mesomorphy values obtained for *Duabanga* (32,999) is indicative of a mesic ecology of the species unlike which has a very low value (2,315). Mangrove has been the subject of much investigation; the community is usually described as xeromorphic.

A very large number of vessels per mm^2 of transection in a species would result in a low ratio, perhaps connoting Zimmermann's 'safety' hypothesis, and certainly also a high degree of xeromorphy. Carlquist (1966) recognised that vessel elements having a few or no bars on their perforation plates represent a more favourable adaptation to dry environmental conditions than do perforation plates with numerous and closely spaced bars. To some extent, palms also display this correlation between form of perforation plates and degree of moisture demand in the environment (Klotz, 1978). The vessel elements of mangrove woods have simple perforation plates except in most members of Rhizophoraceae, which have scalariform perforation plates. *Kandelia candel*, the only species of the family Rhizophoraceae, possesses simple perforation plates. The end wall slope of the vessel elements in Rhizophoraceae also shows higher obliqueness. Scalariform perforation plates distinguish the mangrove Rhizophoraceae from their terrestrial relatives (Van vliet, 1976). According to Tomlinson (1986) Rhizophoraceae is monophyletic and evolved from an ancestor that had scalariform perforation plates in its wood. Scalariform perforations were retained in descendants because they are adaptively neutral.

Janssonius (1950), on the basis of some observations on three different species of *Bruguiera* at different ecological zones in Java, found a correlation between the number of vessels and frequency of inundation by the tidal water. He concluded that the more frequent the area is inundated in which the species grows, the larger the number of vessels per unit sectional area of wood. Aldridge (1978) and Carlquist (1966) in non-mangrove genus *Sonchus*, where they marked decrease in vessel length and breadth from xerophytic to coastal species. Scholander *et al.,* (1964) measured high tensions (negative pressure) in xylem and observed high density of narrow vessels in stems of mangroves. Frequent high tension in xylem increases the likelihood of cavitation within vessels during stressful conditions, which is directly dependent on vessel diameter (Zimmermann, 1983). Hence, the narrowness of vessels in mangrove-woods is for safety since it reduces the loss of conducting units by embolism (Tomlinson, 1986). The features in wood anatomy most directly related to ecology appear to be vessel diameter, vessel element length, and the number of vessels per mm^2 of transection. Shorter, narrower vessels can be cited as indicative of xeromorphy (Carlquist, 1975).

The occurrence of helical wall thickenings on vessel elements of several species seems hardly related to ecological preference (Lens *et al.*, 2004; Wheeler *et al.*, 2011). Carlquist (1982) has hypothesised that helical structure increases the surface area of walls of vessel elements and contribute to their bonding capacity for xylem sap, thus decreasing such risks. The geographical occurrence of species with well-developed helical sculpture seems to emphasize water stress created by either drought or cold; the latter produces physiological drought while soil water is frozen. Either condition can result in high tensions in vessels and ultimately air embolisms can be induced. In Myrtaceae Schmid and Baas (1984) observed the species with helical structure are restricted to temperate environment. Vesture pit in vessels would trap small air bubbles and help to dissolve the trapped gas volume so that normal water transport is restored (Carlquist, 1982). High vessel grouping denotes a greater degree of safety in conduction. Grouping of vessels is regarded as a way of providing alternate conduits whereby adjacent vessels are blocked by air embolism (Carlquist, 2001).

Analysis of wood traits plasticity in several studies has identified hydraulic properties of trees as more plastic than those of leaf structural and other physiological characters, concluding that hydraulic properties is essential for growth control. The wide tolerance of mangroves wood traits to environmental gradient suggesting that even if increases in relative sea level will eventually raise saturation and salinity conditions at ecotonal boundaries, mangroves are capable to advance or invade inland into freshwater marsh and swamp habitats, modifying distribution and composition of the mangrove (Doyle, 2003).

2.3.12. Evolutionary trend in Wood anatomy

Wood anatomy is a great source of traits that may be used in the studies of evolutionary relationships within flowering plants (Wróblewska, 2015). Solitary vessels should be considered as primitive according to the wood advancement code (Yatsenko-Khmelevskiy, 1948). They were evolutionarily succeeded by the grouped vessels in most dicotyledons. Simpson reported that modification of perforation plate from compound scalariform perforation to one with simple perforation. Boodle and Worsdell (1894) described transitions from scalariform to simple perforations which they had observed in the secondary xylem of several dicotyledons. Bailey and Tupper (1930) showed conclusively that the scalariform perforation is primitive and that the simple perforation is specialized. *Bruguiera parviflora* is a more primitive species with longer vessel segments. If the assumption is made that the vessel segment is frequently subjected to collapsing pressures, due to tension of the liquid column, specialization of the end wall is productive of greater rigidity. A brace parallel to the direction of force, such as the transverse end wall, is better adapted to resist crushing forces than an oblique brace. The primitive scalariform perforation has many bars, which are generally lost in slow stages in correlation with the evolutionary development of the perforation.

The specialization of the vessel results in a gradual reduction in length of the vessel segments (Frost, 1930).

In general the breaking down of the scalariform intervascular pitting occurs before or in correlation with this increase in diameter of the vessel. Occasionally, however, the scalariform sculpture persists and in such instances the scalariform pits are apparently drawn out horizontally. *Rhizophora mangle, Bruguiera gymnorrhiza,* and *Vitis* show this condition. The vessels are large in cross-section and show decided evidences of specialization, (Frost, 1931). Bailey and Tupper (1930) reported that length of vessel element decreases from scalariform to transitional to opposite to alternate. Specialization of the scalariform pit produces transitional and opposite pitting. The re-arrangement of opposite pits gives rise to the highly specialized alternate arrangement of intervascular pits.

Within the broad geographic range, mangroves grow in environmental settings ranging from high humid to extremely arid conditions. Mangroves form the dominant intertidal vegetation in tropical and subtrobical regions (Blasco, 1984). Mangroves are highly evolved communities adapted to tolerate high salinity and environmental stress by developing special anatomical, physiological and reproductive features (Knox, 2001; Kathiresan and Qasim, 2005; Ranade, 2007). In Rhizophoraceae the perforation plates remained scalariform, but the low number of widely spaced bars is suggestive of some degree of specialization here. The inter-vessel pits conform to the ancestral scalariform type. The fibre tissue, on the other hand is highly specialized with few minutely bordered to simple pits. The paucity of uniseriate rays may be interpreted as a reduction (cf. Barghoorn, 1941), and the heterogeneous II—III multiseriate rays constitute an example of specialization in themselves. Within the Rhizophoreae some of the genera show signs of further specialization; e.g. *Kandelia* has abundant parenchyma; the occurrence of septate fibres in three genera, but not in *Ceriops* also. The homogeneous type II rays and crystelliferous paranchyma occur in *Heriteria* shows advanced character (Chattaway, 1937). According to Robert *et al.* (2011), the intricate non concentric three dimensional network of phloem and xylem tissue within *Avicennia marina* assured a better linkage for water transport within the tree.

3. MATERIALS AND METHODS

The present investigation entitled "Ecoanatomical characterisation and development of anatomical key of selected mangrove species of West Coast of India" was carried out during the period 2013-2016. The details of materials and methods are explained hereunder.

3.1 Study Area

Wood samples which included blocks as well as increment cores of the mangrove species studied for present investigation were collected from ten locations in the Western Coast of India (Fig. I). Malwan, Achara, Dharivali and Airavali (Airoli) were the four sites selected from Maharashtra coast; Kodibag and Karwar from the Karnataka coast and Ayiramthengu, Vincent thuruthu, Vypin, Chettuwa, and Pulluni were the five sites chosen from the Kerala coast.

3.1.1. Description of study sites

3.1.1.1. Mangroves in Achara and Vengurula, Maharashtra coast

The mangrove pockets which were found in central West Coast of India extends about 720 km. It is a part of Konkan tract and is covered about 55 creeks and estuaries. Achara (16°20' 54.1"N and 73°43'97.3"E) and Vengurula (15°85' 25.4" N and 73°63' 28.7" E) are the two mangrove sites located in Sindhdurg district of South Konkan of Maharshtra coast. Malvan is the southern most part of Maharashtra and located approximately 35 km from the Mumbai-Goa National Highway No.17. It is the most important coastal tehsil of Sindhudurg district and is considered as one of the biologically richest coastal regions in Maharashtra. Achara is one of the main villages in this taluk. Sindhudurg region recorded an average annual rainfall ranging between 3000 and 3500 mm from south-west monsoon during the month of June to middle of October. The climate of Sidhudurg region is humid, which ranges from 65 to 90 % throughout the year and the average temperature ranges from 15°C to 34°C (IMD, 2015). The common mangrove zonation in Maharshtra coast is Rhizophora -

Fig 1.Map showing distribution of true mangroves in the selected sites of West Coast of India

Avicennia, Sonneratia, Aegiceras-Acanthus-Aeluropus (Chaphekar and Deshmukh, 1987). The samples of mangroves were collected from Achara and Vengurula mangrove patch. Karuli is the river flowing through this patch. Two threatened mangrove species were rediscovered from the West Coast of Maharashtra. One was *Heriteria littoralis* Dryand. recorded as rare species (Shaikh *et al.*, 2011) and another true mangrove species, *Xylocarpus granatum* was categorized as critically endangered (Smita *et al.*, 2011). The mangrove wood as well as core samples that were collected from Achara and Vengurula sites were *Sonneratia alba, Sonneratia caseolaris, Avicennia marina, Xylocarpus granatum, Heriteria littoralis, Bruguiera gymnorrhiza, Kandelia candel* and *Excoecaria agallocha.*

3.1.1.2. Dharivali and Airavali (Airoli), Mumbai

According to Blasco (1975), there were cluster of islands found around Mumbai during 1670 (Untawale, 1987). The Britishers realized the importance of these Islands for commercial purpose. These Islands had a luxuriant past of mangrove forests. The shallow marshy Islands reclaimed and filled up and became a solid stretch of landmass, which came to be known as "Greater Bombay". Due to deforestation, rapid development and increase in demographic pressure the mangroves around Mumbai form a fragile ecosystem. Major mangroves are seen today in Mumbai along the Vasai Creek, Manori, Thane Creek, and Malad, Mahim - Bandra, Versova, Siwari, Mumbra - Diva and few more places. The mangrove wood samples were collected from two sites namely Dharivali (19°16' 11.8" N and 72° 79' 84.9" E) and Airavali (Airoli) (19°14' 76.5"N and72°98'43.7"E). Dharivali is situated near the Sanjay Gandhi National park in the northern part of Mumbai. Airavali (Airoli) is located approximately 10 km from Thane. Small patches of mangroves were found in these sites. *Sonneratia apetala* is a patch of mangrove species reported only in Mumbai in West Coast. *Sonneratia alba, Sonneratia apetala, Avicennia officinalis* and *Ceriops tagal* were collected from these sites. The average daily temperature ranges between 22°C to 30°C and humidity reaches 98% in the rainy season and 60% in the winter season. The site enjoys an average rainfall of 2607 mm and pH of the soil ranges between 5.5 to 6.5 (IMD, 2015).

3.1.1.3. Kodibag in Karnataka coast

Several patches of mangroves which are interrupted by the mouths of rivers, creeks, rivulets, sandy ridges and bays were seen in the coastline of Karnataka. It extends about 320 km in length. Kodibag (14°50 17.6" N and74°07 57.1" E) is a small creek that lies on the southern bank of Kali estuarine mouth extending up to 1-2 kms which is located in the coastal districts of Karwar. This station is characterized by high saline water. The depth of the Kali estuary ranges from 2 - 4 meters at the mouth and about 2 - 3 meters towards the river. The river mouth opens into the Arabian Sea through a narrow mouth and tidal limit extends up to 29 km zone during low tide (Nagaraj and Neelakanthan, 1982). From Kali estuary the backwater zone extends both northwards and southwards. The backwater extends to fresh water zone where almost the salinity is almost 0.1 ppm, with negligible mudflats and mangroves. The mangrove environment of this estuary was divided into Rhizophora zone, Avecinnia zone, back mangrove and non-saline zones. There are 13 species from 9 genera under 7 families of mangrove found in this estuary (Achari, 2002). In the present observation, *Rhizophora mucronata* and *Rhizophora apiculata* which were found towards seaward zone is succeded by a patch of *Avicennia officinalis. Aegiceras corniculatum, Bruguiera cylindrica, Bruguiera gymnorrhiza, Excoecaria agallocha* and *Lumnitzera racemosa* were seen towards inland. The wood samples of mangrove species that were collected from this zone and comprises of *Aegiceras corniculatum, Bruguiera cylindrica, Bruguiera gymnorrhiza, Excoecaria agallocha* and *Lumnitzera racemosa.*

3.1.1.4. Pulluni, Malappuram, Kerala coast

Pulluni (10°51 27.57"N and 75°56 13.32"E) is located in Malappuram district of Kerala approximately 8 km distance from Tirur railway station. The district has the mangrove systems of about 26 hectares (Vidyasagaran and Madhusudanan, 2014). These mangrove patches are under threats due to population pressure and land conversion. A sporadic patch of mangroves in Pulluni, was located on the bank of the river Thirupuzha, a tributary of Bharathapuzha This stretch of Kerala coast is composed of purely alluvium of recent deposits (Chattopadhyay, 2010). A patch of *Bruguiera sexangula,* an endangered mangrove species seen only in this are

(Vidyasagaran and Madhusoodhanan, 2014). The mangrove wood as well as core samples were collected from this patch comprises of *Bruguiera cylindrica, Bruguiera sexangula, Rhizophora mucronata* and *Sonneratia caseolaris.*

3.1.1.5. Chettuva, Thrissur, Kerala coast

Chettuva (10°31 '51.6"N and 76°02'55.1"E) is located between Cochin and Calicut is considered as one of the most important mangrove zones in Kerala. The rivers of Chettuwapuzha and Karanjirapuzha joins and form a small estuary in this zone. This zone is located approximately 30 km from Thrissur town. The mangrove ecosystem look like *Rhizophora mucronata* dominated zone and is seen towards seaward side and other species like *Bruguiera cylindrica, Avincennia officinalis* and *Aegiceras corniculatum* were seen towards the landward side. The wood samples of species like *Rhizophora mucronata, Bruguiera cylindrica, Avincennia officinalis* and *Aegiceras corniculatum* were collected from Chettuva.

3.1.1.6. Vypin, Puduveypu, Kerala coast

The wood samples were collected from the mangrove patch associated with Fisheries Research Station, Kerala Fisheries Department at Puduvyppu (9° 58' 17.15" N and 76° 14 40.35" E). This is located in Ernakulam district extending an area of about 100ha. The site belongs to the Elangapuzha Panchayat of Kochi taluk with an altitude of approximately 5m above the mean sea level. It is bound by Arabian sea on the West, the Cochin Bay mouth on the south and landmasses of Vypin on othersides. In this area Avicennia zone is present in the seaward zone and *Rhizophora mucronata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Excoecaria agallocha* were found towards the land.

3.1.1.7. Vincent thuruthu (Vincent island), Kollam, Kerala coast

The estuarine Vincent Island (8°56 16.5" N and 76 °33' 09.00"E) which is located in Ashtamudi Lake at Shakthikulangara in Kollam is a private property covered by an area of 15 hectares of rich mangrove forests. Ashtamudi lake is one of the three Ramsar sites in India. Vincent Island is the only place in Kerala where the 48 rare yellow mangrove (*Ceriops tagal*) was found. This species, believed to be extinct from Kerala coast was rediscovered from the Ashtamudi estuary in 2012. These ecologically vital mangrove forests were reported to be threatened by development activity. The Island is supported by true mangroves such as *Rhizophora mucronata, Bruguiera gymnorrhiza, Avicenna officinalis* and *Sonneratia alba* and mangrove associates.

3.1.1.8. Ayiramthengu, Kollam, Kerala coast

Narrow and continuous belts of mangrove patch of Ayiramthengu (9' 073'2.6"N and 76° 28' 47.8"E) were situated in Kollam district of Kerala. These vegetations are located in the eastern bank of Kayamkulam estuary which is a narrow stretch of tropical backwater on the south west coast part of India. Twenty five acre spread of mangroves area in Ayiramthengu share the boundaries of three panchayaths including Alappad panchayath in western area, Clappana panchayath and Devikulangara panchayath in northern part. After it was ravaged by the Tsunami in 2004 and also threatened with extinction, Ayiramthengu mangrove forest was declared as an environmental hot spot. The mangrove species distributed in Ayiramthengu includes *Rhizophora apiculata, Aegiceras corniculatum, Excoecaria agallocha, Lumnitzera racemosa, Rhizophora mucronata, Sonneratia caseolaris* and *Avicennnia marina* (Vijayan *et al.*, 2015; Praseetha and Rajani, 2015).

3.2. Climatology and Oceanography of West Coast of India

The air temperature along the West Coast of India varies latitudinally with the least in the Kutchch region (26.5 °C) and increase southwards along the coast, having a value of around 28 °C along the Malabar coast. The amount of precipitation due to the orography is relatively more intense along the Konkan and Malabar coasts than along Gujarat coast. The strongest winds occur during summer monsoon period with an average wind speed of 15 m/s from the south-westerly direction. The spatial distribution of sea surface temperature (SST) shows a seasonal cycle with warmest temperature during spring (March-May) and coldest during winter. The sea surface salinity (SSS) along the west coast of India exhibits a strong temporal and spatial intra-annual variability with very low saline waters in the southern part during winter and high salinity towards the northern part (CSIR-NIO, 2015).

3.3. Materials

According to FSI (2015) the area distribution of mangroves in West Coast were estimated about 1367 km^2. Out of the total area, open mangrove constitutes an area of 1086 km^2 (80%) and moderately dense mangrove covers about 281 km^2 (20%) and very dense mangrove patch are totally absent in west coastal tract. Open mangrove cover comprises the canopy density between 10-40% (Annexure III). It is a fragmented patch. In the present study the wood samples of true mangrove species were collected from ten sites. The study sites were shown in map (Fig. 1).

Based on the publications of different workers, 20 true mangroves were reported in West coast of India (Annexure II). In the present study wood as well as core samples of seventeen true mangrove species were collected from ten different sites (Table 1). These species were distributed in 11 genera and 8 families. Rhizophoraceae members comprise seven species viz. *Rhizophora mucronata, Rhizophora apiculata, Ceriops tagal, Kandelia candel, Bruguiera gymnorrhiza, Bruguiera cylindrica* and *Bruguiera sexangula*. Two species of Acanthaceae include *Avicennia officinalis* and *Avicennia marina* and 3 species of Lythraceae family comprising *Sonneratia alba, Sonneratia caseolaris* and *Sonneratia apetala.* Rest five families comprises one species each. Meliaceae family includes *Xylocarpus granatum*, *Lumnitzera racemosa* from Combretaceae family, *Aegiceras corniculatum* from Myrsinaceae family, *Excoecaria agallocha* from Euphorbiaceae family and *Heritiera littoralis* from Malvaceae family (Table 2). The herbarium sheets were prepared and deposited in herbarium lab, College of Forestry.

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Table 1. Location and name of the true mangrove species sampled from West Coast of India

Location	Latitude (N)	Longitude (E)	Wood/Core samples
Vengurula, Malwan, Maharashtra	15°85' 25.4"	73°63' 28.7"	*Heritiera littoralis, Sonneratia alba, Sonneratia caseolaris*
Achara, Malwan, Maharashtra	16°20' 54.1"	73°43' 97.3"	*Xylocarpus granatum, Bruguiera gymnorrhiza, Kandelia candel, Avicennia marina, Excoecaria agallocha*
Dharivali, Mumbai	19°16' 11.8"	72°79' 84.9"	*Ceriops tagal, Sonneratia apetala*
Airavali/Airoli, Mumbai	19°14' 76.5"	72°98' 43.7"	*Avicennia officinalis, Sonneratia alba, Sonneratia apetala, Sonneratia caseolaris*
Kodibag, Karwar, Karanataka	14°50' 17.6"	74°07'57.1"	*Bruguiera cylindrica, Lumnitzera racemosa, Bruguiera gymnorrhiza, Aegiceras corniculatum, Excoecaria agallocha*
Fisheries station vyppin, EKM	9°58'17.15"	76°14'40.35"	*Bruguiera cylindrica, Bruguiera gymnorrhiza, Rhizophora mucronata, Avicennia officinalis, Avicennia marina, Excoecaria agallocha*
Tirur, Malappuram	10°51' 27.57"	75°56'13.32"	*Bruguiera cylindrica, Bruguiera sexangula, Rhizophora mucronata, Sonneratia caseolaris*
Vincent thuruthu	8°56'16.5"	76 °33'09.00"	*Bruguiera gymnorrhiza, Ceriops tagal, Sonneratia alba*
Ayiramthengu	9' 073'2.6"	76° 28' 47.8"	*Lumnitzera racemosa. Aegiceras corniculatum, Rhizophora apiculata, Excoecaria agallocha*
Chettuwa, Thrissur	10°31 '51.6"	76°02'55.1"	*Bruguiera cylindrica, Rhizophora mucronata, Aegiceras corniculatum*

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Table 2. Wood samples of true mangrove species collected from the ten study sites of the West coast of India

Sl No.	Scientific Names of Species	Nature of the plants	Family
1.	*Rhizophora mucronata* Lam.	Tree	Rhizophoraceae
2	*Rhizophora apiculata* Blume	Tree	Rhizophoraceae
3	*Ceriops tagal* (L.) Blume	Tree/Shrub	Rhizophoraceae
4	*Kandelia candel* (I.) Druce	Tree	Rhizophoraceae
5	*Bruguiera gymnorrhiza* (Lour.) Poir	Tree	Rhizophoraceae
6	*Bruguiera cylindrica* (L.) Druce	Tree	Rhizophoraceae
7	*Bruguiera sexangula* (Lour.) Poir	Tree	Rhizophoraceae
8	*Xylocarpus granatum* J.König	Tree	Meliaceae
9	*Lumnitzera racemosa* (L.) Gaertn	Tree	Combretaceae
10	*Avicennia officinalis* Lamark	Tree	Acanthaceae
11	*Avicennia marina* Vierth	Tree	Acanthaceae
12	*Excoecaria agallocha L.*	Tree	Euphorbiaceae
13	*Aegiceras corniculatum* Blanco	Tree/Shrub	Myrsinaceae
14	*Sonneratia alba* Sm.	Tree	Lythraceae
15	*Sonneratia caseolaris* (L.) Engl	Tree	Lythraceae
16	*Sonneratia apetala* Buch.-Ham	Tree	Lythraceae
17	*Heritiera littoralis* Dryand	Tree	Malvaceae

3.4. Methodology

The wood as well as core samples of 17 true mangrove species were collected from 10 sites of West Coast of India. The study sites are shown in the GIS map (Fig.1). The GIS map was prepared using Arc GIS 10.3. The core samples were collected using an increment borer (Haglof 2 thread 10mm increment borer) from the trees with a GBH of 10cm and above. Common name, distribution and tree characteristics were added along with the description of wood characters of each mangrove species. The features which were used in the study for identification includes general features and anatomical features.

3.4.1 General features

These include the features which can be directly observed without the aid of a microscope. The relevant non anatomical features mentioned in the International Association of Wood Anatomists (IAWA) list of microscopic features for hardwood identification (Wheeler, 2011) were also incorporated.

3.4.1.1 Wood basic density

The basic density of wood is determined by using immersion method. This is the ratio between the dry weights of wood and the green volume of the same wood. Wood specimens of size 2.0 cm^3 were made out from each mangrove sample. Majority of the samples were measured directly after harvesting. In some cases measurement was taken after one or two weeks then the wood samples were placed in water to obtain maximum hydration for a given period of time (e.g., overnight). A container capable of holding the sample was filled with water and placed on a digital balance of precision of 0.0001 g. The sample was then carefully sunk in the water, such that it was completely under water. The container should not be completely filled with water; enough room should be made for the sample. The sample should not contact the sides or bottom of the container, and it should be forced underwater with a thin needle. The measured weight of displaced water is equal to the sample's volume. This is called green volume. Oven dry weight were obtained by drying wood samples between 100 - 105°C until constant mass was attained (typically 24-48h).

3.4.2. Wood anatomical properties

Wood anatomy was studied with the help of two techniques: wood microtomy and maceration.

3.4.2.1 Microtomy

Wood specimens of size 1.0 cm^3 and core samples size of 1cm were chiselled out from each samples and used for anatomical studies. The specimens 53 were then softened by keeping in water bath (Rotex water bath) at 100 °C depending on the nature of specimen. Transverse section (TS), longitudinal section (TLS) and radial (RLS) sections of 10-15 μm thickness were prepared using a Leica sliding wood microtome (Leica SM 2000R). The sections were stained using saffranin and later washed through a series of alcohol solutions at different concentrations (70 %, 90 % and 95 %) to ensure complete dehydration. They were subsequently dipped in acetone followed by xylene and finally mounted in DPX mountant to prepare permanent slides (Johansen, 1940).

3.4.2.2 Maceration

Maceration of the wood samples was done using Jeffrey's method (Jeffrey, 1917). For maceration, Jeffrey's solution was used and it was prepared by mixing equal volumes of 10 per cent potassium dichromate and 10 per cent nitric acid. Radial chips of wood shavings were taken from the 2 cm^3 wood blocks. These chips were boiled in the maceration fluid for 15-20 minutes so that the individual fibres were separated. Then these test tubes were kept for 5-10 minutes so that the fibres settled at the bottom. The solution was discarded and the resultant material was thoroughly washed in distilled water until traces of acid were removed. The samples were stained using saffranin and mounted on temporary slides using glycerin as the mountant.

3.4.2.3 Image Analysis

Microscopic examination and quantification of sections were undertaken using an Image Analyzer (Labomed-Digi 4). It consists of a microscope, digital camera and PC (Personal computer). The image analyzer provides quick and accurate data replacing the more laborious traditional methods. The digital camera provides digitized images which are analysed by the computer software (Labomed DigiPro-4). The software provides several classes of measurements like length, diameter, area and frequency of sections.

3.4.2.4 Observations

The observations were taken from the three planes of sections includes TS, TLS and RLS. Both quantitative and qualitative observations were recorded. From each species five samples were taken except from *Heritiera littoralis* and *Xylocarpus granatum*. Two samples were taken from *Heritiera littoralis* and one sample from *Xylocarpus granatum*. For each sample, 25 measurements were taken from each parameter.

The transverse sections (T.S) of the species were used to determine quantitative and qualitative features. The quantitative features such as vessel frequency (vessels per mm^2), vessel diameter, vessel area, vessel grouping and cambial variants were taken. Vessel frequency was determined by counting the number of pores in randomly selected fields of the section with the help of the image analysis software, Labomed-Digi 4 and was expressed as number per millimeter (mm). In measuring vessel diameter, only the tangential diameter has been used (Chattaway, 1937). Vessel grouping is defined as the ratio of total number of vessels to total number of vessel groupings (including solitary and grouped vessels). Vessel grouping was also calculated by Carlquist (1984) methodology. Also calculated in terms of solitary vessel percentage. The qualitative features like growth rings, nature of porosity, vessel arrangement, solitary vessel outline, axial parenchyma type were determined from transverse section.

The ray features such as ray frequency, ray width and ray height were taken from the tangential section. The qualitative features such as types of perforation plates, arrangement of intervessel pits, vestured pit (minute outgrowths from the secondary cell wall), vessel ray pitting, vessel parenchyma pitting, helical thickening on vessel element, septate and non septate nature of fibre, storied structure, laciferous tubes, mineral inclusions and sheath cells were observed in both radial and tangential section. Type of ray cells, pits on fibres, sclerieds were also recorded from radial section. The observations like fibre length, fibre diameter, fibre wall thickness and vessel length were taken through maceration. The vessel length was measured including tails (Van vliet, 1976). Fibre wall classification is according to IAWA classification (Wheeler, 2011). For describing microscopic features, the IAWA list of microscopic card key features for hardwood identification (Wheeler, 2011) are given in Annexure I. A perforated card key based on the IAWA list of microscopic card features for hardwood identification was also prepared.

3.5 Ecoanatomical wood features of mangroves species

The important ecoanatomical wood features that were taken for the study were vessel length, vessel diameter, vessel frequency, solitary vessel percentage. These were compared with the nearest terrestrial relative of each mangrove species (Weerdt, 2010; Lindorf, 1994). The data for the nearest terrestrial relative were taken from the other published literature which are mentioned below. The phylogenetic relationship between the mangrove genera and their upland relative were confirmed by different molecular cladistics analyses through Maximum Parsimony (MP) (Hilu and Borsch, 2003) or Maximum Likelihood (ML) (Tomlinson, 1986) method from various published literature and is shown in Annexure IV. Wood anatomical indices of vulnerability (mean vessel member diameter divided by mean vessel frequency) and mesomorphy (vulnerability multiplied by mean vessel member length) were calculated from species means according to the formulae of Carlquist (1977).

3.6. Evolutionary trend in wood anatomy of mangroves

Some ecological trends were well established for ecological wood anatomy and have been suggested to be one of the main forces of wood evolution through adaptation (Baas *et al.*, 2004). Nevertheless, the wood of mangrove families has neither been fully described nor adequately interpreted ecologically and evolutionarily. In order to establish an evolutionary trend of mangrove species it is necessary to mention the features recognized for trend of evolution (Carlquist, 2001). The trends in evolution are evident in a number of features which are mentioned by several authors (Carlquist, 2001; Frost, 1930; Kribs, 1935; 1937).

3.7 Statistical analysis

The statistical method used for the analysis of present investigation for comparing 17 mangrove species and also for comparing the genera within family were one way ANOVA by using IBM SPSS software.

4. RESULTS

The results pertaining to the wood blocks as well as core samples of 17 true mangroves collected from the ten sites of West Coast of India are presented here and are divided into two parts. Part I comprises of descriptive and comparative wood anatomy and also the IAWA key preparation of seventeen true mangroves. In part II the ecoanatomical wood features of true mangrove species are studied and compared with data from the nearest terrestrial relative of each mangrove genera.

4.1 Description of mangrove wood anatomy

4.1.1. *Rhizophora mucronata* Lam.

Common name: Long fruited stilted mangrove

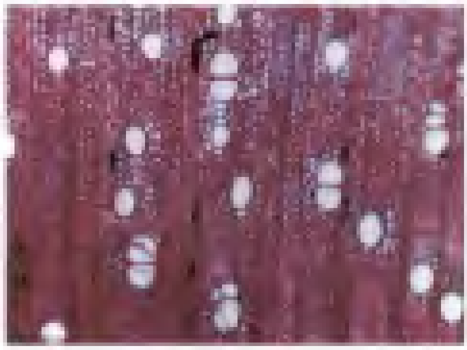
Local name: Peekandal (Malayalam), Garjan or Khamo (Bengali)

Family: Rhizophoraceae

4.1.1.1.Tree: Medium to tall tree, upto 15m high having cylindrical bole with diameter upto 2m. Trunk is supported by profuse prop roots, stilt root and knee roots (Plate 18m).

4.1.1.2.Distribution

This species is very widespread. The species is distributed in South Asian range includes Bangladesh, Brunei Darussalam, Cambodia, Taiwan, Japan, India, Indonesia, Malaysia, Myanmar, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, and Southern Vietnam. The species is also distributed in Australasian range which includes Northeast Australia, Federated States of Micronesia, Palau, Papua New Guinea, Solomon Islands and Vanuatu. In East Africa and the Middle East it is present in Egypt, Eritrea, Iran, Kenya, Madagascar, Maldives, Mauritius, Mozambique, Saudi Arabia, Seychelles, Somalia, South Africa, Sudan, Tanzania,



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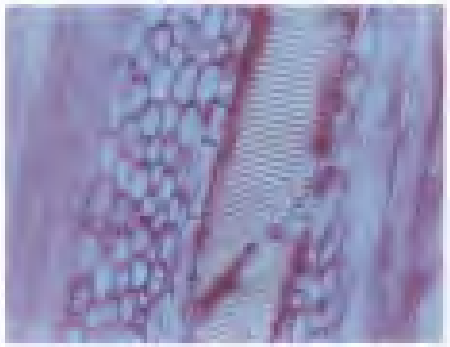

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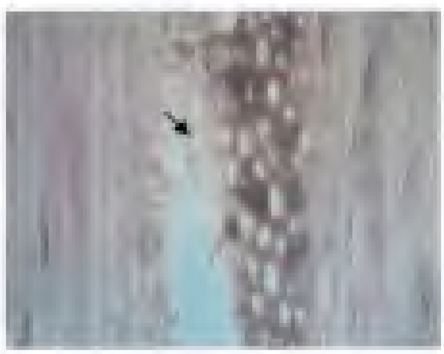
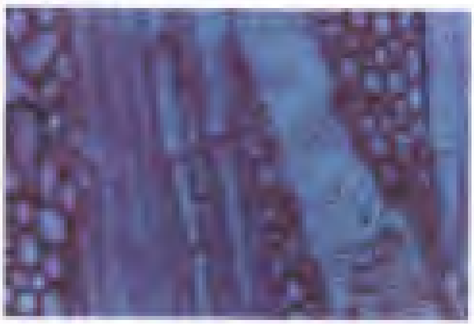


1f

Plate 1. Wood anatomical features of *Rhizophora mucronata* (*a.* TS 4X b. TLS 10X c. RLS 40X d. Scalariform lateral wall pitting (TLS 40X) e. Vessel bars with oblique end (Maceration 40X) f. Black arrow indicates vessel ray uniseriate bordered pit (TLS 40X)



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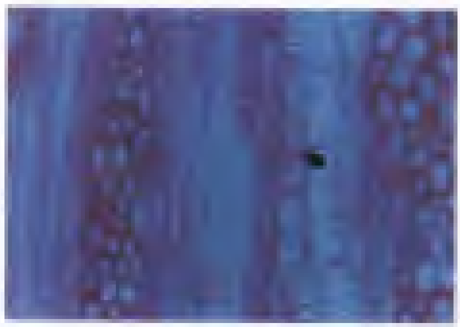

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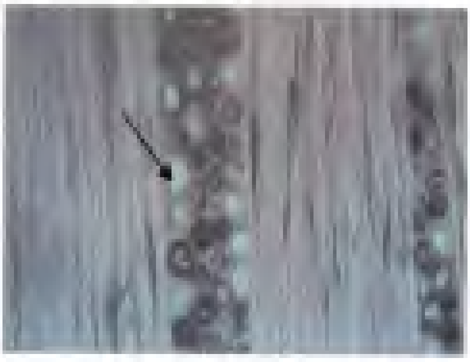

1i

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1k

1l

(Plate 1. Wood anatomical features of *Rhizophora mucronata* g. Reticulate bordered vessel ray pit (TLS 40X) h. Scalariform bordered ray parenchyma pit (TLS 40X) i. Prismatic crystals (black arrow) in ray cells (TLS 40X) j. Globular inclusions in ray cells (RLS 40X) k. Thick walled fibres and lumen completely closed (Maceration 40X) l. Non septate fibre with minute pits (RLS 40X)

Yemen, Oman, and United Arab Emirates. In India *Rhizophora mucronata* are distributed in both East and West Coast and Andaman and Nicobar Islands.

4.1.1.3. IUCN status: Least concern

4.1.1.4. Wood anatomical features

Growth ring boundaries were indistinct or absent (Plate 1a, IAWA key no. 2). Diffuse-porous wood (IAWA key no. 5). Vessels are solitary and in radial multiples of 2-4, 60-85% solitary. Perforations are scalariform (IAWA key no. 14) in oblique end walls (Plate 1e), with thick 6-7 vessel bar (Plate 1e, IAWA key no. 15) with an average width of 16µm. Inter-vessel pits scalariform, extending over the entire inter-vessel walls (IAWA key no. 20). Vessel-ray pits bordered to simple opposite to reticulate, uniseriate (Plate 1f,1g,1h), round to elongate. Vessel-parenchyma pits large and almost simple, infrequently half-bordered, uniseriate, biseriate, scalariform, or diffuse (Plate 1h). Solid granular contents frequently present in the vessels. Diameter of vessel lumina is in the range between 50-117µm with an average of 88 µm. Vessel frequency ranges between 5-20 vessels per mm^2 with an average of $12.9/mm^2$ (IAWA key no. 47). Vessel length ranges between 350-800 µm. Vessel area with an average of 4417 µm. Dark brown colour contents frequently present in the vessels. Fibres with simple to minutely bordered pits (Plate 28, IAWA key no. 61). Frequently non septate fibre (IAWA key no. 66) and infrequently septate fibre (IAWA key no.65). Fibres are very thick walled to thin walled having mean fibre length 1493 µm and mean diameter of 29 µm. Axial parenchyma paratracheal scanty (IAWA key no. 78), vasicentric abundant (IAWA key no. 79) to rarely aliform confluent (IAWA key no. 83). Eight (5-8) cells per parenchyma strand (IAWA key no. 93). Heterogeneous III ray type and ray frequency ranges between $4\text{-}7/mm^2$. Ray width ranges between 1-3 cells of small rays and large rays 4-8 cells wide, ray height upto 2217 µm (IAWA key no.103). Body ray cells procumbent with one row of upright and / or square marginal cells and body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells. Sheath cells present (IAWA key no. 107). Granular inclusions are present in ray cells (Plate 1j). Prismatic crystals are reported in procumbent and square cells in rays (IAWA key no.137 and 138, Plate 1i).

4.1.2. *Rhizophora apiculata* Blume

Common name: Tall stilted mangrove

Local name: Kayakandal/Vallikandal (Malayalam)

4.1.2.1. Tree: Medium to tall tree, upto 10-12m high having cylindrical bole with diameter upto 2m (Plate 18e). Trunk is supported by profuse prop roots, stilt root and knee roots.

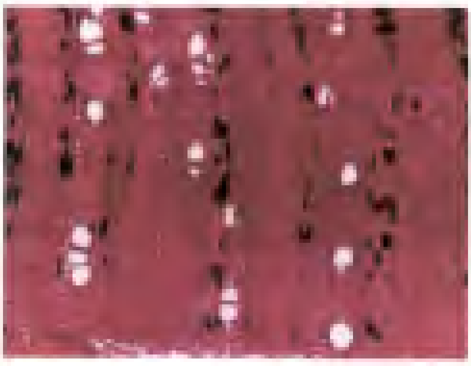
4.1.2.2. Distribution

This species is found in South Asia extending upto Bangladesh, India, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Brunei Darussalam, Cambodia, southern Viet Nam, and China (Hainan Island), Northern Maldives. In Australasia, its range includes Northwest Australia, Northeast Australia, Federated States of Micronesia, Guam, New Caledonia, Palau, Papua New Guinea, Solomon Islands, and Vanuatu. In India it is found in both east and west coast and Andaman Island.

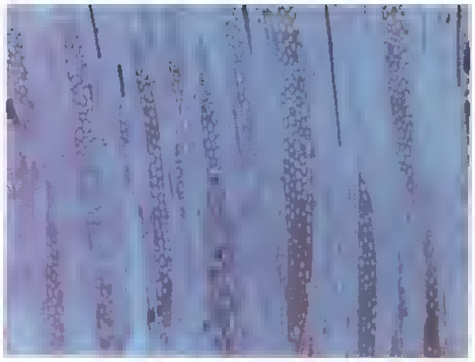
4.1.2.3. IUCN status: Least concern

4.1.2.4. Wood anatomical description

Growth ring boundaries were indistinct or absent (Plate 2a, IAWA key no. 2). Wood is diffuse-porous (IAWA key no. 5). Vessels are solitary and in radial multiples of 2-4, 60-80% solitary. Perforations are scalariform in oblique end walls (plate 2d, IAWA key no. 14), 6-7 thick vessel bar (Plate 2h, IAWA key no. 15) with an average width of 19μm. Inter-vessel pits scalariform, extending over the entire inter-vessel walls (Plate 2d). Vessel-ray pits bordered to simple opposite to reticulate, round to elongate scalariform pit (Plate 2i). Vessel-parenchyma pits large and almost simple, bordered, uniseriate, biseriate, scalariform, or diffuse. Diameter of vessel lumina is in the range between 50-100μm with an average of 61 μm (IAWA key



2a



2b

2c

2d

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2f

Plate 2. Wood anatomical features of *Rhizophora apiculata*. a. TS 40X b. TLS 40X c. RLS 40X d. Scalariform plates with oblique end wall (TLS 40X) e. Sheath cells present in rays (TLS 40X) d. Scalariform plates with oblique end wall (TLS 40X) e. Sheath cells present in rays (TLS 40X) f. Globular content present on rays (RLS 40X)

2g

2h

2i

2j

Plate 2. Wood anatomical features of *Rhizophora apiculata* g. Rhomboidal crystals present on rays (RLS 40X) h. Thick vessel bars (RLS 40X) i. Scalariform bordered vessel ray pit (TLS 40X) j. Minute pits on non septate fibres (RLS 40X)

no.41). Vessel frequency with an average of 12 vessels per square millimeter (IAWA key no. 47). Vessel length ranges between 390-800 µm (IAWA key no. 53). Vessel area with an average of 5932 µm. Brown coloured contents frequently present in the vessels (Plate 2i). Vasicentric tracheids present. Fibres with simple to minutely bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66) and fibres are thick walled. The mean fibre length 1170 µm (IAWA key no. 72) and mean diameter of 25 µm. Both paratracheal scanty (IAWA key no. 78) and vasicentric abundant (IAWA key no. 79) axial parenchyma are present. Eight (5-8) cells per parenchyma strand (IAWA key no. 93).

Rays are heterogeneous III, ray frequency range between 6-7/mm^2 and ray width ranges between 1-3 cells of small rays and large rays 4-8 cells wide, ray height upto 1360 µm (IAWA key no. 103). Body ray cells procumbent with one row of upright and / or square marginal cells and body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (IAWA key no. 106 & 107). Sheath cells present (IAWA key no.110). Granular inclusions are present in ray cells (Plate 2f, 2g). Prismatic crystals are present in procumbent (Plate 2g, IAWA key no.138) and square cells (IAWA key no. 137) in rays.

4.1.3. *Bruguiera cylindrica* (L.) Druce

Common name: Small leaved orange mangrove

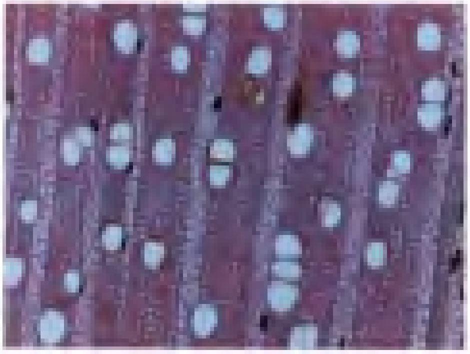
Local name: Kuttikandal (Malayalam), Bakul kankara or Bakul (Bengali)

Family: Rhizophoraceae

4.1.3.1. Tree: Medium to tall tree, upto 15m high with cylindrical bole and diameter ranges from 20-40cm. Dark green foliage wood (Plate 18 l). Bark deep black to grey. Horizontal root deep, knee roots and root buttresses are formed.

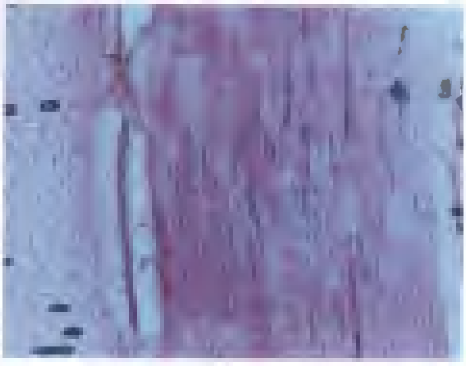
4.1.3.2. Distribution

This species is found in Brunei Darussalam, China, Taiwan, India,



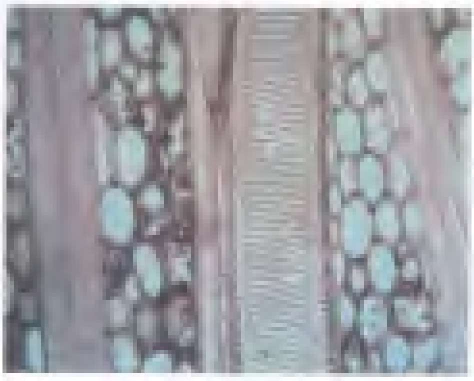
3a

3b



3c

3d



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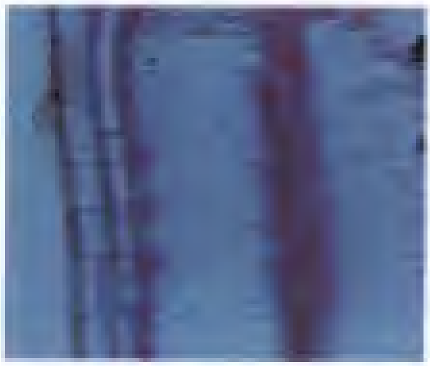
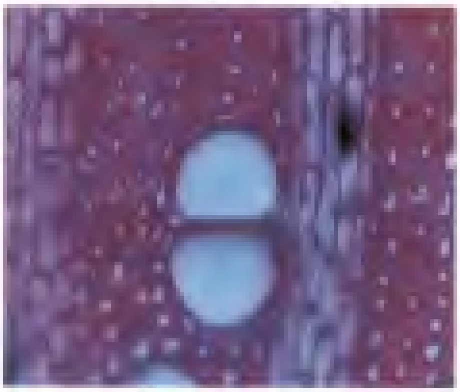
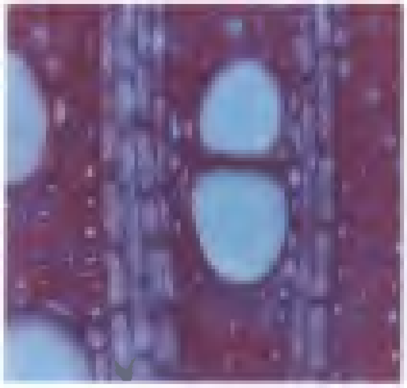


3f

Plate 3.Wood anatomical features of *Bruguiera cylindrica* a. TS 10 X b. TLS 40X c. RLS 40X d. Vessel bar with oblique end (Maceration 40X) e. Transitional lateral wall pitting (TLS 40X) f. Vessel parenchyma pit (RLS 40X)



3g



3h

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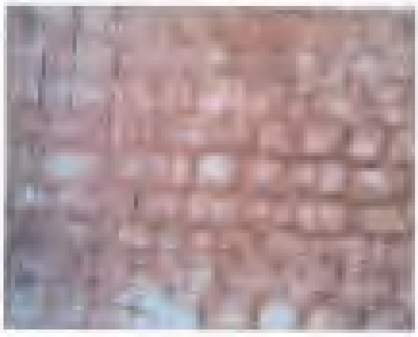


3l

Plate 3. Wood anatomical features of *Bruguiera cylindrica* g. Axial parenchyma absent (TS 40X) h. Paratracheal vasicentric scanty parenchyma (TS 40X) i. Scalariform vessel ray pit (RLS 40X) j. Half bordered vessel parenchyma pit (RLS 40X) k. Globular content present on ray cells (TLS 40X) l. Presence of colourless circular granules on procumbent ray(RLS 10X)

Indonesia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, northeast Australia, Papua New Guinea, Pacific Islands and the Maldives. In India it is distributed in both East and West Coast and Andaman Island.

4.1.3.3. IUCN status: Least concern

4.1.3.4. Wood anatomical description

Growth ring boundaries are indistinct or absent (Plate 3a, IAWA key no. 2). Wood is diffuse-porous (IAWA key no. 5). Vessels are solitary and in radial multiples of 2-3, 30-40% solitary, round to oval. Perforations are scalariform (Plate 59) with oblique end walls (Plate 3d), 7-8 thick vessel bar (Plate 3d, IAWA key no. 15) with an average width of 10μm. Inter-vessel pits scalariform (IAWA key no.14), infrequently transitional (Plate 3e) extending over the entire inter-vessel walls. Vessel-ray pits are bordered to simple opposite to reticulate, round to elongate scalariform pit in uniseriate, biseriate and alternate pattern (Plate 3f). Vessel-parenchyma pits are simple, half bordered and bordered. Diameter of vessel lumina is in the range of 50-100μm.Vessel frequency with an average of 16 vessels per square millimeter (IAWA key no.47). Vessel length with an average of 637μm (IAWA key no. 53). Average vessel area 5932 μm. Tyloses frequently present in the vessels. Gums and other deposits present in heartwood vessels. Gash like appearance are observed on vessels (Plate 3j). Fibres with simple to minutely bordered pits are present (IAWA key no.61). Non septate fibre (IAWA key no. 66) and infrequently septate fibre (IAWA key no. 65) are reported. Fibres thick walled having mean fibre length 1182 μm and mean diameter of 27 μm. Axial parenchyma rare or absent (Plate 3g), paratracheal scanty (Plate 3h). Eight (5-8) cells per parenchyma strand (IAWA key no. 93). Rays areheterogeneous III, ray frequency range between 4-5/mm^2. Ray width ranges between 1-3 cells and large rays with 4-8 cells wide, ray height upto 1288 μm. Body ray cells procumbent with one row of upright and / or square marginal cells (IAWA key no. 106) and body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (IAWA key no. 107) . Sheath cells are present (IAWA key no. 110). Granular inclusions were found in ray cells. Prismatic crystals are also present in ray cells (Plate 3k, IAWA key no.75& 78).

4.1.4. *Bruguiera gymnorrhiza* (L.) Poir.

Common name: Large-leaved orange mangrove

Local name: Penakandal (Malayalam), Kankara (Bengali)

Family: Rhizophoraceae

4.1.4.1. Tree: Medium to tall tree, upto 12-14 m high with diameter ranges from 25-80cm. Wood, dark green foliage. Bark deep black to grey. Knee roots and thick root buttresses are formed.

4.1.4.2. Distribution

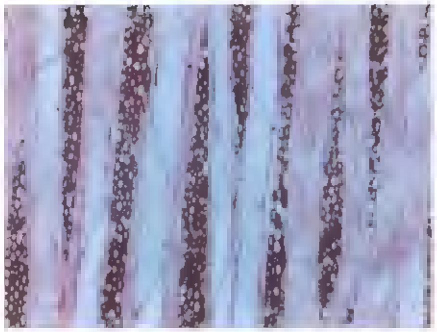
The species are distributed in Central South Asia, Brunei Darussalam, Cambodia, China, Hong Kong, India, Indonesia, Japan, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, and Bangladesh. In Australasia it is found in American Samoa, Northwest Australia, Northeast Australia, Southeast Australia, Federated States of Micronesia, Fiji, Guam, New Caledonia, Palau, Papua New Guinea, Solomon Islands, Tonga, Vanuatu, and Western Samoa. In East Africa and the Middle East, it is found in Kenya, Madagascar, Maldives, Mauritius, Mozambique, Seychelles, Reunion, Somalia, South Africa, Tanzania. In India it is distributed in Sundarbans, throughout East and West Coast and Andaman Nicobar Islands.

4.1.4.3. IUCN status: Least concern

4.1.4.4. Wood anatomical description

Growth ring boundaries were indistinct or absent (Plate 4a, IAWA key no. 2). Wood is diffuse-porous (IAWA key no.5). Vessels are solitary and in radial multiples of 4 or more, 35-40% solitary, round to oval. Perforations are

4a



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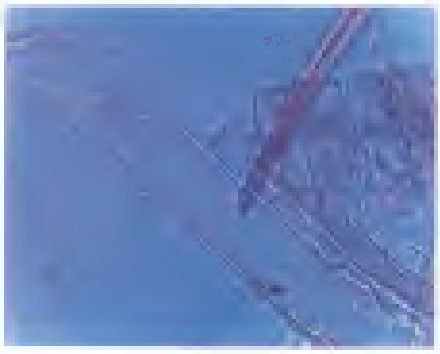

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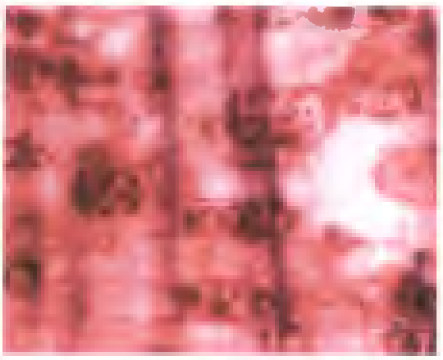

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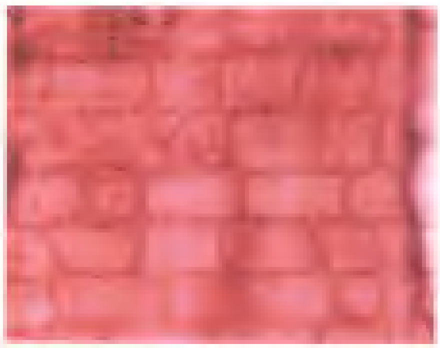
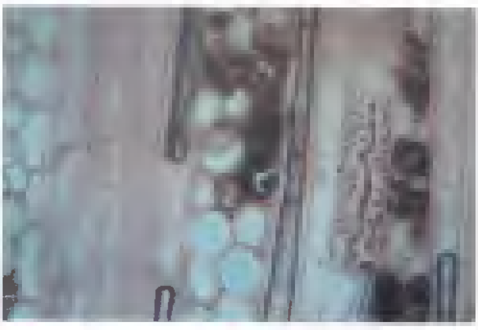


4f

Plate 4. Wood anatomical features of *Bruguiera gymnorrhiza* a. TS 4X b. TLS 10X c. Vessel bars present on vessel plates (RLS 40X) d. Scalariform vessel plate with oblique end (Maceration 40X) e. Globular content on procumbent ray cell (RLS 40X) f. Polygonal crystal present on ray cells (RLS 40X)



4g

4h

4i

4j

Plate 4. Wood anatomical features of *Bruguiera gymnorrhiza* g. Granular content present on parenchyma (TLS 40X) h. Crystals present on fibre (RLS 40X) i. Helical thickenings present in fibres (TLS 40X) j. Simple bordered vessel ray pit (RLS 40X)

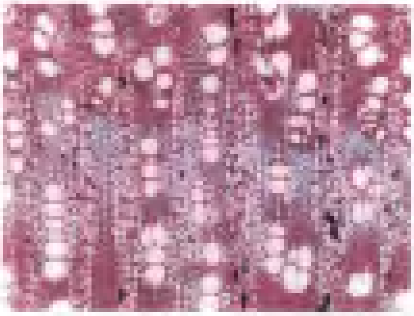
scalariform, in oblique end walls (Plate 4d), with thick 12-16 vessel bar (Plate 4c, IAWA key no. 16) with an average width of 14µm. Inter-vessel pits scalariform (Plate 4d), infrequently transitional extending over the entire lateral vessel walls. Vessel-ray pits bordered, half bordered to simple opposite to round to elongate scalariform pit in uniseriate, biseriate and alternate pattern. Vessel-parenchyma pits simple, half bordered and bordered. Vessel ray pits of two distinct sizes or types in the same ray cell present. Diameter of vessel lumina is in the range between 50-100µm.Vessel frequency had an average of 16 vessels per square millimeter (IAWA key no. 47). Vessel length with an average of 637µm. Average vessel area 5932 µm. Tyloses like brown colour contents are frequently present in the vessels. Gums and other deposits in heartwood vessels. Fibres with simple to minutely bordered pits (IAWA key no.61). Non septate fibre (IAWA key no. 66) and infrequently septate (IAWA key no. 65). Fibres thick walled having mean fibre length 1182 µm and mean diameter of 27 µm. Helical appearance are present on fibres (Plate 4i, IAWA key no. 64). Crystals are reported to be present in fibres (Plate 4f). Elongated crystals are also present. Axial parenchyma rare or absent, paratracheal scanty (IAWA key no. 93). Eight (5-8) cells per parenchyma strand (IAWA key no. 75 and 78).

Rays heterogeneous type III, ray frequency ranges between 4-5/mm^2, small rays with ray width 1-3 cells and large rays with 4-8 cells wide, ray height up to 2237 µm. Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells. Sheath cells are present. Granular inclusions are found in ray cells (Plate 4g). Prismatic crystals and polygonal crystals observed in square cells in rays (Plate 4f, IAWA key no.137).

4.1.5. *Bruguiera sexangula* (Lour.) Poir

Common name: Large-leaved orange mangrove

Local name: Swarnakandal (Malayalam), Kankara (Bengali)



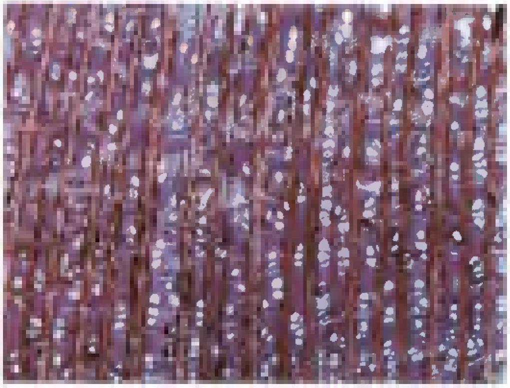
5a

5b

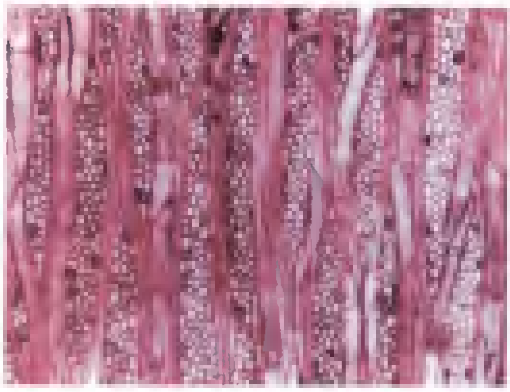
5c

5d

Plate 5. Wood anatomical features of *Bruguiera sexangula* a.TS 10 X b. TLS 10X c. Branched and unbranched vessel bar (RLS 40X) d. Vessel ray pit (RLS 40X)



6a



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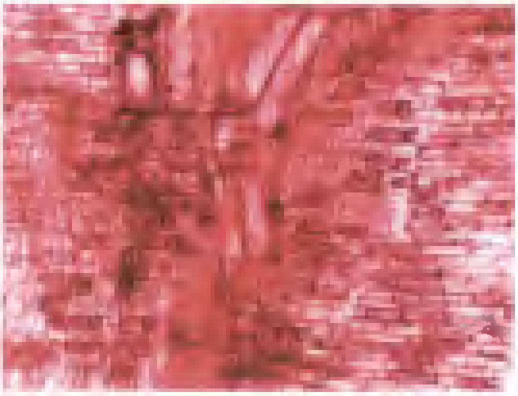

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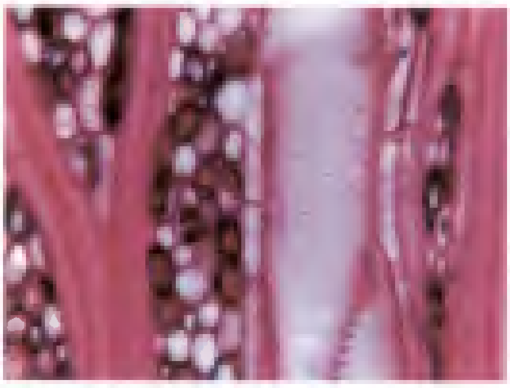


6d

Plate 6. Wood anatomical features of *Kandelia candel* a.TS 4 X b. TLS 10X c. RLS 40X d. Scalariform lateral wall pitting (TLS 40X)

Family: Rhizophoraceae

4.1.5.1. Tree: Medium to tall tree, up to 12 m high had cylindrical bole with diameter ranges from 15-20 cm. Dark green foliage wood. Knee roots and thick root buttresses are formed.

4.1.5.2. Distribution

This species is widespread and found in India, Bangladesh, Brunei Darussalam, China, Taiwan, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Northeast Australia, Papua New Guinea, and the Solomon Islands. In China, this species is restricted to Hainan Island. It was introduced into Hawaii in 1922. In India it is distributed in South West Coast of India and throughout Andaman Nicobar Islands.

4.1.5.3. IUCN status: Least concern

4.1.5.4. Wood anatomical description

Growth ring boundaries were indistinct or absent (Plate 5a, IAWA key no.2). Wood is diffuse-porous (IAWA key no.5). Vessels are solitary and in radial multiples of 6 or more, 18-25% solitary, round to oval. Solitary vessel having angular outline (IAWA key no.12). Perforations are scalariform end walls are oblique, with 7-8 vessel bar (Plate 5c, IAWA key no.15) with an average width of 13μm. Inter-vessel pits scalariform, infrequently transitional extending over the entire inter-vessel walls. Vessel-ray pits bordered to simple opposite to reticulate, round to elongate scalariform pit in uniseriate, biseriate and alternate pattern (Plate 5d). Vessel-parenchyma pits simple, and bordered. Vessel ray pits of two distinct sizes or types in the same ray cell present. Diameter of vessel lumina is in the range between 50-100μm with an average of 62 μm (IAWA key no. 41). Vessel frequency with an average of 26 vessels per square millimeter (IAWA key no. 47). Vessel length is in the range between 350-800 μm with an average of 652μm. Average vessel area 5116 μm. Fibres with simple to minutely bordered pits. Non septate fibre (IAWA key no. 66) and infrequently septate (IAWA key no.65). Fibres thick walled to thin walled. Fibre length is in the range between

800 to 2000 μm with an average of 1182 μm and mean diameter 25 μm. Axial parenchyma paratracheal scanty (IAWA key no. 78) and vasicentric abundant (IAWA key no.79). Eight (5-8) cells per parenchyma strand were present (IAWA key no.93).

Rays heterogeneous type III, ray frequency ranges between 4-5/mm^2, small rays with ray width 1-3 cells and large rays 4-8 cells wide, ray height up to 2237 μm (Plate 5b, IAWA key no. 103). Body ray cells procumbent with mostly 2-4 rows or over 4 of upright and / or square marginal cells. Sheath cells present (IAWA key no. 110). Granular inclusions present in ray cells.

4.1.6. *Kandelia candel* (L.) Druce

Local name: Cherukandal, Ezhuthanikandal (Malayalam), Goria (Bengali)

Family: Rhizophoraceae

4.1.6.1. Tree: Medium to tall tree, up to 12 m high having cylindrical bole with girth ranges from 15-20cm. Dark green foliage wood. Knee roots and thick root buttresses are formed.

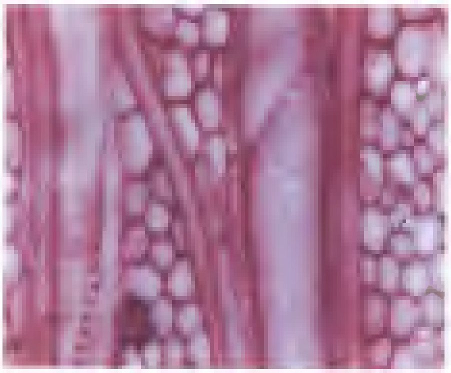
4.1.6.2. Distribution

This species is very widespread and is found in India, Indonesia, Malaysia, Myanmar, Singapore, Thailand, South Vietnam, and in Indonesia. In India Western Coast, Andaman Islands, Orissa and Sundarban.

4.1.6.3. IUCN status: Least concern

4.1.6.4. Wood anatomical description

Growth ring boundaries are indistinct or absent (Plate 6a, IAWA key no. 2). Wood is diffuse-porous (IAWA key no. 5). Vessels clusters are common, 18-25% solitary, round to oval. Perforations are scalariform with oblique end walls (Plate 6d), 7-8 vessel bar (IAWA key no. 15) with an average width of 13μm. Inter-vessel pits



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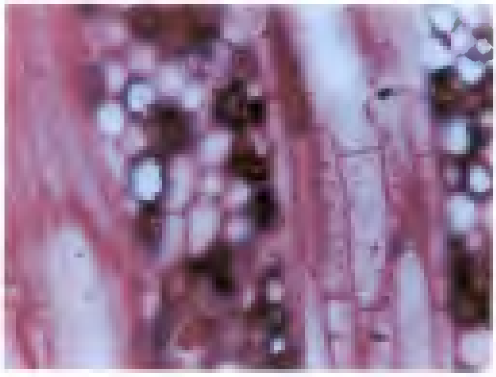

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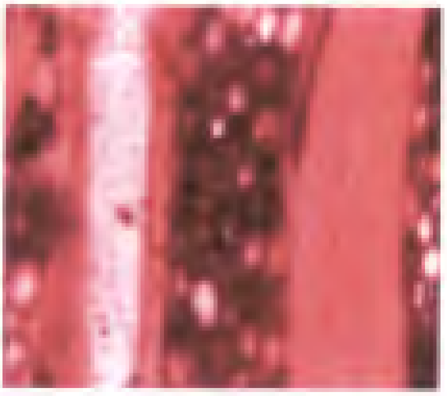

6g

6h

Plate 6. Wood anatomical features of *Kandelia candel* e.Transitional lateral wall pitting (TLS 40X) f. Alternate oval shape ray parenchyma pit (TLS 40X) g. Alternate oval shape ray parenchyma pit (TLS 40X) h. Alternate bordered scalariform vessel ray pit (TLS 40X)

scalariform, infrequently transitional extending over the entire inter-vessel walls. Vessel-ray pits bordered to simple opposite to reticulate, round to elongate scalariform pit in uniseriate, biseriate and alternate pattern (Plate 6h). Vessel-parenchyma pits simple and bordered. Diameter of vessel ranges between 50-100μm with an average of 74 μm. Vessel frequency with an average of 17 vessels per square millimeter (IAWA key no. 47). Vessel length ranges from 350-800 μm with an average of 481 μm (IAWA key no. 53). Average vessel area 6372 μm. Fibres with simple to minutely bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66) and infrequently septate (IAWA key no. 66). Fibres are thick walled and mean fibre length in the range between 800 to 2000 μm with an average of 1182 μm and mean diameter of 25 μm. Axial parenchyma bands three or more cells wide (Plate 6a, IAWA key no. 85 & 86). Eight (5-8) cells per parenchyma strand (Plate 6b, IAWA key no. 93). Rays heterogeneous type III, 5-6/mm^2, ray width 1-3 cells of small rays and large rays 4-8 cells wide, ray height up to 1593 μm. Body ray cells procumbent with mostly 2-4 rows or over 4 made up of upright and / or square marginal cells. Sheath cells present (Plate 156, IAWA key no.110). Granular inclusions are also present in ray cells (Plate 6c).

4.1.7. *Ceriops tagal* (Perr.) Robinson

Common name: Yellow mangrove

Local name: Manjakandal (Malayalam), Mat-Garon or Jat-Garon (Bengali)

Family: Rhizophoraceae

4.1.7.1. Tree/shrub: Small to medium, 7- 12m high having cylindrical bole with girth ranges from 15-20cm. Aerial roots and buttresses are formed on trunk base (Plate 18c).

4.1.7.2. Distribution

This species is widespread and found in Bangladesh, Brunei Darussalam, China, Taiwan, India (including Nicobar and Andaman Islands), Indonesia,

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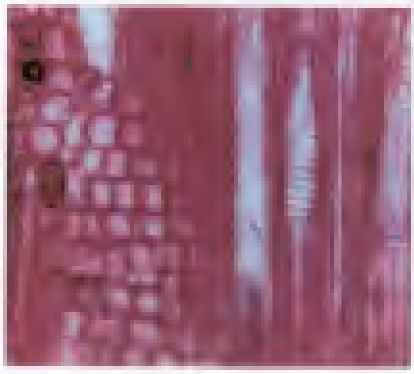


7f

Plate 7. Wood anatomical features of *Ceriops tagal* a. Axial parenchyma aliform, aliform confluent and aliform winged (TS 4X) b. Uniseriate scalariform vessel ray pit (RLS 40X) c. Globular inclusions in ray cells (RLS 40X) d. Scalariform(blue arrow) and opposite (black arrow) lateral wall pitting (RLS 40X) e. Crystals in ray cells and branched vessel bars (RLS 40X) f. Scalariform oblique end wall with long tail (RLS 40X)

Malaysia, Myanmar, Pakistan, Philippines (in Luzon it is absent in La Union province), Singapore, Sri Lanka, Thailand, southern Vietnam, and Cambodia. In Australasia it can be found in southwest Australia, northwest Australia, northeast Australia, Federated States of Micronesia, New Caledonia, Palau, Papua New Guinea, Solomon Islands, and Vanuatu. In East Africa and the Middle East the species is found in Tanzania, Mozambique, Somalia, Madagascar, Seychelles, Kenya, Maldives and South Africa. In India it is widely distributed in Sundarbans, Andaman and Nicobar Islands and throughout East and West Coast of India.

4.1.7.3. IUCN status: Least concern

4.1.7.4. Wood anatomical description

Growth ring boundaries are indistinct or absent (Plate 7a, IAWA key no. 2). Wood diffuse-porous (IAWA key no. 5). Vessels solitary and in radial multiples of 3 or more, 35-40 % solitary, round. Perforations are scalariform with oblique end walls with long tail, 7-8 vessel bar (Plate 7f, IAWA key no. 15) with an average width of 13µm. Inter-vessel pits scalariform (Plate 7d, IAWA key no. 20), infrequently opposite (Plate 7d, IAWA key no. 21) extending over the entire inter-vessel walls. Vessel- ray pits bordered to simple round to elongate scalariform pit in uniseriate, biseriate and alternate pattern. Vessel-parenchyma pits are simple oval shape. Diameter of vessel ranges from 50-100 µm with an average of 66 µm (IAWA key no. 41).Vessel frequency with an average of 35 vessels per square millimeter (IAWA key no. 48). Vessel length ranges between 350-800 µm with an average of 591 µm (IAWA key no. 53). Average vessel area 7651 µm. Fibres with simple to minutely bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66). Fibres thick walled having mean fibre length in the range between 800 to 1200 µm with an average of 1051 µm and mean diameter of 22 µm. Axial parenchyma are rare or absent (IAWA key no. 75), paratracheal scanty (IAWA key no.78), frequently aliform (IAWA key no. 80), aliform confluent, aliform winged (Plate 7a). Eight (5-8) cells per parenchyma strand (IAWA key no. 93). Rays heterogeneous type III, ray frequency ranges between 6-7/mm^2. Ray width 1-3 cells of small rays and large rays 4-8 cells wide, ray height up to 1678 μm. Body ray cells procumbent with mostly over 4 made up of upright and / or square marginal cells. Sheath cells (IAWA key no. 110), granular inclusions (plate 7c) and different types of crystals are present on ray cells. Prismatic, polygonal and rhomboidal crystals (Plate 7e) are also observed.

4.1.8. *Avicennia marina* Vierth

Common name: Grey mangrove

Local name: Cheruppotti (Malayalam), Peyara Ban (Bengali)

Family: Acanthaceae

4.1.8.1. Tree: Evergreen medium to large tree, 10-15m high having much branched trunk with girth ranges upto 2m. Bark smooth brown to yellowish and peeling nature. Aerial roots present (Plate 18 f) and pencil like pneumatophores developed from horizontal roots.

4.1.8.2 Distribution

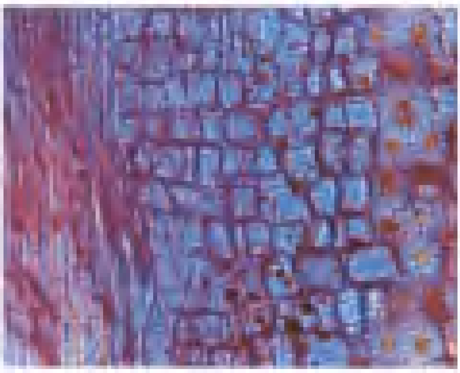
This species is distributed in Australia, Bahrain, Bangladesh, Brunei Darussalam, Cambodia, China, Comoros, Djibouti, Egypt, Eritrea, Guam, India, Indonesia, Iran, Islamic Republic of Japan, Kenya, Madagascar, Malaysia, Maldives, Mayotte, Mozambique, Myanmar, New Caledonia, New Zealand, Northern Mariana Islands, Oman, Pakistan, Papua New Guinea, Philippines, Qatar, Saudi Arabia, Seychelles, Singapore, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Taiwan, Province of China, Tanzania, United Republic of; Thailand, United Arab Emirates, Vanuatu, Vietnam and Yemen. In India it is distributed throughout East and West Coast and also Andaman Nicobar Islands.

4.1.8.3. IUCN status: Least concern

4.1.8.4. Wood anatomical description

Growth ring boundaries are distinct (Plate 8a, IAWA key no. 1). Wood is

8a



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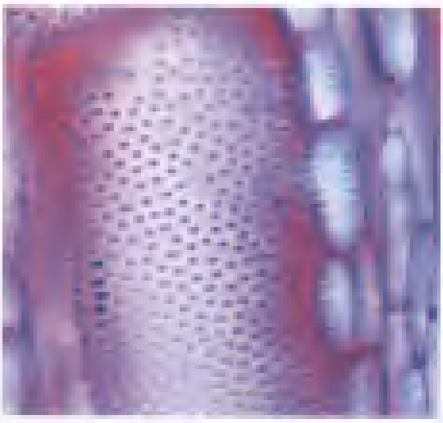

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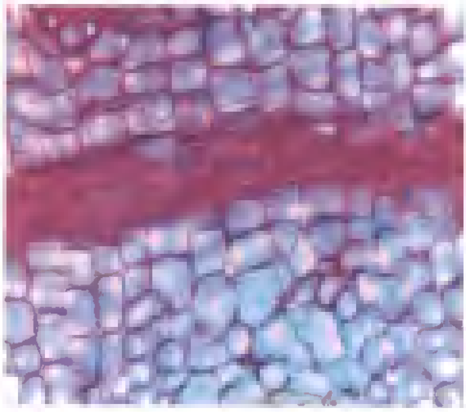

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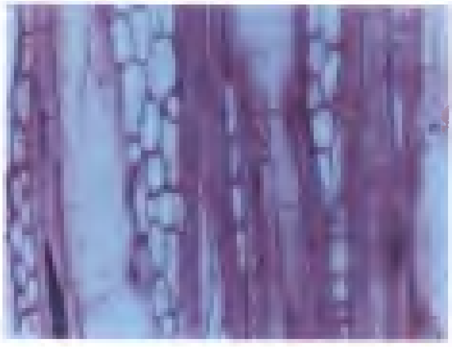


8e

8f

Plate 8. Wood anatomical features of *Avicennia marina* a. Successive cambium (TS 4X) b. Yellow gummy deposits on scleried band c. Alternate pitting polygonal shape (TLS 40X) d. Band of sclerieds TS (40X) e. Helical thickening associated with vessel f. Concentric included phloem (TS 40X) elements (TLS 40X)

diffuse-porous (IAWA key no.5). Successive cambium present (Plate 8a). Vessels in diagonal and / or radial pattern, radial multiples of 4 or more common. 6-10 % solitary vessel. Solitary vessel outline are angular. Simple perforation plates (Plate 8c, IAWA key no. 13) and intervessel pits alternate with polygonal shape (Plate 8c). Vestured pits present (IAWA key no. 29), not so prominent. Vessel numerous with 21/mm^2 (IAWA key no. 48).Vessel diameter with an average 83 µm. Vessel ray pit same as that of the intervessel pit. Vessel length ranges between 200-300 µm with an average of 277µm. Vasicentric tracheids are present. A narrow parenchyma band first formed by the cambium is in the inside. Cambium initials cease to function in the inside of the phloem. Conjuctive tissue between two phloem initials continue to divide and again differentiate. Band of sclereids present (Plate 8d). Yellow gummy deposits on sclereids (Plate 8b). Fibre length ranges between 800-1090 µm with an average of 1007 µm. Non septate fibres with simple pits. Thin walled to thick walled fibre. Fibre length range between 900-1600 µm with an average 1007 µm. Axial parenchyma are paratracheal scanty (IAWA key no. 78) and vasicentric abundant (IAWA key no. 79). Four (3-4) cells per parenchyma strand (IAWA key no. 92). Rays heterogeneous type III, 15/mm^2, biseriate rays with an average diameter 10µm and multiseriate rays with an average diameter 30 µm. Biseriate rays with an average height 195 µm and multiseriate rays with an average height 521 µm. Body ray cells procumbent with mostly over 4 made up of upright and / or square marginal cells (IAWA key no. 108). Globular granules are present on ray cells (Plate 8b).

4.1.9. *Avicennia officinalis* Lamark

Common name: Grey mangrove

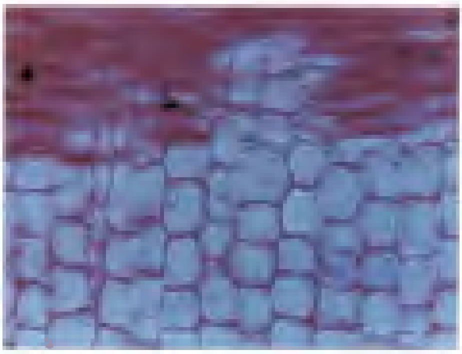
Local name: Upputti (Malayalam), Jat ban (Bengali)

Family: Acanthaceae

4.1.9.1. Tree: Evergreen medium to large tree, 10-15m high having much

9a

9b



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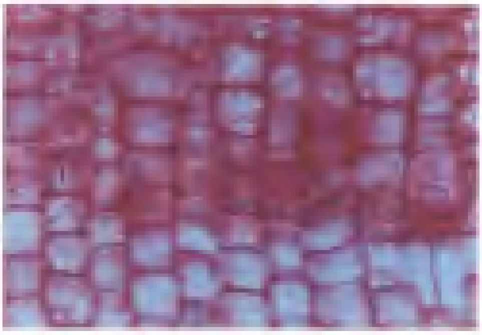

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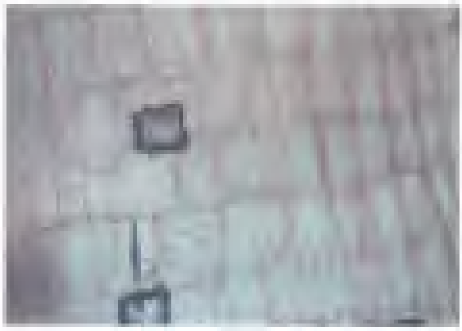


9e

Plate 9. Wood anatomical features of *Avicennia officianalis a.* Continuous series of vessel (TLS 10X) b.Aliform and aliform confluent axial parenchyma (TS 10X) c. Simple perforated vessel with transverse end (Maceration 10X) d. Crystals on parenchyma cells (TS 40X) e. Druses on parenchyma cells (TS 40X) f. Elongated crystals present in ray cells (RLS 40X)

branched trunk with girth ranges up to 2m. Irregularly spreading branches. Bark smooth and grey. Aerial roots broom like and pneumatophores erect pencil like developed from horizontal roots (Plate 18 p).

4.1.9.2. Distribution

This species is widely distributed in India, Banghladesh, Sri Lanka, Burma, Malaya, Java, Indonesia, Philippines, Papua New Guinea, Austalia and other SE Asian mangrove forest. In India distributed throughout East and West Coast and Andaman Nicobar Islands.

4.1.9.3. IUCN status: Least concern

Growth ring boundaries are distinct (IAWA key no. 1). Successive cambium present (Plate 9a). Wood is diffuse-porous (IAWA key no. 5). Vessels in diagonal and /or radial pattern, radial multiples of 4 or more common. 6-10 % solitary vessel. Solitary vessel outline angular (IAWA key no. 12). Simple perforation plates (Plate 9c, IAWA key no. 13). Intervessel pits alternate with polygonal shape. Vestured pits are present (IAWA key no. 29), more prominent than *Avicennia marina*. Vessel frequency between 17/mm^2 (IAWA key no. 47). Vessel diameter ranges between 75-90 μm. Vessel ray pit same as that of the intervessel pit. Vessel length range with an average of 322 μm. Vasicentric tracheids are present. A narrow parenchyma band first formed by the cambium is in the inside. Cambium initials cease to function in the inside of the phloem. Conjuctive tissue between two phloem initials continue to divide and again differentiate. Band of sclereids are present. Yellow gummy deposits were found on sclereids. These deposits are not frequent on sclereids. Fibre length ranges between 800-1090 μm with an average of 1007 μm. Non septate fibres (Plate 237, IAWA key no. 66) with simple pits. Thin walled to thick walled fibre. Fibre length ranges between 600-1250 μm with an average 1007 μm. Axial parenchyma are paratracheal scanty (IAWA key no. 78) and vasicentric abundant (IAWA key no. 79), aliform (Plate 9b, IAWA key no. 80) and aliform confluent (IAWA key no. 83) parenchyma present. Four (3-4) cells per parenchyma strand (IAWA key no. 92).

85

Druses are present on parenchyma cells (Plate 9e, IAWA key no. 145). Rays heterogeneous type III, 11/mm^2, biseriate rays with an average diameter of 30 μm and multiseriate rays with an average diameter 55 μm. Biseriate rays with an average height of 374 μm and multiseriate rays with an average height 1019 μm. Body ray cells are procumbent with mostly over 4 of upright and / or square marginal cells (IAWA key no. 108). Elongated crystals and square shape crystals are present on square and upright cells (Plate 9f).

4.1.10. *Sonneratia alba* Sm

Common name: Mangrove apple

Local name: Nakshatra kandal (Malayalam)

Family: Lythraceae

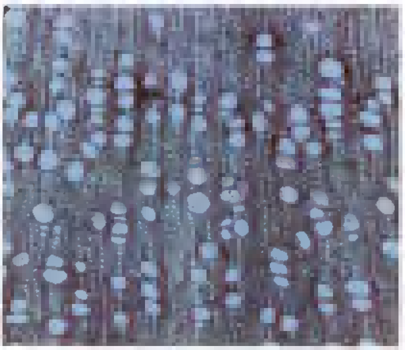
4.1.10.1. Tree: Evergreen small to medium tree, 10-15 m high having deliquescent branching and dark, dense evergreen leaves (Plate 20 b). The girth of tree ranges from 25-50 cm. Bark is thin, brownish to grey. Thick erect pneumatophores developed from horizontal roots.

4.1.10.2. Distribution

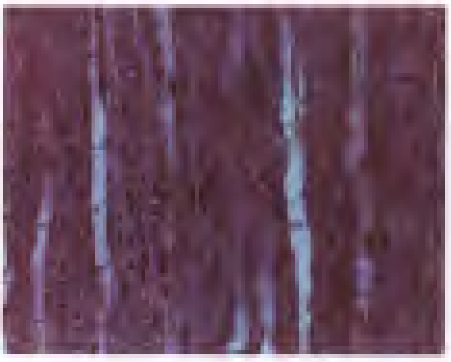
This species is widely distributed in India, Bangladesh, Sri Lanka, Burma, Malaya, Java, Indonesia, Philippines, Papua New Guinea, Australia and other SE Asian mangrove forest. In India distributed throughout East and West Coast and Andaman and Nicobar Islands.

4.1.10.3. IUCN status: Least concern

Growth ring boundaries indistinct or absent (Plate 10a, IAWA key no. 2). Wood diffuse-porous (IAWA key no. 5). Vessels are found in radial multiples of 2-4, mostly oval, 20-25% solitary. Perforation plates simple (Plate 10c, IAWA key no. 13). Intervessel pit alternate (IAWA key no. 22). Oblique to transverse vessel had tail at the end (Plate 10c). Vestured pits are present (Plate 10c, IAWA key no. 29). Vessel frequency 20/mm^2 (IAWA key no. 47), vessel diameter with



10a



10b

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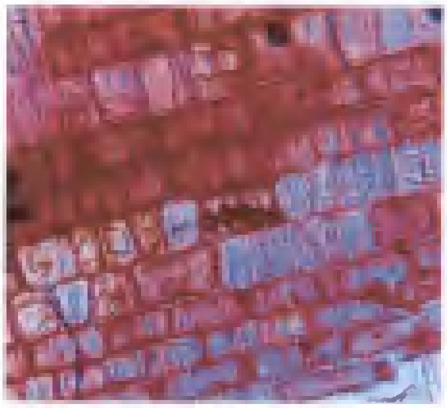


10f

Plate 10. Wood anatomical features of *Sonneratia alba* a. Parenchyma absent (TS 10X) b. TLS 10X c. Vestured pit (TLS 40X) d. Transverse vessel plate with tail at both end (Maceration10X) e. Gash like vessel ray pit (RLS 40X) f. Globular inclusions and prismatic crystals on rays (RLS 40X)

10g

10h

Plate 10 g. Helical appearance on fibres (RLS 40X) h. Gummy deposits on vessels (RLS 40X) an average 83 µm. Vessel length ranges between 250-600 with an average of 493µm.Tyloses and gummy deposits are frequent (Plate 10h). Vasicentric tracheids are present. Axial parenchyma absent. Fibres with simple to minutely bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66) and infrequently septate (IAWA key no. 65). Flattened thin walled fibres had mean fibre length 950 µm. Fibre tracheids are reported. Helical appearance on fibres were present (Plate 10g). Rays homogeneous type III, 33-34/mm^2.Uniseriate rays with an average diameter 19 µm and ray height up to 383 µm. Body ray cells procumbent (IAWA key no. 104). Prismatic crystals and granular inclusions are present in ray cells (Plate 10f).

4.1.11. *Sonneratia apetala* Buch.-Ham

Common name: Fire fly Mangrove

Local name: Keora (Bengali)

Family: Lythraceae

4.1.11.1.Tree: Evergreen small to medium tree, 10-15 m high having deliquescent branching and dark, dense evergreen leaves. The girth of tree ranges from 25-50cm. Branches are pendulous or drooping similar to Eucalyptus sp. Bark is thin, greenish to grey. Thick erect pneumatophores developed from horizontal roots.

4.1.11.2. IUCN status: Least concern

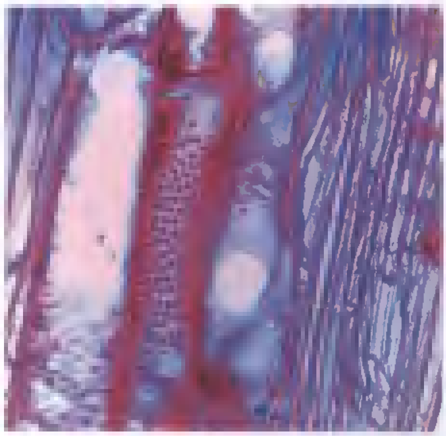
4.1.11.3. Distribution

This species is found in Bangladesh, Myanmar, and India. It has been introduced into Fujian and Guangdong provinces China. In India it is distributed in Andaman and Nicobar Islands, East Coast and rare in West Coast. In West Coast it is reported in Mumbai.

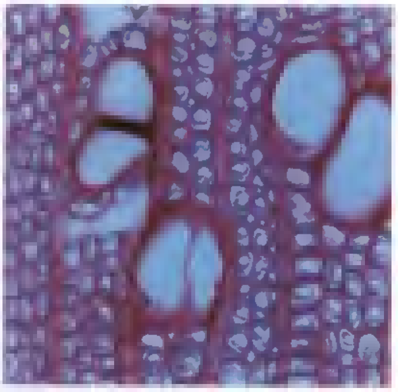
4.1.11.4. Wood anatomical description

Growth ring boundaries indistinct or absent (Plate 11a, IAWA key no. 2). Wood diffuse-porous (IAWA key no. 5). Vessels in in radial multiples of 2-3,

11a



11b



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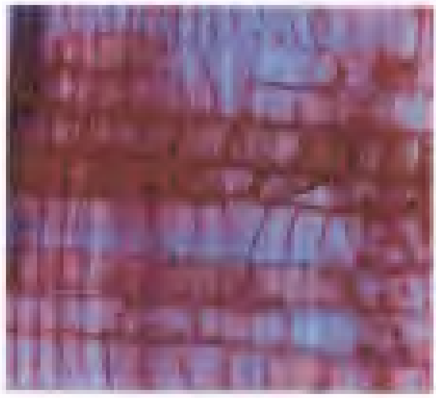


11d

Plate 11. Wood anatomical features of *Sonneratia apetala* a. Parenchyma absent (TS 10X) b. Simple vessel plate (RLS 40X) c. Gelatinous fibre (TS 40X) d. Gummy deposits on ray cells (RLS 40X)

mostly oval, 12-15% solitary. Perforation plates simple (Plate 11b, IAWA key no. 13). Intervessel pit alternate (IAWA key no. 22). Continuous series of vessels. Vessels with transverse end having tail on both sides . Vestured pits are present (Plate 11b, IAWA key no. 29). Vessel frequency 26/mm^2 (IAWA key no. 48). Vessel diameter with an average 90 µm. Vessel length range between 450-550 µm with an average of 490µm. Tyloses and gummy deposits are present (Plate 11d). Axial parenchyma absent (IAWA key no. 75). Fibres with simple to minutely bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66) and infrequently septate (IAWA key no. 65). Flattened thin walled fibres with mean fibre length 899 µm. Fibre tracheids are present. Rays homogeneous type III, ray frequency ranges between 22-24/mm^2. Uniseriate rays with an average diameter 25 µm, ray height upto 471 µm. Body ray cells exclusively procumbent (IAWA key no. 104). Gelatinous fibres were observed (Plate 11c). Granular inclusions are also present.

4.1.12. *Sonneratia caseolaris* (L.) Engl

Common name: Mangrove apple

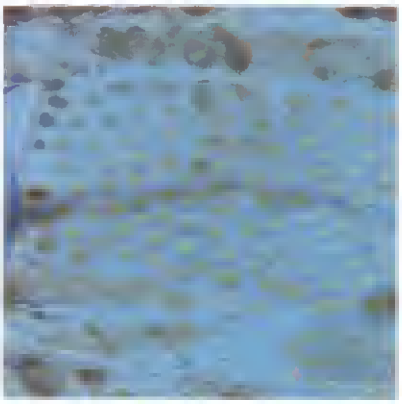
Local name: Chakkara kandal (Malayalam)

Family: Lythraceae

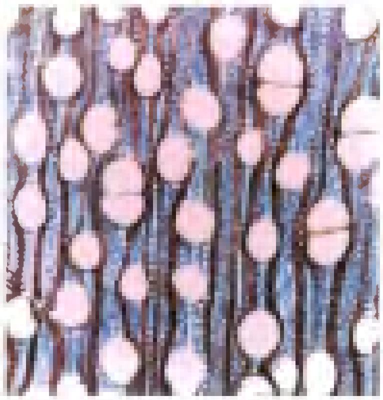
4.1.12.1. Tree: Evergreen small to medium tree, 10-15 m high having deliquescent branching and dark, dense evergreen leaves. The girth of tree ranges from 25-50cm. Branches are not drooping. Bark is thin, pale brown. Thick erect pneumatophores developed from horizontal roots (Plate 20 a).

4.1.12.2. Distribution

This species is widespread and can be found in Bangladesh, Brunei Darussalam, Cambodia, China (Hainan Island), India, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Northeast Australia, Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia, and the Maldives. In India it is distributed in Andaman and Nicobar Islands, East

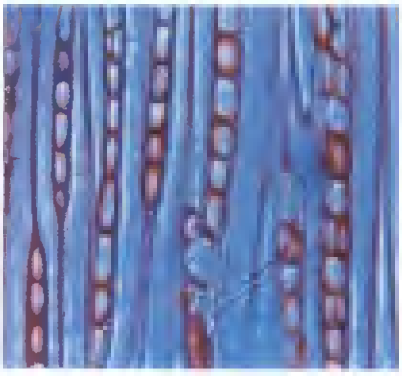


12a



12b

12c



12d

Plate 12. Wood anatomical features of *Sonneratia caseolaris* a. Oval shape vessels (TS 40X) b. Vestured vessel ray pit (RLS 40X) c. Radially flattened fibre (Maceration 10X) d. Exclusively uniseriate rays (TLS 40X)

Coast and in West Coast.

4.1.12.3. IUCN status: Least concern

4.1.12.4. Wood anatomical description

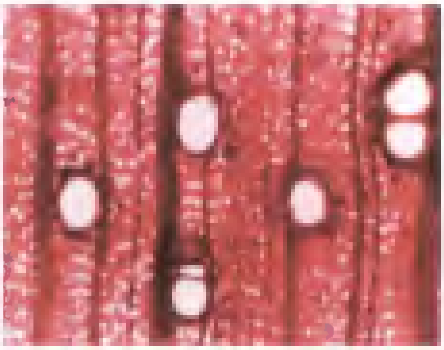
Growth ring boundaries are indistinct or absent (Plate 12a, IAWA key no. 2). Wood is diffuse-porous (IAWA key no. 5). Vessels are found in radial multiples of 2-4, mostly oval, 35-40% solitary. Perforation plates are simple (Plate 302, IAWA key no. 13). Intervessel pits alternate (IAWA key no. 22). Vestured pits are present (Plate 12b, IAWA key no. 29). Vessel frequency with 15/mm^2 (IAWA key no. 47). Vessel diameter of 108 µm. Vessel length range between 300-800 with an average of 493µm. Tyloses and gummy deposits are present. Axial parenchyma are absent (IAWA key no. 75). Fibres with simple to minutely bordered pits (Plate 299, IAWA key no. 61). Non septate fibre (IAWA key no. 66) and infrequently septate (IAWA key no. 65). Flattened thin walled fibres with mean fibre length 928 µm. Fibre tracheids are present. Rays homogeneous type III, 28-30/mm^2. Uniseriate rays with an average diameter 16 µm, ray height upto 383 µm. Body ray cells exclusively procumbent (Plate 12d, IAWA key no. 104). Prismatic crystals and granular inclusions are frequent.

4.1.13. *Heritiera littoralis* Dryand
Common name: Looking glass mangrove
Local name: Sundari (Bengali)
Family: Malvaceae

4.1.13. 1. Tree: Evergreen medium to large tree, 20-55m high having deliquescent branching and dark, dense evergreen leaves(Plate 18g). The girth of tree upto 2m. Bark grey brown reddish after peeling.

4.1.13. 2. Distribution

In South and Southeast Asia, this species is found in Brunei Darussalam, southern China, Taiwan, India, Indonesia, Japan, Malaysia, Philippines,



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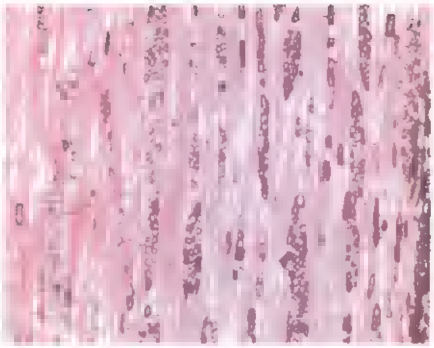

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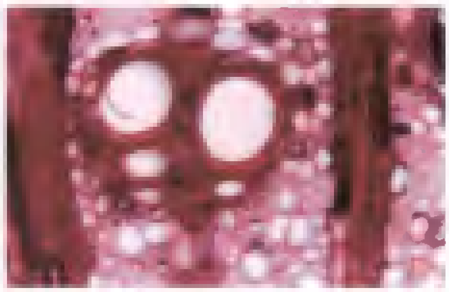
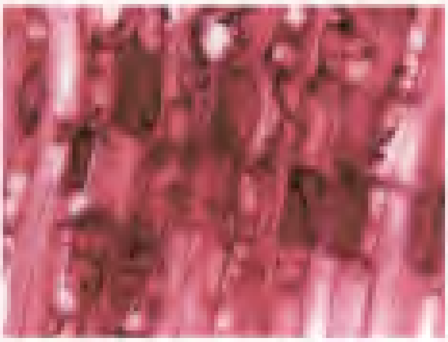


13 c

13d



13 e

13f

Plate 13. Wood anatomical features of *Heritiera littoralis a.* Diffuse aggregate parenchyma b.Storied rays and parenchyma (TLS 10X) c .Angular outline in solitary vessels (TS 40X) d. Globular deposits in storied parenchyma (RLS 40X) e. Inclusions present in parenchyma (RLS 40 X) f. Helical secondary wall associated with vessel plate (RLS 40 X)

Singapore, Sri Lanka, Thailand, Vietnam, and Cambodia. However, it is extinct in Bangladesh. In Australasia, it is found in Northeast Australia, Federated States of Micronesia, Fiji, Guam, New Caledonia, Palau, Papua New Guinea, Solomon Islands, Tonga, and Vanuatu. It occurs in East Africa, including Kenya, Madagascar, Mozambique, and Tanzania. In India it is distributed in Sundarbans of East Coast and Mumbai in West Coast.

4.1.13. 3. IUCN status: Least concern

4.1.13. 4.Wood anatomical description

Growth ring boundaries are indistinct or absent (Plate 13a, IAWA key no. 2). Wood diffuse-porous (IAWA key no. 5). Vessels are found in radial multiples of 2-3, infrequently clustered, round to oval shape, 36-40% solitary. Angular outline present in solitary vessel (Plate 13c, IAWA key no. 12). Perforation plates simple (Plate 13f, IAWA key no. 13). Intervessel pit alternate (IAWA key no. 22 and 23) with polygonal shape. Vessel frequency ranges between 5-6/mm^2 (IAWA key no. 47). Vessel diameter ranges between 120-150 µm with an average 136 µm. Vessel length ranges from 300-400 with an average of 376 µm. Vasicentric tracheids are present. Helical structure associated with vessel element are present (IAWA key no. 36). Fibres with simple pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66). Fibres thin to thick walled and mean fibre length of 959 µm and mean diameter of 19 µm. Axial parenchyma are storeyed, apotracheal diffuse in aggregate (Plate 13a) frequently present, paratracheal scanty (IAWA key no. 78) and vasicentric abundant (IAWA key no. 79). Two cells per parenchyma strand (IAWA key no. 91) and four (3-4) cells per parenchyma strand (IAWA key no. 92) were observed. Granular inclusions are present in the storyed parenchyma (IAWA key no. 142). Crystalliferous deposits are also frequent. Rays homogeneous type II, storeyed rays, 9-10/mm^2, ray width 1-3 cells of small rays and large rays 4-8 cells wide, ray height upto 502 µm. All ray cells are procumbent (IAWA key no. 104). Sheath cells (IAWA key no. 110) and granular inclusions are present in ray cells (Plate 13e).

95

4. 1. 14. ***Xylocarpus granatum* J.König**

Common name: Cannon ball mangrove

Local name: Dhundhul (Bengali)

Family: Meliaceae

4. 1. 14.1. Tree: Dark green, much branched short to medium tree, 10-12m height. Smooth bark with dense foliage. The girth of tree upto 25-50cm (Plate 21b).

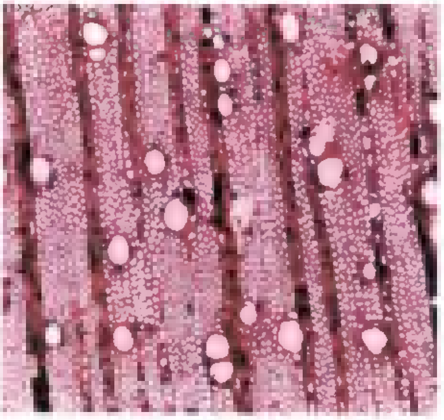
4. 1. 14. 2. Distribution

This species is found in South Asia, including Bangladesh, Brunei Darussalam, China (Hainan Island), India, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Viet Nam, and Cambodia. The Australasian range includes Northwest Australia, Northeast Australia, Federated States of Micronesia, Fiji, New Caledonia, Palau, Papua New Guinea, Solomon Islands, Tonga, and Vanuatu. It is also found in East Africa, including Somalia, Kenya, Madagascar, Mozambique, Seychelles, and Tanzania. In India it is distributed in Andaman and Nicobar Islands, East coast and in West Coast.

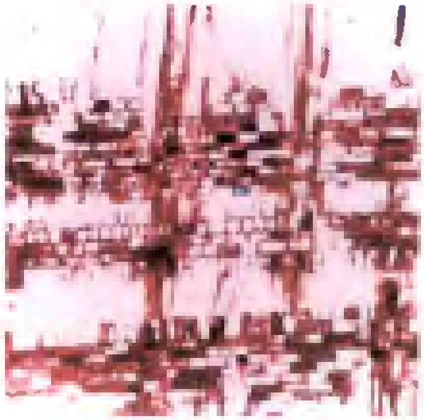
4. 1. 14.3. IUCN status: Least concern

4. 1. 14.4. Wood anatomical description

Growth ring boundaries are indistinct or absent (Plate 14a, IAWA key no. 2). Wood diffuse-porous (IAWA key no. 5). Vessels in radial multiples of 2-3 round to oval shape, 30-34% solitary. Solitary vessel outline angular (IAWA key no. 12). Perforation plates are simple (Plate 14c, IAWA key no. 13). Intervessel pit alternate (Plate 14c, IAWA key no. 22 & 23) with polygonal shape, vestured pits (Plate 14d, IAWA key no. 29) are present. Numerous vessels with vessel density of 12 per mm^2 (IAWA key no. 47). Vessel diameter ranges between 50-80 µm with an average 63 µm. Vessel length ranges between 270-590 with an average of 372 µm.Vasicentric tracheids are present. Small narrow vessel along with the large vessel and part of helical secondary wall associated with vessel element are present. Fibres with simple 96

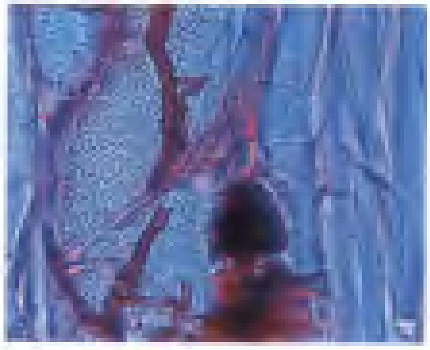


14a



14b

14c



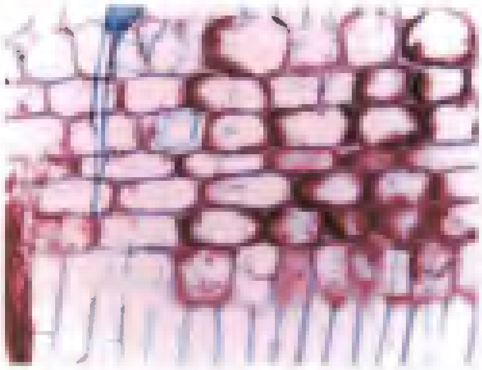
14d

14e

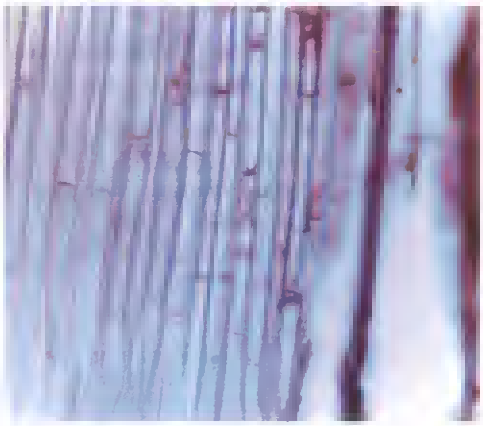
14f

Plate 14. Wood anatomical features of *Xylocarpus granatum* a. Scanty paratracheal parenchyma (TS 10X) b. Deposits on ray cells (RLS 10X) c. Simple perforated vessel with tails at both end (Maceration 10X) d. Vestured pit (RLS 40X) e. Prismatic crystals on parenchyma (RLS 40X) f. Bordered vessel ray pit (RLS 40X)

14g



14h



14i

14j

Plate 14. Wood anatomical features of *Xylocarpus granatum* g. Globular inclusions present in square cells (RLS 40X) h. Crystals in ray cells (RLS 40X) i. Septate fibre with minute pits (RLS 40X) j. Thin walled fibre (Maceration 10X)

to bordered pits (IAWA key no. 61). Septate fibre (IAWA key no. 65). Fibres thin to thick walled had mean fibre length 993 µm and mean diameter of 24 µm. Axial parenchyma vasicentric abundant (IAWA key no. 79) observed frequently and banded in marginal or seemingly marginal bands. Four (3-4) cells per parenchyma strand and eight (5-8) cells per parenchyma strand. Prismatic crystals are present in non chambered axial parenchyma (Plate 359). Rays heterogeneous type II and type III, 12/mm^2. Ray width 1-3 cells of small rays and large rays 4-8 cells wide, ray height upto 435 µm. Body ray cells procumbent with mostly one row or 2-4 rows of upright and / or square marginal cells. Granular inclusions are present in ray cells (Plate 14g). Rhomboidal crystals and prismatic crystals present in square and procumbent ray cells (Plate 14h).

4.1.15. *Excoecaria agallocha.* L.

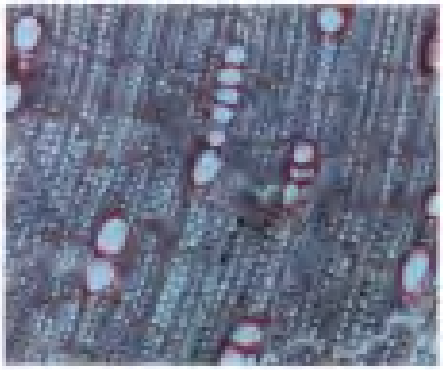
Common name: Blind your eye mangrove
Local name: Kannampotti (Malayalam), Geoal (Bengali)
Family: Euphorbiaceae

4.1.15.1. Tree: Medium tree, 15-20m height. Woody perennial deliquescent, partially deciduous tree with girth range between 25-60cm (Plate 18 d). Bark greyish with poisonous milky latex. Lenticels are prominent in bark.

4.1.15.2. Distribution

In South Asia this species is found in Bangladesh, Brunei Darussalam, China, Taiwan, Hong Kong, India, Indonesia, Japan, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Vietnam. The species also occurs in the Maldives. In Australasia it can be found in Northwest Australia, Northeast Australia, Southeast Australia, Federated States of Micronesia, Fiji, Guam, New Caledonia, Palau, Papua New Guinea, Solomon Islands, Tonga, Vanuatu. In India it is distributed in Andaman and Nicobar Islands, East Coast and in West Coast.

4.1.15.3. IUCN status: Least concern



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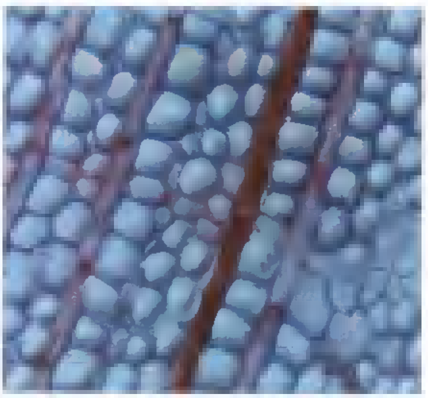


15e

15f

Plate 15. Wood anatomical features of *Excoecaria agallocha* a. Banded parenchyma in narrow bands with two cells wide (TS 10X) b. Continous series of vessels (TLS 10X) c.Vessel having vestured pit with transverse end (TLS 40X) d. Laticifers tubes (RLS 40X) e. Gummy deposits on rays (TLS 40X) f. Silica deposits on parenchyma (TLS 40X)

4.1.15.4. Wood anatomical description

Growth ring boundaries are indistinct or absent (Plate 15a, IAWA key no. 2). Wood is diffuse-porous (IAWA key no. 5). Vessels are found in radial multiples of 4 or more common, round to oval shape, 28-30% solitary. Solitary vessel outline angular (IAWA key no. 12). Perforation plates are simple (Plate 15b, IAWA key no. 13). Intervessel pit alternate (IAWA key no. 22 & 23) with polygonal shape and vestured pits (Plate 15c, IAWA key no. 29) are found. Vessel ray pit distinct borders. Vessel frequency ranges between 7-8/mm^2 (IAWA key no. 47). Vessel diameter range between 78-112 µm with an average 80 µm. Vessel length ranges between 300-400 with an average of 376 µm. Deposits are present in vessels. Fibres with simple to minute bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66). Fibres thin walled with mean fibre length 911 µm and mean diameter of 27 µm. Axial parenchyma are banded in narrow bands with two cells wide Plate 15a). Four (3-4) cells per parenchyma strand. Laticifers tube with creamy granular deposits are present (Plate 15d, IAWA key no. 132). Rays homogeneous type III, ray frequency of 17/mm^2. Frequently uniseriate rays and infrequently biseriate with an average ray width 20 µm, ray height upto 387 µm. All ray cells are procumbent. Granular inclusions and gummy deposits are present in ray cells. Prismatic crystals and globular bodies in procumbent ray cells also present (IAWA key no. 136).Silica deposits were observed in parenchyma (Plate 15f).

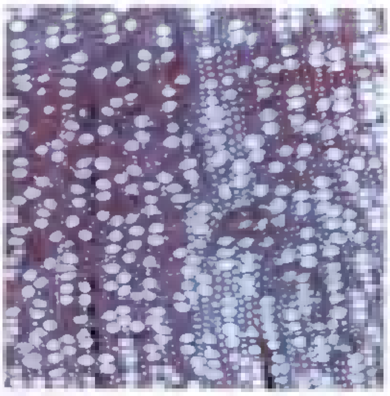
4.1.16. *Aegiceras corniculatum* Blanco

Common name: River mangrove
Local name: Pookandal (Malayalam), Khalsi (Bengali)
Family: Myrsinaceae

4.1.16.1. Tree/Shrub: Small tree or shrub upto 7m height. The girth range between 10-20cm. Branches diffuse. Bark smooth pale grey to dark grey.

4.1.16.2. Distribution

In South Asia, this species is present in Bangladesh, Brunei Darussalam, 101



16a

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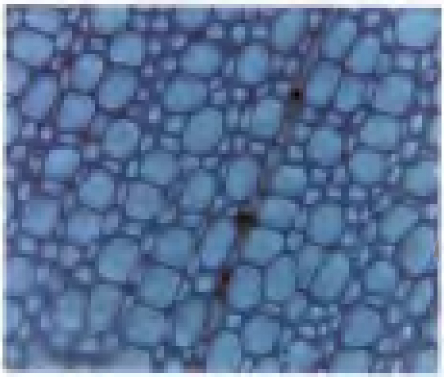

16d

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16f

Plate 16. Wood anatomical features of *Aegiceras corniculatum a.* High vessel frequency (TS 10X) b.Break down area on rays (TLS 10X) c. Scleried deposits on ray cells (TLS 40X) d. Axial parenchyma diffuse and scanty paratracheal (TS 40X) e. Simple vessel plate with transverse end (Maceration 10X) f. Helical thickening associated with vessel element (RLS 40X)

China, Taiwan, Hong Kong, India (sparse distribution along western coastline), Indonesia, Malaysia, Myanmar, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, and Cambodia. In Australasia, it is found in northwest Australia, northeast Australia, southeast Australia, Papua New Guinea, and the Solomon Islands. In India it is distributed in Andaman and Nicobar Islands, East Coast and in West Coast.

4.1.16.3. IUCN status: Least concern

4.1.16.4. Wood anatomical description

Growth ring boundaries are indistinct or absent (Plate 16a, IAWA key no. 2). Wood is diffuse-porous (IAWA key no. 5). Vessels are found in diagonal or radial with multiples of 4 or more common, round to oval shape, 36-40% solitary. Perforation plates are simple (Plate 16e, IAWA key no. 13), transverse end having tail. Intervessel pit alternate (IAWA key no. 22) with polygonal shape. Vestured pit present (IAWA key no. 29). Vessel frequency ranges between 66-170/mm^2 (IAWA key no. 50) with an average of 165/mm^2.Vessel diameter ranges between 30-45 μm with an average 36 μm. Vessel length range between 100-380 with an average of 280 μm. Helical structure associated with vessel, were observed (Plate 16f). Gums and other deposits present. Fibres with simple to minutely bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66). Fibres thin walled with mean fibre length 482 μm and mean diameter of 27 μm. Fibre tracheids are present. Globular starch like substance present. Both apotracheal diffuse (Plate 16d, IAWA key no. 76) and paratracheal scanty (IAWA key no. 79) axial parenchyma are present. Two cells per parenchyma strand and four (3-4) cells per parenchyma strand are present. Rays homogeneous type II, 6/mm^2.Ray width with small rays 1-3 cells wide and large rays with 4-10 cells with an average ray diameter of 43 μm wide, ray height upto 521 μm. Break down area present in rays (Plate 16b) and sclereid-like substance deposited in this area (Plate 16c). All ray cells are procumbent (IAWA key no. 104), gummy deposits and sheath cells (IAWA key no. 110) are observed.

17a

17b

17c

17d

17e

17f

Plate 17. Wood anatomical features of *Lumnitzera racemosa a.* Fairly distinct growth rings b. Gash like vessel ray pit (RLS 40X) c. Slit like pit on fibres (RLS 40X) d. Uniseriate bordered vessel ray pit (RLS 40X) e. Starch grains on parenchyma (RLS 40X) f. Simple vessel plate with transverse end (Maceration 10X)

4.1.17.*Lumnitzera racemosa* (L.) Gaertn

Common name: Black mangrove

Local name: Kripa (Bengali)

Family: Combretaceae

4.1.17.1. Tree/Shrub: Small evergreen tree upto 10 m height. The girth range between 10-25 cm. Deliquescent diffuse, dark green branch. Bark smooth dark grey(Plate 20c).

4.1.17.2. Distribution

This species is found in South Asia in Brunei Darussalam, China, Taiwan, India, Indonesia, Japan, Malaysia, Philippines, Sri Lanka, Singapore, Thailand, and Viet Nam. In Australasia, it is found in Northwest Australia, Northeast Australia, and Papua New Guinea. In East Africa and the Middle East, this species is found in British Indian Ocean Territory, Kenya, Madagascar, Maldives, Mozambique, Seychelles, Somalia, South Africa, Tanzania. In India it is distributed in Andaman and Nicobar Islands, East coast and in West Coast.

4.1.17.3. IUCN status: Least concern

4.1.17.4. Wood anatomical description

Growth ring boundaries are fairly distinct (Plate 17a, IAWA key no. 1). Included phloem are present. Wood is diffuse-porous (IAWA key no. 5). Vessels are found in radial multiples of 3 or more common, round to oval shape, 36-40% solitary. Perforation plates are simple (Plate 17f, IAWA key no. 13). Intervessel pit alternate (Plate 17f, IAWA key no. 22) and polygonal shape. Vessel ray pit had distinct border present, vestured pit (IAWA key no. 29) and large gash like pit common, alternate scalariform bordered and round bordered pit also reported (Plate 17d). Vessel frequency ranges between 25/mm^2 (IAWA key no. 48). Vessel diameter ranges between 50-112 μm with an average diameter of 69 μm. Vessel length ranges between 200-650 μm with an average of 425 μm. Fibres with simple to minutely bordered pits (IAWA key no. 61). Non septate fibre (IAWA key no. 66). Fibres thin walled with mean fibre length 959 μm and mean diameter of 19 μm. Fibre tracheids are present. Apotracheal diffuse parenchyma (IAWA key no. 76) frequently present, paratracheal scanty (IAWA key no. 78) and vasicentric abundant (IAWA key no. 79) also observed. Two cells per parenchyma strand. Ray heterogeneous type II, 17 /mm^2, rays exclusively uniseriate with an average diameter of 19 μm, ray height upto 375 μm. Body ray cells procumbent with over 4 rows of upright and / or square marginal cells. Circular starch like granules are present (Plate 17e).

4.2. Comparative wood anatomy of true mangrove species of West Coast of India

The wood anatomical features such as vessel frequency, vessel diameter, vessel length, vessel area, ray frequency, ray height, ray diameter, fibre length, fibre wall thickness and fibre diameter of seventeen true mangroves species collected from West coast of India were compared using statistical analysis. Also these features were compared statistically in the genera within the families comprising Rhizophoraceae, Acanthaceae and Lythraceae.

4.2.1. Vessel features of seventeen mangrove species

In the present study wood samples of 17 true mangrove species distributed in 11 genera 8 families were collected from the ten sites of West Coast of India. The vessel features such as vessel frequency, vessel diameter, vessel length and vessel area of seventeen mangrove species were compared (Table 3).

4.2.1. Vessel frequency

Analysis of variance revealed that the vessel frequency of mangrove species shows significant difference at 1 % level (Table 5). All the species were on par with each other except *Aegiceras corniculatum.* The vessel frequency of *Aegiceras corniculatum* was highest (165/mm^2). *Rhizophora mucronata* and *Rhizophora apiculata* were recorded with the vessel frequency 12/mm^2 while the vessel frequency of *Bruguiera cylindrica* and *Bruguiera gymnorrhiza* were recorded with vessel frequency of 15/mm^2 and 17/mm^2 respectively. The vessel frequency of *Ceriops tagal* was 35/mm^2. *Avicennia officinalis* and *Avicennia marina* had vessel frequency of 17/mm^2 and 21/mm^2 respectively. *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* were recorded with the vessel frequency of 20/mm^2, 26/mm^2 and 15/mm^2 respectively. The vessel frequency of *Lumnitzera racemosa* and *Xylocarpus granatum* were 25/mm^2 and 12/mm^2. Among all the species *Heritiera littoralis* was recorded with the lowest vessel frequency of 5/mm^2.

4.2.2. Vessel diameter

There is a significant difference between the vessel areas of mangrove species (Table 3). *Aegiceras corniculatum* was recorded with the smallest diameter of 36 µm and *Heritiera littoralis* was recorded with largest diameter of 136µm among the seventeen species. The vessel diameter of *Rhizophora mucronata* (88 µm) and *Rhizophora apiculata* (61 µm) were significantly different. The vessel diameter of *Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera sexangula, Kandelia candel, Ceriops tagal, Avicennia marina, Excoecaria agallocha* and *Lumnitzera racemosa* were on par with each other.

4.2.3. Vessel length

The statistical analysis showed that there is a significant difference between the vessel lengths of the mangrove species (Table 3). The vessel length of *Rhizophora mucronata* had the longest vessel length of 8906 µm whereas *Rhizophora apiculata* recorded the vessel length of 540 µm. *Avicennia marina* (277 µm) had the shortest vessel length followed by *Aegiceras corniculatum* (280 µm) among the seventeen species. The vessel length of *Bruguiera cylindrica, Bruguiera gymnorrhiza* and *Bruguiera sexangula* were 637 µm, 556 µm and 652 µm respectively. *Kandelia candel* and *Ceriops tagal* with the vessel length of 481 µm and 591 µm respectively. The vessel length of *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris were* 493 µm 490 µm and 497 µm respectively. *Heritiera littoralis, Lumnitzera racemosa* and *Xylocarpus granatum* had the vessel length of 376 μm, 425 μm and 372 μm respectively.

Table 3. Comparison of vessel features among seventeen mangrove species

Sl .No	Species	Vessel frequency (no./mm^2)	Vessel diameter (μm)	Vessel length (μm)	Vessel area (μm)
1	*Rhizophora mucronata*	12.9 ± 4.01^{b}	88.4 ± 6.2^{bcde}	8906 ± 1044^{a}	4417 ± 2326^{c}
2	*Rhizophora apiculata*	12.1 ± 1.4^{b}	61.0 ± 13.3^{g}	540 ± 38.6^{b}	5932 ± 242^{c}
3	*Bruguiera cylindrica*	15.7 ± 2.5^{b}	86.1 ± 4.9^{cdef}	637 ± 59^{b}	7757 ± 214^{c}
4	*Bruguiera gymnorrhiza*	17.2 ± 1.9^{b}	84.4 ± 1.7^{cdefg}	556 ± 120^{b}	7293 ± 902^{c}
5	*Bruguiera sexangula*	26.4 ± 0.93^{b}	62.3 ± 5.9^{fg}	652 ± 49.7^{b}	5116 ± 301^{c}
6	*Kandelia candel*	17.08 ± 0.53^{b}	74 ± 4.6^{cdefg}	481 ± 28.5^{b}	6372 ± 972^{c}
7	*Ceriops tagal*	35.4 ± 5.4^{b}	66.1 ± 14.2^{efg}	591 ± 5.3^{b}	7651 ± 3377^{c}
8	*Avicennia officinalis*	17.01 ± 2.9^{b}	96.1 ± 12.6^{bc}	322 ± 34^{b}	9794 ± 1911^{c}
9	*Avicennia marina*	21.7 ± 2.3^{b}	83.6 ± 2.6^{cdefg}	277.2 ± 17.9^{b}	6114 ± 1611^{c}
10	*Sonneratia alba*	20.5 ± 1.5^{b}	83.0 ± 8.2^{cdefg}	493 ± 56.2^{b}	9308 ± 1171^{bc}
11	*Sonneratia apetala*	26.6 ± 3.6^{b}	90.0 ± 5.1^{bcd}	490.08 ± 5.1^{b}	11352 ± 2273^{bc}
12	*Sonneratia caseolaris*	15.9 ± 2.3^{b}	108 ± 5.2^{b}	497.4 ± 60^{b}	21852 ± 5348^{b}
13	*Excoecaria agallocha*	7.87 ± 0.99^{b}	80 ± 4.4^{cdefg}	566.5 ± 34.9^{b}	9877 ± 902^{bc}
14	*Aegiceras corniculatum*	165 ± 36^{a}	36.5 ± 1.5^{h}	280 ± 24.5^{b}	1413 ± 218^{c}
15	*Heritiera littoralis*	4.7 ± 0.24^{b}	136 ± 3.2^{a}	376 ± 7.9^{b}	33858 ± 14774^{a}
16	*Lumnitzera racemosa*	25.1 ± 4.5^{b}	69.0 ± 20^{cdef}	425 ± 112^{b}	7250 ± 570^{c}
17	*Xylocarpus granatum*	12.8 ± 0.38^{b}	63.1 ± 2.2^{fg}	372 ± 23.8^{b}	6392 ± 920^{c}
F value		16.127**	9.346**	63.256**	3.485**

Means with same letter as superscript indicates homogeneous group.

**Significant at 1%level * Significant at 5% level ns Non-significant at 1%level

4.2.4. Vessel area

Analysis of variance showed that there is a significant difference between the vessel area of the mangrove species (Table 3). *Heritiera littoralis* had the highest vessel area (33858 µm) and was significantly different from other species. The vessel area of *Rhizophora mucronata, Rhizophora apiculata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera sexangula, Kandelia candel, Ceriops tagal, Avicennia officinalis, Avicennia marina, Sonneratia alba, Sonneratia apetala, Excoecaria agallocha, Lumnitzera racemosa, Xylocarpus granatum* and *Aegiceras corniculatum* are on par with each other. The vessel area of *Aegiceras corniculatum* (1413 µm) was recorded as the smallest vessel area with respect to other species.

4.2.5. Ray features of seventeen mangrove species

The ray features such as ray frequency, ray height and ray diameter of seventeen mangrove species were compared (Table 4).

4.2.5.1. Ray frequency

Analysis of variance of showed that there was a significant difference between the ray frequency of mangrove species (Table 4). *Sonneratia alba* (34/mm^2) recorded the highest ray frequency followed by *Sonneratia caseolaris* (30/mm^2) and *Sonneratia apetala* (24/mm^2).The ray frequency of *Aegiceras corniculatum* (6/mm^2) and *Rhizophora apiculata* (6/mm^2) were on par with the ray frequency of *Rhizophora mucronata* (5/mm^2), *Bruguiera cylindrical* (4/mm^2), *Bruguiera gymnorrhiza* (4/mm^2) and *Bruguiera sexangula* (5/mm^2). The ray frequency of *Heritiera littoralis* (19/mm^2) was on par with *Xylocarpus granatum* having ray frequency (12/mm^2) whereas the ray frequency of *Avicennia marina* (15/mm^2), *Excoecaria agallocha (*17/mm^2) and *Lumnitzera racemosa (*17/mm^2) were found to be statistically on par with each other.

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4.2.5.2. Ray height

Analysis of variance revealed that the ray height of mangrove species shows significant difference (Table 4). The higher ray height of *Bruguiera gymnorrhiza* (2237 µm) and *Bruguiera sexangula* (2237 µm) followed by *Rhizophora mucronata* (2217 µm) were found to be statistically on par with each other. *Rhizophora apiculata* and *Bruguiera cylindrica* are on par with *Kandelia candel* and *Ceriops tagal.* The ray frequency of *Avicennia officinalis* were recorded 1019 µm. *Avicennia marina* (521 µm), *Sonneratia alba* (383 µm), *Sonneratia caseolaris* (383 µm), *Sonneratia apetala* (471 µm), *Excoecaria agallocha* (387 µm), *Aegiceras corniculatum* (521 µm), *Heritiera littoralis* (502 µm), *Lumnitzera racemosa* (375 µm) and *Xylocarpus granatum* (435 µm) were found to be on par with each other.

Table 4. Comparison of ray features among seventeen mangrove species

Sl .No	Species	Ray frequency (no./mm^2)	Ray height (µm)	Ray diameter (µm)
1	*Rhizophora mucronata*	4.8 ± 0.47^{g}	2217 ± 194^{a}	67 ± 4.06^{d}
2	*Rhizophora apiculata*	6.4 ± 0.36^{fg}	1360 ± 118^{bc}	87 ± 2.7^{c}
3	*Bruguiera cylindrica*	4.3 ± 0.64^{g}	1288 ± 348^{bc}	91 ± 4.6^{c}
4	*Bruguiera gymnorrhiza*	4.4 ± 0.43^{g}	2237 ± 346^{a}	108 ± 4.9^{b}
5	*Bruguiera sexangula*	4.5 ± 0.17^{g}	2237 ± 80^{a}	143 ± 2.3^{a}
6	*Kandelia candel*	5.8 ± 0.25^{g}	1593 ± 52^{b}	137 ± 5.4^{a}
7	*Ceriops tagal*	6.3 ± 0.87^{fg}	1678 ± 134^{b}	80.84 ± 11.8^{c}
8	*Avicennia officinalis*	11.1 ± 1.6^{e}	1019 ± 138^{c}	$55.5\pm6.9d^{e}$
9	*Avicennia marina*	15.4 ± 0.88^{d}	521 ± 42.7^{d}	30.62 ± 2.9^{fg}
10	*Sonneratia alba*	34.6 ± 1.4^{a}	383 ± 35.2^{d}	19.08 ± 0.73^{g}
11	*Sonneratia apetala*	24.6 ± 2.5^{c}	471 ± 26^{d}	25.03 ± 2.02^{g}
12	*Sonneratia caseolaris*	30.3 ± 1.2^{b}	383 ± 11.5^{d}	16.7 ± 1.0^{g}
13	*Excoecaria agallocha*	17.3 ± 1.0^{d}	387 ± 46^{d}	20.64 ± 1.2^{g}
14	*Aegiceras corniculatum*	6.11 ± 0.98^{fg}	521 ± 93^{d}	43.8 ± 8.2^{ef}
15	*Heritiera littoralis*	9.3 ± 0.42^{ef}	502 ± 33.7^{d}	59.4 ± 5^{d}
16	*Lumnitzera racemosa*	17.5 ± 1.22^{d}	375 ± 47.2^{d}	19.5 ± 1.8^{g}
17	*Xylocarpus granatum*	12.05 ± 1.03^{e}	435 ± 39.5^{d}	39.7 ± 1.31^{f}
F value		80.168**	25.514**	74.142**

Means with same letter as superscript indicates homogeneous group. **Significant at 1%level * Significant at 5%level ns Non-significant at 1% level

4.2.5.3. Ray diameter

The ray diameter of mangrove species shows significant difference at 1% level (Table 4). *Bruguiera sexangula* and *Kandelia candel* recorded maximum ray diameter of 143 µm and 137 µm respectively. *Bruguiera gymnorrhiza* shows ray diameter of 108 µm. The ray diameter of *Rhizophora apiculata* (87 µm) is on par with *Bruguiera cylindrica* (91 µm) and, *Avicennia officinalis* (55µm).The ray diameter of *Aegiceras corniculatum and Avicennia marina* (30 µm), *Sonneratia alba* (19 µm), *Sonneratia apetala* (25 µm), *Sonneratia caseolaris* (16 µm), *Excoecaria agallocha* (20 µm) *and Lumnitzera racemosa* (19 µm) were found to be on par with each other.

4.2.5.4. Fibre features of seventeen mangrove species

The fibre features such as fibre frequency, fibre height and fibre diameter of seventeen mangrove species were compared (Table 5).

4.2.6. Fibre diameter and fibre lumen diameter

Analysis of variance revealed that there is no significant difference between the fibre diameter and fibre lumen diameter of seventeen mangrove species (Table 5).

4.2.6.1. Fibre length

The fibre length of mangrove species were recorded statistically significant at 1% level (Table 5). *Rhizophora mucronata* (1493 µm) with longest fibre length and *Aegiceras corniculatum* with smallest fibre length of 482 µm were presented. *Rhizophora apiculata*, *Bruguiera cylindrica* , *Bruguiera gymnorrhiza*, *Bruguiera sexangula* has the fibre length of 1170 µm, 1182 µm, 1155 µm, 1287 µm respectively and are on par with each other. The fibre length of *Ceriops tagal* (1051 µm), *Avicennia officinalis* (1088 µm), *Avicennia marina* (1007 µm), *Sonneratia alba* (950 µm), *Sonneratia apetala* (899 µm), *Sonneratia caseolaris* (934 µm), *Excoecaria agallocha* (911 µm), *Heritiera littoralis* (959 µm), *Lumnitzera racemosa* (1076 µm), *Xylocarpus granatum* (993 µm) were found to be statistically on par with each other.

Table 5. Comparison of fibre features among seventeen mangrove species

Sl .No	Species	Fibre diameter (µm)	Fibre length (µm)	Fibre lumen diameter (µm)	Fibre wall thickness (µm)
1	*Rhizophora mucronata*	29.2 ± 1.5^{b}	1493 ± 72^{a}	12.08±1.08	8.58 ± 0.87^{a}
2	*Rhizophora apiculata*	25.1 ± 0.58^{b}	1170 ± 72.9^{bc}	12.98±0.71	6.02 ± 0.33^{bc}
3	*Bruguiera cylindrica*	27.4 ± 2.4^{b}	1182 ± 101^{bc}	9.2±1.1	9.06 ± 1.5^{a}
4	*Bruguiera gymnorrhiza*	30.3 ± 2.2^{b}	1155 ± 41^{bc}	15.8±2.4	7.5 ± 1.4^{ab}
5	*Bruguiera sexangula*	25.5 ± 0.89^{b}	1287 ± 72.5^{b}	13.6±0.62	5.85 ± 0.23^{bcd}
6	*Kandelia candel*	31 ± 258^{b}	1098 ± 33^{cd}	20.5±33.3	5.06 ± 0.26^{cde}
7	*Ceriops tagal*	22.2 ± 0.32^{b}	1051 ± 13.7^{cde}	22.82±16.5	7.46 ± 0.59^{ab}
8	*Avicennia officinalis*	24.6 ± 0.66^{b}	1088 ± 59^{cde}	13.5±0.53	5.46 ± 0.54^{bcd}
9	*Avicennia marina*	21.3 ± 1.08^{b}	1007 ± 54^{cde}	9.7±0.81	5.76 ± 0.16^{bcd}
10	*Sonneratia alba*	29.7 ± 1.6^{b}	950 ± 54.8^{de}	21.1±1.1	4.15 ± 0.53^{cdef}
11	*Sonneratia apetala*	25.6 ± 0.53^{b}	899 ± 42^{e}	21.1±0.81	2.41 ± 0.24^{f}
12	*Sonneratia caseolaris*	32 ± 0.87^{b}	$934 \pm 18d^{e}$	27.6±1.05	2.31 ± 0.24^{f}
13	*Excoecaria agallocha*	27.8 ± 1.4^{b}	$911 \pm 85.8d^{e}$	20±2.0	3.80 ± 0.35^{def}
14	*Aegiceras corniculatum*	27.06 ± 0.93^{b}	482 ± 38.9^{f}	17.9±0.73	4.55 ± 0.30^{cde}
15	*Heritiera littoralis*	19.7 ± 0.39^{b}	959 ± 22.6^{de}	11.2±1.3	4.18 ± 0.04^{cdef}
16	*Lumnitzera racemosa*	21.06 ± 1.8^{b}	1076 ± 85^{cde}	11.6±1.7	4.82 ± 0.71^{cde}
17	*Xylocarpus granatum*	24.2 ± 0.42^{b}	993.56 ± 32^{cde}	17.9±0.73	3.15 ± 0.25^{ef}
	F value	2.711^{ns}	12.713**	1.5^{ns}	8.868**

Means with same letter as superscript indicates homogeneous group.

**Significant at 1%level * Significant at 5%level ns Non-significant at 1%level

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4.2.6.2. Fibre wall thickness

Analysis of variance revealed that the fibre wall thickness of mangrove species shows significant difference (Table 5). The highest fibre wall thickness recorded in *Bruguiera cylindrica* (9µm) was on par with *Rhizophora mucronata* (8µm).The fibre wall thickness of *Rhizophora apiculata* (6 µm), *Bruguiera gymnorrhiza* (7µm) , *Bruguiera sexangula* (6 µm), *Ceriops tagal* (7 µm) , *Avicennia officinalis* (5 µm), *Avicennia marina* (6 µm) are statistically on par with each other. *Sonneratia alba* (4 µm), *Sonneratia apetala* (2 µm), *Sonneratia caseolaris* (2 µm), *Excoecaria agallocha* (3 µm), *Heritiera littoralis* (4 µm) and *Xylocarpus granatum* (3 µm) are statistically on par with each other.

4.2.7. Vessel features of mangrove species of Rhizophoraceae family

In the present study seven species Rhizophoraceae family of four genera were collected. The vessel features such as vessel frequency, vessel diameter, vessel length and vessel area of seventeen mangrove species were compared within Rhizophoraceae family (Table 6).

4.2.7. Vessel frequency

Analysis of variance revealed that the vessel frequency of mangrove species of Rhizophoraceae family were significantly different (Table 6). The vessel frequency of *Ceriops tagal (35/mm*^{2}) is on par with *Bruguiera sexangula* (26/mm^2) *and* the vessel frequency of *Rhizophora mucronata* (13/mm^2), *Rhizophora apiculata* (12/mm^2), *Bruguiera cylindrica*(15/mm^2) and *Kandelia candel*(17/mm^2) are on par with each other.

4.2.7.1. Vessel diameter and Vessel area

The vessel diameter and vessel area of mangrove species of Rhizophoraceae family were not found to be significantly different (Table 6).

Table 6. Comparison of vessel features among mangrove species of Rhizophoraceae family

Sl .No	Species	Vessel frequency (no./mm^2)	Vessel diameter (µm)	Vessel length (µm)	Vessel area (µm)	Vessel bar	Vessel bar width (µm)
1	*Rhizophora mucronata*	12.9 ± 1.8^{c}	88.4 ± 6.3	8906 ± 1044^{a}	4417 ± 2326	$6.6\pm.04^{c}$	16.8 ± 1.52^{ab}
2	*Rhizophora apiculata*	12.1 ± 1.4^{c}	61.02 ± 13.3	540 ± 38^{b}	5932 ± 242	$6.4\pm.31^{c}$	19.1 ± 3.2^{a}
3	*Bruguiera cylindrica*	15.8 ± 2.6^{c}	86.1 ± 4.9	637 ± 59^{b}	7757 ± 214	$8.6\pm.24^{b}$	10.1 ± 0.69^{c}
4	*Bruguiera gymnorrhiza*	17.2 ± 1.9^{c}	84.5 ± 1.7	556 ± 120^{b}	7293 ± 902	$12.7\pm.82^{b}$	14 ± 0.53^{bc}
5	*Bruguiera sexangula*	$26.4\pm.93^{b}$	62.3 ± 2.6	652 ± 49.7^{b}	5116 ± 301	8.8 ± 1.3^{b}	12.6 ± 0.49^{bc}
6	*Kandelia candel*	$17.1\pm.53^{c}$	74.6 ± 4.6	481 ± 28.5^{b}	6372 ± 972	$9.5\pm.25^{b}$	11.4 ± 2.3^{c}
7	*Ceriops tagal*	35.5 ± 5.4^{a}	66.1 ± 31.9	591 ± 5.3^{b}	7651 ± 3377	$8.1\pm.28^{bc}$	10 ± 0.14^{c}
	F-value	10.803**	0.96^{ns}	62.335**	0.71^{ns}	11.18**	4.39*

Means with same letter as superscript indicates homogeneous group.

**Significant at 1%level * Significant at 5%level ns Non-significant at 1%level

4.2.7.2. Vessel length

The vessel length of mangrove species of Rhizophoraceae family were found to be significantly different. *Rhizophora mucronata* which had the highest vessel length (8906µm) were significantly different from other members (Table 6).The vessel length of *Rhizophora apiculata* (540 µm), *Bruguiera cylindrica* (637 µm), *Bruguiera gymnorrhiza* (556 µm), *Bruguiera sexangula* (652 µm), *Kandelia candel* (481 µm) and *Ceriops tagal* (591 µm) were found to be statistically on par with each other.

4.2.7.3. Vessel bar

Analysis of variance revealed that the vessel bar of mangrove species of Rhizophoraceae family were significantly different at 1% (Table 6). *Bruguiera* *gymnorrhiza* had the highest number of vessel bar (13). The vessel bar number of *Rhizophora mucronata* and *Rhizophora apiculata* was on par with *Ceriops tagal Bruguiera cylindrica, Bruguiera sexangula, Kandelia candel* and *Ceriops tagal* recorded the vessel bars 8.6, 8.8, 9.5, 8.1 respectively were on par with each other.

4.2.7.4. Vessel bar width

Analysis of variance revealed that the vessel bar width of mangrove species of Rhizophoraceae family were significantly different at 5% (Table 6). Vessel bar width of *Rhizophora apiculata (*19.1 μm) is statistically on par with *Rhizophora mucronata* (16.8 μm). The vessel bar width of *Bruguiera cylindrica (*10 μm), *Bruguiera gymnorrhiza (*14 μm), *Bruguiera sexangula* (12.6 μm), *Kandelia candel* (11 μm) and *Ceriops tagal* (10 μm) were on par with each other.

4.2.8 Ray parameters of mangrove species within Rhizophoraceae family

The ray features such as ray frequency, ray height and ray diameter of seventeen mangrove species were compared (Table 7).

4.2.8.1. Ray frequency

There is a significant difference between the ray frequencies of mangrove species in Rhizophoraceae family at 5% level (Table 7). The ray frequency of *Ceriops tagal* (6.3/mm^2*)* was on par with *Kandelia candel* (5.8/mm^2), *Rhizophora mucronata* (5/mm^2) and *Rhizophora apiculata* (6.4/mm^2). The ray frequency *Rhizophora mucronata* (4.8/mm^2), *Bruguiera cylindrical* (4.3/mm^2), *Bruguiera gymnorrhiza* (4/mm^2), *Bruguiera sexangula* (4.5/mm^2) and *Kandelia candel* (5.8/mm^2) were found to be on par with each other.

Table 7. Comparison of ray parameters among mangrove species of Rhizophoraceae family

Sl .No	Species	Ray frequency (no./mm^2)	Ray height (µm)	Ray diameter (µm)
1	*Rhizophora mucronata*	4.8 ± 0.48^{ab}	2217 ± 194^{a}	67 ± 4.06^{d}
2	*Rhizophora apiculata*	6.4 ± 0.37^{ab}	1360 ± 118^{c}	87 ± 2.7^{c}
3	*Bruguiera cylindrica*	4.3 ± 0.64^{b}	1288 ± 348^{c}	91 ± 4.6^{bc}
4	*Bruguiera gymnorrhiza*	4.4 ± 0.43^{b}	2237 ± 346^{ab}	108 ± 4.9^{b}
5	*Bruguiera sexangula*	4.5 ± 0.17^{b}	2237 ± 80^{a}	143 ± 2.3^{a}
6	*Kandelia candel*	5.8 ± 0.56^{ab}	1593 ± 52^{bc}	137 ± 5.4^{a}
7	*Ceriops tagal*	$6.3\pm.87^{a}$	1678 ± 134^{abc}	80 ± 11^{cd}
F value		3.3*	4.2*	23.9**

Means with same letter as superscript indicates homogeneous group.

**Significant at 1 % level * Significant at 5 % level ns Non-significant at 1 % level

4.2.8.2. Ray height

Analysis of variance showed that the ray height of mangrove species of Rhizophoraceae family were significantly different at 5% level (Table 7). The ray height of *Bruguiera sexangula* (2237 µm) which were found to be statistically on par with *Bruguiera gymnorrhiza* (2237 µm) were highest followed by *Rhizophora mucronata (*2217 µm), *Ceriops tagal(*1678 µm) and *Bruguiera gymnorrhiza* (2217 µm) which were found to be statistically on par with each other. *Rhizophora apiculata, Bruguiera cylindrica* and *Kandelia candel* showed the ray height of 1360 µm, 1288 µm and 1593 µm respectively on par with each other.

4.2.8.3. Ray diameter

The ray diameter of mangrove species of Rhizophoraceae family were significantly different at 5 % level (Table 7). The ray diameter of *Bruguiera sexangula* (143 µm) were recorded the highest followed by *Kandelia candel* (137 µm) and is statistically on par with each other. *Rhizophora apiculata* had ray diameter of 87 µm which is on par with *Bruguiera cylindrica* (91 µm). The ray diameter of *Bruguiera cylindrica* (91 µm) is on par with *Bruguiera gymnorrhiza* (108 µm) and the ray diameter of *Rhizophora mucronata* (67 µm) were found to be statistically on par with *Ceriops tagal* (80 µm).

4.2.9. Fibre parameters among mangrove species of Rhizophoraceae family

The fibre features such as fibre frequency, fibre height and fibre diameter of seventeen mangrove species were compared (Table 8).

4.2.9. Fibre diameter and fibre lumen diameter

Analysis of variance showed that the fibre diameter and fibre lumen diameter of mangrove species of Rhizophoraceae family were not significantly different (Table 8).

4.2.9.1. Fibre length

Analysis of variance showed that the fibre diameter of mangrove species of Rhizophoraceae family were significantly different at 5% level (Table 8). The fibre length recorded was the highest in *Rhizophora mucronata* (1493 µm) when compared to other species of Rhizophoraceae family. *Rhizophora apiculata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera sexangula* were recorded to have fibre length of 1170 µm, 1182 µm, 1155 µm, 1287 µm respectively which are statistically on par with each other.

4.2.9.2. Fibre wall thickness

There is a significant difference between fibre wall thickness of mangrove species of Rhizophoraceae family at 5% level (Table 8). The fibre wall thickness of *Rhizophora mucronata* (8.5 µm), *Rhizophora apiculata* (6 µm), *Bruguiera cylindrica* (9 µm), *Bruguiera gymnorrhiza* (7.5 µm) and *Bruguiera sexangula* (5.8 117 μm), *Kandelia candel* (5 μm) and *Ceriops tagal* (7.4 μm) were found to be statistically on par with each other.

Table 8. Comparison of fibre parameters among mangrove species of Rhizophoraceae family

Sl .No	Species	Fibre diameter (μm)	Fibre length (μm)	Fibre lumen diameter (μm)	Fibre wall thickness (μm)
1	*Rhizophora mucronata*	29 ± 1.6^{b}	1493 ± 72^{a}	12 ± 1.0	8.5 ± 0.87^{ab}
2	*Rhizophora apiculata*	25 ± 0.58^{b}	1170 ± 72^{bc}	12 ± 0.71	$6.0\pm.33^{bc}$
3	*Bruguiera cylindrica*	27 ± 2.4^{b}	1182 ± 101^{bc}	9.2 ± 1.1	9.0 ± 1.6^{bc}
4	*Bruguiera gymnorrhiza*	30 ± 2.2^{b}	1155 ± 41^{bc}	15 ± 5.5	7.5 ± 1.4^{abc}
5	*Bruguiera sexangula*	25 ± 0.89^{b}	1287 ± 72^{bc}	13 ± 0.62	5.8 ± 0.24^{bc}
6	*Kandelia candel*	31 ± 258^{b}	1098 ± 33^{bc}	20 ± 0.77	5 ± 0.27^{bc}
7	*Ceriops tagal*	22 ± 0.32^{b}	1051 ± 30^{c}	22 ± 16.2	7.4 ± 0.59^{abc}
F value		2.7^{ns}	5.2*	0.74^{ns}	2.54*

Means with same letter as superscript indicates homogeneous group.

**Significant at 1 % level * Significant at 5 % l evel ns -Non-significant at 1 % level

4.2.10. Vessel features between mangrove species of Acanthaceae family

In the present study *Avicennia officinalis* and *Avicennia marina* are the members of Acanthaceae family were collected. The vessel features such as vessel frequency, vessel diameter, vessel length and vessel area of Acanthaceae were compared (Table 9). Statistical analysis showed that there is no significant difference between the vessel features of Acanthaceae family.

Table 9. Comparison of vessel features between mangrove species of Acanthaceae family

Sl .No	Species	Vessel frequency (no./mm²)	Vessel diameter(µm)	Vessel length (µm)	Vessel area (µm)
1	*Avicennia officinalis*	17±2.9	96±12.6	322±34	9794±1911
2	*Avicennia marina*	21±1.3	83±2.6	277±17	6114±1611
F value		2.18^{ns}	0.93^{ns}	0.38^{ns}	2.16^{ns}

Means with same letter as superscript indicates homogeneous group.

**Significant at 1 % level * Significant at 5 % level ns Non-significant at 1 % level

4.2.10.1. The ray parameters between mangrove species of Acanthaceae family

The ray features such as ray frequency, ray height and ray diameter of Acanthaceae mangrove members were compared (Table 10)

Table 10. Comparison of ray parameters between mangrove species of Acanthaceae family

Species	Ray frequency (no./mm²)	Biseriate ray height (µm)	Multiseriate ray height(µm)	Biseriate ray diameter (µm)	Multiseriate ray diameter (µm)
Avicennia officinalis	11±1.6	374±27	1019±138	30±0.86	55±6.9
Avicennia marina	15±0.88	195±51	521±42	10±0.85	30±2.9
F value	5.5*	9.5*	11.8*	264**	10.9*

Means with same letter as superscript indicates homogeneous group.

**Significant at 1 % level * Significant at 5%level ns Non-significant at 1 % level

4.2.10.1.1. Ray frequency

Analysis of variance showed that the ray frequency of mangrove species of Acanthaceae family was significantly different at 5% level (Table 12). The ray frequency of *Avicennia officinalis* was 11/mm^2 while *Avicennia marina* was 15/mm^2.

4.2.10.1.2. Ray height

There is a significant difference between biseriate and multiseriate ray height of mangrove species of Acanthaceae family at 5% level (Table 12). The biseriate ray height of *Avicennia officinalis* is 374 µm and is significantly different from *Avicennia marina* having the height of 195 µm. Analysis of variance revealed that the multiseriate ray height of *Avicennia officinalis* is 1019 µm and is significantly different from *Avicennia marina* with ray height of 521 µm.

4.2.10.1.3. Ray diameter

Analysis of variance revealed that there is a significant difference between biseriate and multiseriate diameter of mangrove species of Acanthaceae family (Table 12). The biseriate ray diameter of *Avicennia officinalis* is 30 µm and is significantly different from *Avicennia marina* having the diameter of 10 µm. The multiseriate ray diameter of *Avicennia officinalis* is 55 µm and is significantly different from *Avicennia marina* with the diameter of 30 µm.

4.2.10.2. Fibre parameters of Acanthaceae mangrove members

The fibre features such as fibre frequency, fibre height and fibre diameter of *Avicennia officinalis* and *Avicennia marina* were compared (Table 11).

4.2.10. 2.1. Fibre diameter

Analysis of variance showed that the fibre diameter of mangrove species of Acanthaceae family were significantly different at 5% level (Table 11). The biseriate fibre diameter of *Avicennia officinalis* is 24 µm and is significantly different from *Avicennia marina* of 21 µm diameter.

Table 11. Comparison of fibre parameters between mangrove species of Acanthaceae family

Sl .No	Species	Fibre diameter (µm)	Fibre length (µm)	Fibre lumen diameter (µm)	Fibre wall thickness (µm)
1	*Avicennia officinalis*	24±0.66	1088±59	13±0.53	5.4±0.54
2	*Avicennia marina*	21±1.08	1007±54	9.7±0.81	5.7±0.16
F value		6.6*	1.01^{ns}	14.3^{ns}	0.28^{ns}

Means with same letter as superscript indicates homogeneous group.

**Significant at 1%level * Significant at 5%level ns Non-significant at 1%level

4.2.10.2. Vessel parameters between mangrove species of Lythraceae family

In the present study three members from Lythraceae family comprising

Sonneratia alba, Sonneratia apetala and *Sonneratia caseolaris* were collected. The vessel features such as vessel frequency, vessel diameter, vessel length and vessel area were compared within Lythraceae family (Table 12).

Table 12. Comparison of vessel parameters between mangrove species of Lythraceae family

Sl .No	Species	Vessel frequency (no./mm^2)	Vessel diameter (µm)	Vessel length (µm)	Vessel area (µm)
1	*Sonneratia alba*	20±1.5^{ab}	83±8.2^{b}	493±56^{a}	9308±1171
2	*Sonneratia apetala*	26±3.6^{a}	90±5.1^{ab}	490±5.1^{a}	11352±2273
3	*Sonneratia caseolaris*	15±2.3^{b}	108±5.2^{a}	497±60^{a}	21852±5348
F value		4.1*	4.3*	24.1^{ns}	3.8^{ns}

Means with same letter as superscript indicates homogeneous group.

**Significant at 1%level * Significant at 5%level ns Non-significant at 1%level

4.1.2.10.1. Vessel frequency

There is a significant difference between of mangrove species of Lythraceae family in case of vessel frequency at 5% level (Table 14). The vessel frequency of *Sonneratia alba* is on par with the vessel frequency of *Sonneratia apetala* (26/mm^2) and the vessel frequency of *Sonneratia caseolaris* (15/mm^2). But the vessel frequency of *Sonneratia apetala* significantly different from *Sonneratia caseolaris.*

4.1.2.10.2. Vessel diameter

Analysis of variance showed that the vessel diameter of mangrove species of Lythraceae family were significantly different at 5% level (Table 14). The vessel diameter of *Sonneratia apetala* (90 µm) is on par with the vessel diameter of *Sonneratia alba* (90 µm) and *Sonneratia caseolaris* (15 µm). The vessel diameter of *Sonneratia alba* (90 µm) was significantly differed from *Sonneratia caseolaris* (15 µm).

4.1.2.10.3. Vessel length and vessel area

Analysis of variance showed that there is no significant difference between the vessel length and vessel area of the three species of Lythraceae family (Table 14).

4.1.2.11. Ray parameters of Lythraceae family

The ray features such as ray frequency, ray height and ray diameter of *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* were compared (Table 13).

Table 13. Comparison of ray parameters between mangrove species of Lythraceae family

Species	Ray frequency (no./mm^2)	Ray height (µm)	Ray diameter (µm)
Sonneratia alba	34±1.4	383±35	19±0.73^b
Sonneratia apetala	24±5.6	471±26	25±2.0^a
Sonneratia caseolaris	30±1.2	383±11	16±1^b
F value	7.4^{ns}	3.74^{ns}	9.6*

Means with same letter as superscript indicates homogeneous group.

**Significant at 1%level * Significant at 5%level   ns Non-significant at 1%level

4.1.2.11.1. Ray diameter

The ray diameter of mangrove species of Lythraceae family were significantly different at 5 % level (Table 15). *Sonneratia apetala* having ray diameter of (25 µm) is significantly different from *Sonneratia alba* (19 µm) and *Sonneratia caseolaris* (16 µm) which is on par with each other.

4.1.2.12. Fibre parameters of mangrove species of Lythraceae family

The fibre features such as fibre frequency, fibre length and fibre diameter of *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* were compared (Table 13).

Table 14. Comparison of fibre parameters between mangrove species of Lythraceae family

Sl .No	Species	Fibre diameter(µm)	Fibre length (µm)	Fibre lumen diameter (µm)	Fibre wall thickness (µm)
1	*Sonneratia alba*	29±1.6^{a}	950±54	21±1.1^{b}	4.1±0.53^{a}
2	*Sonneratia apetala*	25±0.53^{b}	899±42	21±0.81^{b}	2.4±0.24^{b}
3	*Sonneratia caseolaris*	32±0.87^{a}	928±22	27±1.0^{a}	2.3±0.24^{b}
F value		9.1*	0.39^{ns}	14.0*	7.87*

Means with same letter as superscript indicates homogeneous group.
**Significant at 1 % level * Significant at 5 % level ns Non-significant at 1 % level

4.1.12.1. Fibre diameter

Analysis of variance revealed that the fibre diameter of mangrove species of Lythraceae family were significantly different at 5 % level (Table 14). *Sonneratia caseolaris* (32 µm) having highest fibre diameter is significantly different from *Sonneratia alba* (29 µm) and *Sonneratia apetala* (25 µm) which is on par with each other.

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4.1.2.12.2. Fibre length

Analysis of variance showed that there is no significant difference between the fibre length of the three species of Lythraceae family (Table 14).

4.1.2.12.3. Fibre Lumen Diameter

There is a significant difference between the fibre lumen diameter of mangrove species of Lythraceae family at 5% level (Table 14). The lumen diameter of *Sonneratia caseolaris* was 27 μm which was significantly different from *Sonneratia alba* (21 μm) and *Sonneratia apetala* (21 μm)

4.1.2.12.4 Fibre wall thickness

The statistical analysis showed that the fibre diameter of mangrove species of Lythraceae family were significantly different at 5% level. The fibre wall thickness of *Sonneratia alba* (4 μm) was significantly different from *Sonneratia caseolaris* (2.3 μm) and *Sonneratia apetala* (2.4 μm) which were on par with each other (Table 14).

4.2. Ecoanatomical wood features of mangroves species

The eco anatomical wood features includes vessel length, vessel diameter, vessel frequency, vessel grouping and nature of perforation plates of mangrove genera in the present investigations were compared with its terrestrial relatives reported from other literature and are discussed underneath.

4.2.1. Ecoanatomical wood features of Rhizophoraceae members and its terrestrial relatives

Ecoanatomical wood characters like solitary vessel percentage, vessel frequency, vessel diameter, vessel length, and nature of perforation plates of Rhizophoraceae members including *Rhizophora mucronata, Rhizophora apiculata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera sexangula, Kandelia candel* and *Ceriops tagal* were compared with their terrestrial relatives such as *Cassipourea guianensis* from dry habitat and *Carallia brachiate* from semi evergreen forest (Table 15). The phylogenetic relationship between 124

Rhizophoraceae members and their terrestrial relatives *Cassipourea spp.* and *Carallia spp.* are shown in Annexure IV.

4.2. 1.1. Solitary vessel percentage

In the present investigation the solitary vessel percentage of *Rhizophora mucronata* and *Rhizophora apiculata* were recorded 60% and 54% respectively. *Bruguiera cylindrica, Bruguiera gymnorrhiza* and *Bruguiera sexangula* have shown solitary vessel percentage of 38 %, 37 % and 18 % respectively. *Kandelia candel* and *Ceriops tagal* had solitary vessel percentage of 22 % and 41 % respectively. The terrestrial relatives such as *Cassipourea guianensis* and *Carallia brachiate* had 100% and 50-60 % solitary vessel respectively (Table 15).

4.2. 1.2. Vessel frequency

The vessel frequency of *Rhizophora mucronata and Rhizophora apiculata* in the present investigation were found to be $13/mm^2$ and $12/mm^2$ respectively (Table 15). *Bruguiera cylindrica, Bruguiera gymnorrhiza* and *Bruguiera sexangula* has vessel frequency of $16/mm^2$, $17\ /mm^2$, $26/mm^2$ respectively. The vessel frequency of $17/mm^2$ and $35/mm^2$ respectively were recorded for *Kandelia candel* and *Ceriops tagal*. The terrestrial relatives such as *Cassipourea guianensis* has shown the vessel frequency range between $30\text{-}47/mm^2$ and for *Carallia brachiate* was found to be $13/mm^2$.

4.2. 1.3. Vessel diameter

In the present investigation the vessel diameter of mangrove members were recorded within 100 µm and whereas the vessel diameter of terrestrial relatives were recorded more than 100 µm. *Rhizophora mucronata, Rhizophora apiculata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera sexangula, Kandelia candel* and *Ceriops tagal* showed vessel diameter of 88 µm, 61 µm, 86 µm, 84 µm,62 µm,74 µm and 66 µm respectively (Table 15). And the terrestrial relatives *Cassipourea* *guianensis and Carallia brachiate* has been recorded with vessel diameter of 66 µm and 130 µm respectively.

4.2.1.4 Vessel length and nature of vessel plates

The range of vessel length of mangrove species were recorded in between 480-8900 µm with scalariform vessel plate and the terrestrial relatives showed the range between 600-1700 with simple plates. The vessel length of *Rhizophora mucronata, Rhizophora apiculata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera sexangula, Kandelia candel* and *Ceriops tagal* were 8906 µm, 540 µm, 637 µm 556 µm, 652 µm, 481 µm and 591 µm respectively. The terrestrial relatives such as *Cassipourea guianensis* and *Carallia brachiate* had vessel length of 1220 µm and 1780 µm respectively (Table 15).

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Table 15. Comparison of ecoanatomical characters of Rhizophoraceae members and its terrestrial relatives

Species	Order/Family	Solitary vessel percentage (%)	Vessel Frequency (no./mm^2)	Vessel diameter (µm)	Vessel length (µm)	Perforation vessel plate	References
Rhizophora mucronata	Malpighiales, Rhizophoraceae	60	12.9	88	8906	Scalariform	Present study
Rhizophora apiculata		54	12.1	61	540	Scalariform	
Bruguiera cylindrica		38	15.7	86	637	Scalariform	
Bruguiera gymnorrhiza		37	17.2	84	556	Scalariform	
Bruguiera sexangula		18	26.4	62	652	Scalariform	
Kandelia candel		22	17.08	74	481	Scalariform	
Ceriops tagal		41	35.4	66	591	Scalariform	
Cassiporea guianensis		100	30-47	66	1220	Simple	Van vliet, 1976
Carallia brachiata		50-60	13	130	1780	Simple	Van vliet, 1976

4.2.2. Ecoanatomical characters of Acanthaceae mangrove members and its terrestrial relatives

The ecoantomical characters such as vessel grouping, vessel frequency, vessel diameter and vessel length of Acanthaceae mangrove members in the present study were compared with their terrestrial relatives from other published data. Phylogenetic relationship of the Aviennia species was compared with its upland sister clade *Thumbergia* and *Tectona* based on the gene sequence *rbcL, trnL intron, trnL-trnF space,nr DNA* obtained from both Maximum parsimony and Maximum likelihood method (Fig. 4 and Table 6). The Acanthaceae mangrove members such as *Avicennia officinalis* and *Avicennia marina* were compared with its terrestrial relatives *Tectona grandis* from the moist habitat and *Thumbergia alata* from the dry habitat (Table 16).

4.2.2.1 Vessel frequency and vessel diameter

The vessel frequency of the mangrove species such as *Avicennia officinalis* and *Avicennia marina* were recorded 17/mm^2 and 21/mm^2 respectively from the present investigation whereas the vessel frequency of *Tectona grandis* was recorded in the range between 6-7/mm^2 (Ahmed and Chun, 2011) and *Thunbergia alata* was recorded vessel frequency of 53/mm^2 (Carlquist, 1988). In the present study *Avicennia officinalis* and *Avicennia marina* have shown the vessel diameter of 96/mm^2 and 83/mm^2 respectively and *Tectona grandis* was recorded with vessel diameter ranging between 278-305 μm (Ahmed and Chun, 2011) and *Thunbergia spp.* with vessel diameter of 50 μm (Carlquist, 1988) were shown in Table 16.

Table 16. Comparison of ecoanatomical characters of Acanthacea mangrove members and its terrestrial relatives

Species	Order/ Family	Vessel frequency (no. /mm^2)	Vessel diameter (µm)	Vessel grouping	Vestured pit	References
Avicennia officinalis	Lamiales, Lamiaceae	17	96	4	Present	Present study
Avicennia marina		21	83	4	Present	
Tectona grandis		6-7	278-305	Mostly solitary	Absent	Hussain and Nasir, 2012., Ahmed and Chun, 2011
Thunbergia spp.		53	50	3.4	Present	Carlquist, 1988

4.2. 2.2 Vessel grouping and vestured pit

The vessel grouping of *Avicennia officinalis* and *Avicennia marina* were compared with its terrestrial relatives *Tectona grandis* and *Thumbergia* spp. The vessel grouping of *Avicennia officinalis* and *Avicennia marina* were found to be 4 from the present study and for *Tectona grandis* the vessels are mostly solitary (Hussain and Nasir, 2012). Carlquist (1988) reported the vessel grouping of *Thunbergia* spp. as 3.4 (Table 16). Vestured pit present in *Avicennia spp* and *Thunbergia* spp. and it is absent in *Tectona grandis.*

4.2.3. Ecoanatomical characters of Lythraceae mangrove members and their terrestrial relatives

In the present investigation the ecoantomical characters such as solitary vessel percentage, vessel frequency, vessel diameter and vessel length of Lythraceae mangrove members such as *Sonneratia alba, Sonneratia apetala* and

Sonneratia caseolaris were compared with their terrestrial relatives *Duabanga molluccana* from wet sites and *Lagerstroemia microcarpa* from dry sites (Table 17). Phylogenetic relationship between Lythraceae mangrove members and their upland relatives *Lagerstroemia* and *Duabanga* based on the DNA sequence *nr DNA* using parsimony method were shown in Annexure IV.

4.2. 3.1. Vessel frequency and vessel diameter

The vessel frequency and vessel diameter of the mangrove species such as *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* were compared with their terrestrial relatives *Duabanga molluccana* and *Lagerstroemia microcarpa* as shown in Table 17. The vessel frequency of *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* were recorded as 20/mm^2, 26/mm^2 and 15/mm^2 respectively whereas the vessel diameter of *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* were recorded 83 µm, 90 µm and 108 µm were recorded respectively from the present study. The vessel frequency of *Duabanga molluccana* was found to be 5/mm^2 and vessel diameter was recorded as 258 µm (Rao *et al.*, 1987) whereas Baas and Zweypfenning (1979) recorded the vessel frequency of 12/mm^2 and vessel diameter of 220 µm (Table 17) for *Lagerstroemia microcarpa.*

Table 17. Comparison of ecoanatomical characters of Lythraceae mangrove members and their terrestrial relatives

Sl .No	Species	Order /Family	Vessel frequency (no./mm²)	Vessel diameter (µm)	Vessel length (µm)	Solitary vessel percentage (%)	Vestured pit	References
1	*Sonneratia alba*	Myrtales, Lythraceae	20	83	493	12-15	Present	Present study
2	*Sonneratia apetala*		26	90	490	20-25	Present	
3	*Sonneratia caseolaris*		15	108	497	35-40	Present	
4	*Duabanga molluccana*		5	258	750	55-62	Absent	Rao *et al.*, 1987; Wheeler, 2011
5	*Lagerstroemia microcarpa*		12	220	400	40	Absent	Baas and Zweypfenning, 1979

4.2.3.2 Vessel length and solitary vessel percentage

The vessel length and solitary vessel percentage of *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* in the present investigation were compared with its terrestrial relative *Duabanga molluccana* and *Lagerstroemia microcarpa.* The vessel length of the mangrove species such as *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* were recorded 493µm,490 µm amd 497µm respectively whereas the vessel length of *Duabanga molluccana* (750 µm) and *Lagerstroemia microcarpa* (400 µm) were recorded from the published data (Table 19). The solitary vessel percentage of *Sonneratia alba* (12-15%), *Sonneratia apetala* (20-25%) and *Sonneratia caseolaris* (35-40%) were recorded from the present study. The terrestrial relative *Duabanga molluccana* showed the solitary vessel percentage range between 55-62% whereas *Lagerstroemia microcarpa* recorded 40% from the published data (Table 17).

4.2.4 Ecoanatomical characters of mangrove species *Excoecaria agallocha* and its terrestrial relatives

The ecoantomical characters such as solitary vessel percentage, vessel frequency, vessel diameter and vessel length of *Excoecaria agallocha* were compared with its terrestrial relatives *Hura spp.* and *Bridelia retusa.* Cladogram of Malpighiales using plastid and nuclear DNA sequences, with particular reference to the embryology of Euphorbiaceae shows the phylogenetic relationship between mangrove species *Excoecaria agallocha* and its upland relatives *Hura* spp. and *Bridelia retusa* of Phyllanthaceae member are shown in Annexure IV.

4.2.4.1. Vessel frequency and vessel diameter

In the present investigation the vessel frequency and vessel diameter of true mangrove species *Excoecaria agallocha* were compared with their terrestrial relatives *Hura* spp. and *Bridelia retusa* (Table 18). The vessel frequency of *Excoecaria agallocha* was found to be 8/mm^2 in the present study whereas in *Hura* spp (Mennega, 2005) and *Bridelia retusa* (Nair *et al*., 1981), it was recorded as $2/mm^2$ and $36\text{-}60/mm^2$ respectively.

Table 18. Comparison of ecoanatomical characters of mangrove species *Excoecaria agallocha* and its terrestrial relatives

Species	Order/ Family	Vessel frequency ($no./mm^2$)	Vessel diameter (µm)	Vessel Length (µm)	Solitary vessel percentage (%) /vessel grouping	References
Excoecaria agallocha	Malpighiales, Euphorbiaceae	8	80	566	28-30	Present study
Hura spp.		2	100-200	525	50-60%	Mennega, 2005
Bridelia retusa		34-60	77	509-530	Radial multiples of 4 or more	Nair *et al.*, 1981; Wheeler, 2011

The vessel diameter of *Excoecaria agallocha* was 80 µm in the current investigation. The vessel diameter of terrestrial relative *Hura spp.* from the records is found to range between 100-200 µm (Mennega, 2005) and for *Bridelia retusa* the recorded the vessel diameter ranges between 509-530 µm (Nair *et al.*, 1981).

4.2.4.2 Vessel length and solitary vessel percentage/vessel grouping

The vessel length of *Excoecaria agallocha* was recorded 566 µm in the present study while its terrestrial relatives *Hura* spp. had vessel length of 525 µm and *Bridelia retusa* had vessel length recorded the range between 509-530 µm. The solitary vessel percentage of *Excoecaria agallocha* was found to be 28-30% in the present investigation whereas solitary vessel percentage of *Hura* spp. was recorded in the range between 50-60% with radial multiples of 4 or more common in *Bridelia retusa* (Table 18)

4.2.5 Ecoanatomical characters of mangrove species *Aegiceras corniculatum* and its terrestrial relatives

The ecoantomical characters such as solitary vessel percentage, vessel frequency, vessel diameter and vessel length of *Aegiceras corniculatum* of present investigation were compared with its terrestrial relative *Myrsine sandwicensis* (Table 19). Phylogenetic relationship between *Aegicerus spp.* and *Myrsine spp.* based on combined morphological and DNA sequence (*atpB, ndhF and rbcL*) data are presented in Annexure IV.

Table 19. Comparison of ecoanatomical characters of mangrove species *Aegiceras corniculatum* and its terrestrial relatives

Species	Order/ Family	Vessel frequency (no./mm^2)	Vessel diameter (μm)	Vessel length (μm)	Solitary vessel percentage (%) /vessel grouping	References
Aegiceras corniculatum	Ericales, Myrsinaceae	165	36.5	280	36-40	Present study
Myrsine sandwicensis		18-29	47-50	350-680	Mostly solitary	Lens *et al.*, 2005

4.2.5.1 Vessel frequency and vessel diameter

The vessel frequency of mangrove species *Aegiceras corniculatum* was recorded 165/mm^2 in the present investigation and its terrestrial relative *Myrsine sandwicensis* was found to be in a range between 18-29/mm^2 (Lens *et al.*, 2005). The vessel diameter of *Aegiceras corniculatum* was found to be 36 μm in the current investigation whereas *Myrsine sandwicensis* has been reported to have vessel diameter in the range between 35-60 μm (Lens *et al.*, 2005). 134

4.2.5.2. Vessel length and solitary vessel percentage/vessel grouping

The vessel length and solitary vessel percentage/vessel grouping of *Aegiceras corniculatum* in the present investigation were compared with the terrestrial relative *Myrsine sandwicensis.* The vessel length of the mangrove species *Aegiceras corniculatum* was reported to be 280 μm in the present study whereas vessel length of *Myrsine sandwicensis* was recorded in the range between 350-680 μm from the published data. The solitary vessel percentage of *Aegiceras corniculatum* was recorded 36-40% from the present study and mostly solitary vessels are seen in *Myrsine sandwicensis* (Lens *et al.*, 2005).

4.2.6. Ecoanatomical characters of *Heritiera littoralis* and its terrestrial relatives

The ecoanatomical characters such as solitary vessel percentage, vessel frequency, vessel diameter and vessel length of *Heritiera littoralis* of present study were compared with its terrestrial relative *Argyrodendron trifoliolatum* (Table 20). The cladogram of Sterculioideae shows the phylogenetic relationship between *Heritiera spp.* and *Argyrodendron spp.* using the Chloroplast Gene *ndhF* are shown in the Annexure IV.

4.2.6.1. Vessel frequency and vessel diameter

The vessel frequency of mangrove species *Heritiera littoralis* was recorded to be 4-5/mm^2 in the present investigation and its terrestrial relative *Argyrodendron trifoliolatum* was found to be in a range between 5-20/mm^2 (Wheeler, 2011). The vessel diameter of *Heritiera littoralis* was found to be 136μm from the present study and vessel diameter of *Discocalyx megacarpa* was reported in the range between 60-180 μm (Chattaway, 1937).

Table 20. Comparison of ecoanatomical characters of mangrove species *Heritiera littoralis* and its terrestrial relatives

Species	Order/ Family	Vessel frequency (no./ mm^2)	Vessel diameter (µm)	Vessel length (µm)	Solitary vessel percentage (%)	Helical thickening	References
Heritiera littoralis	Malvales, Malvaceae	5	136	376	36-40	Present	Present study
Argyrodendron trifoliolatum	Malvales, Malvaceae	5-20	60-180	250-470	20	Absent	Chattaway, 1937; Wheeler, 2011

4.2.6.2. Vessel length and Solitary vessel percentage

The vessel length and solitary vessel percentage of *Heritiera littoralis* in the present investigation was compared with its terrestrial relative *Argyrodendron trifoliolatum.* The vessel length of the mangrove species *Heritiera littoralis* was found to be 376 µm whereas the vessel length of *Argyrodendron trifoliolatum* was reported in the range between 250-470µm from the published data. The solitary vessel percentage of *Heritiera littoralis* was recorded as 36-40% from the present investigation and *Argyrodendron trifoliolatum* reported 20 % solitary vessel percentage from the published data (Chattaway, 1937). Helical thickening on vessel elements was observed in *Heritiera littoralis* but it was absent in *Argyrodendron trifoliolatum.*

4.2.7. Ecoanatomical characters of *Lumnitzera racemosa* and its terrestrial relatives

The ecoantomical characters such as solitary vessel percentage, vessel frequency, vessel diameter and vessel length of *Lumnitzera racemosa* of present 136 investigation were compared with its terrestrial relatives *Anogeissus latifolia* and *Terminalia nitens* (Table 21). The phylogenitic relationship between mangrove genera *Lumnitzera* and upland relatives *Anogeissus* and *Terminalia* using maximum parsimony (MP) and maximum likelihood (ML) analyses based on combined molecular data was shown in Annexure IV.

Table 21. Comparison of ecoanatomical characters of mangrove species *Lumnitzera racemosa* and its terrestrial relatives

Species	Order/Family	Vessel frequency (no./mm^2)	Vessel diameter (µm)	Vessel length (µm)	Solitary vessel percentage (%)	References
Lumnitzera racemosa	Myrtales, Combretaceae	25	69	425	36-40	Present study
Anogeissus latifolia	Myrtales, Combretaceae	44-46	90-105	480-680	35	Van vliet, 1979
Terminalia nitens		6-7	207	470-670	60	

4.2.7.1. Vessel frequency and vessel diameter

The vessel frequency of mangrove species *Lumnitzera racemosa* was recorded 25/mm^2 in the present investigation and its terrestrial relative *Anogeissus latifolia* and *Terminalia nitens* were found to be 44-46/mm^2 and 6-7/mm^2 respectively (Van vliet, 1979). The vessel diameter of *Lumnitzera racemosa* was found to be 69 µm. The vessel diameter of *Anogeissus latifolia* and *Terminalia nitens* were found to be 165 µm and 217 µm respectively (Van vliet, 1979).

4.2.7.2. Vessel length and solitary vessel percentage

The vessel length and solitary vessel percentage of *Lumnitzera racemosa* in the present investigation were compared with the terrestrial relatives *Anogeissus latifolia and Terminalia nitens* (Van vliet, 1979). The vessel length of the mangrove species *Lumnitzera racemosa* was recorded 425 µm in the present investigation whereas vessel length of *Anogeissus latifolia* was found to be ranging between 480-680 µm and *Terminalia nitens* with vessel length 470-670 µm was found to be reported from the published data (Van vliet,1979). The solitary vessel percentage of *Lumnitzera racemosa* (36-40 %) were reported from the present study. The solitary vessel percentage of *Anogeissus latifolia and Terminalia nitens* were recorded 35 %and 60 % from the published data (Van vliet, 1979).

4.2.8 Ecoanatomical characters of mangrove species *Xylocarpus granatum* and its terrestrial relatives

The ecoantomical characters such as vessel frequency, vessel diameter and vessel length of *Xylocarpus granatum* of present study were compared with its terrestrial relative *Azadirachta indica* (Table 22). The phylogenetic relationship between the mangrove genera *Xylocarpus* and its terrestrial relative *Azadirachta indica* obtained from the maximum parsimony analysis of the *rbcL* data were shown in Annexure IV.

4.2.8.1 Vessel frequency, vessel diameter and vessel length

The vessel frequency of mangrove species *Xylocarpus granatum* were recorded 13/mm^2 and its terrestrial relative *Azadirachta indica* were found to be 19/mm^2.The mangrove species *Xylocarpus granatum* with vessel diameter of 63 µm and its terrestrial relative *Azadirachta indica* were recorded the vessel diameter of 100µm. The mangrove species *Xylocarpus granatum* were recorded the vessel length of 372 µm in the present investigation and its terrestrial relative *Azadirachta indica* with vessel length of 284 µm.

Table 22. Comparison of ecoanatomical characters of *Xylocarpus granatum* and its terrestrial relatives

Species	Order/ Family	Vessel frequency (no./mm^2)	Vessel diameter (µm)	Vessel length (µm)	Solitary vessel percentage (%) or vessel grouping	References
Xylocarpus granatum	Sapindales Meliaceae	13	63	372	34	Present study
Azadirachta indica		19	100	284	Radial multiples and clusters	Nair, 1988

4.2.9. Vulnerability and mesomorphy nature of 17 mangrove species

Vessel vulnerability and mesomorphy of 17 mangrove species were compared and were shown in Table 23.

4.2.9.1. Vulnerability ratio

Analysis of variance showed that there is a significant difference between vulnerability ratios of seventeen mangrove species (Table 23). The vulnerability ratio was the highest in *Heritiera littoralis* (31) and lowest in *Aegiceras corniculatum* (0.27). *Rhizophora mucronata, Rhizophora apiculata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Avicennia officinalis, Sonneratia caseolaris* and *Xylocarpus granatum* had vulnerability ratios of 7.2, 7.3, 6.3,5.4, 7.5, 5.05 respectively and were found to be statistically on par with each other. The vulnerability ratio of *Bruguiera sexangula* (2.6), *Kandelia candel (4.3), Ceriops tagal* (2.1), *Avicennia marina* (3.9), *Sonneratia alba* (3.8), *Sonneratia apetala* (3.7), *Lumnitzera racemosa* (3.1) were on par with each other. *Sonneratia caseolaris* and *Excoecaria agallocha* having the vulnerability ratio of 7.5 and 12.2 respectively.

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Table 23. Comparison of vulnerability and mesomorphy nature among seventeen mangrove species

Sl .No	Species	Vulnerability	Mesomorphy
1	*Rhizophora mucronata*	7.2 ± 0.62^{cd}	7203 ± 1522^{b}
2	*Rhizophora apiculata*	7.35 ± 1.2^{cd}	4177 ± 937^{cd}
3	*Bruguiera cylindrica*	$6.3\pm1.2cd^{e}$	4276 ± 1140^{c}
4	*Bruguiera gymnorrhiza*	$5.4\pm0.54cd^{ef}$	3860 ± 471^{cde}
5	*Bruguiera sexangula*	$2.6\pm0.1.2^{fg}$	1695 ± 164^{ef}
6	*Kandelia candel*	$4.3\pm0.20d^{efg}$	2100±69cdef
7	*Ceriops tagal*	2.1 ± 0.59^{gh}	1345 ± 413^{f}
8	*Avicennia officinalis*	6.9 ± 1.5^{cd}	2347 ± 573^{cdef}
9	*Avicennia marina*	3.9 ± 0.29^{efg}	1123 ± 136^{f}
10	*Sonneratia alba*	3.8 ± 0.79^{efg}	1995 ± 573^{def}
11	*Sonneratia apetala*	3.7 ± 0.47^{efg}	1870 ± 288^{ef}
12	*Sonneratia caseolaris*	7.5 ± 0.91^{c}	3776 ± 663^{cde}
13	*Excoecaria agallocha*	12.2 ± 1.6^{b}	6947 ± 1021^{b}
14	*Aegiceras corniculatum*	0.27 ± 0.05^{h}	80.27 ± 22^{f}
15	*Heritiera littoralis*	31.8 ± 1.6^{a}	12418 ± 696^{a}
16	*Lumnitzera racemosa*	3.14 ± 0.92^{fg}	1737 ± 609^{ef}
17	*Xylocarpus granatum*	5.05 ± 0.28^{cdefg}	1909 ± 139^{ef}
F value		58.132**	19.213**

Means with same letter as superscript indicates homogeneous group.

**Significant at 1%level * Significant at 5%levelns Non-significant at 1%level

4.2.9.2 Mesomorphy ratio

Statistical analysis revealed that there is a significant difference between mesomorphy ratios of 17 mangrove species at 5% level (Table 23). The mesomorphic ratio of *Heritiera littoralis* was found to be the highest value (12418) and *Aegiceras corniculatum* recorded the lowest value (80). The mesomorphic ratio of *Bruguiera sexangula(*1695), *Kandelia candel(*2100), *Ceriops tagal* (1345), *Avicennia officinalis* (2347), *Avicennia marina* (1123), *Sonneratia alba*(1995), *Sonneratia apetala (*1870), *Aegiceras corniculatum(*80), *Lumnitzera racemosa* (1737) and *Xylocarpus granatum* (1909) were found to be statistically on par with each other.

4.2.10. Qualitative ecoanatomical features of West Coast of India

4.2.10.1. Type of vessel plate

Two types of vessel plates such as scalariform and simple plates were found in mangrove species collected from West coast of India (Table 24). Scalariform plates were observed in Rhizophoraceae members such as *Rhizophora mucronata, Rhizophora apiculata, Bruguiera gymnorrhiza, Bruguiera cylindrica, Bruguiera sexangula*, *Ceriops tagal* and *Kandelia candel.* Simple vessel plates were found in *Avicennia officinalis, Avicennia marina, Sonneratia alba, Sonneratia caseolaris Sonneratia apetala. Xylocarpus granatum, Lumnitzera racemosa, Aegiceras corniculatum, Excoecaria agallocha* and *Heritiera littoralis.*

4.2.10.2. Lateral wall pitting

In the present investigation four types of lateral wall pitting such as scalariform, transitional, opposite and alternate were observed (Table 24). Only scalariform pitting were observed in *Rhizophora mucronata* and *Rhizophora apiculata.* Scalariform and transitional wall pitting were found in *Bruguiera gymnorrhiza, Bruguiera cylindrica, Bruguiera sexangula* and *Kandelia candel.* Scalariform and opposite wall pitting was seen in *Ceriops tagal.* Alternate lateral wall pitting was found in rest of the species such as *Avicennia officinalis, Avicennia marina, Sonneratia alba,, Sonneratia caseolaris, Sonneratia apetala. Xylocarpus granatum, Lumnitzera racemosa, Aegiceras corniculatum, Excoecaria agallocha* and *Heritiera littoralis.*

4.2.10.3 Vestured pit

Vestured pits were found in 9 species out of 17 true mangrove species (Table 24). Those species are *Avicennia officinalis, Avicennia marina, Sonneratia alba, Sonneratia caseolaris, Sonneratia apetala. Xylocarpus granatum, Lumnitzera racemosa, Aegiceras corniculatum* and *Excoecaria agallocha.* 141

4.2.10.4 Vasicentric tracheid

Vasicentric tracheids were observed only in 11 species viz. *Avicennia officinalis, Avicennia marina, Bruguiera gymnorrhiza, Bruguiera sexangula Sonneratia alba, Sonneratia caseolaris Sonneratia apetala. Xylocarpus granatum*, *Lumnitzera racemosa* and *Heritiera littoralis* (Table 24).

4.2.10.5. Sclerieds

The sclerieds were seen in species *Rhizophora apiculata, Avicennia officinalis* and *Avicennia marina* (Table 24).

4.2.10.6 Crystals

Different types of crystals were observed in the mangrove species collected from the West coast of India. 11 species were reported to be with crystals out of 17 species (Table 24). The crystals were found in *Rhizophora mucronata, Rhizophora apiculata, Bruguiera gymnorrhiza, Bruguiera cylindrica, Ceriops tagal, Avicennia officinalis, Sonneratia alba, Sonneratia caseolaris, Xylocarpus granatum*, *Excoecaria agallocha* and *Heritiera littoralis*

Table 24. Qualitative ecoanatomical features of mangrove species of West Coast of India

Sl .No	Species	Type of vessel plate	Lateral wall pitting	Vestured pit	Vasicentric tracheid	Sclereid	Crystal
1	*Rhizophora mucronata*	Scalariform	Scalariform	-	-	-	+
2	*Rhizophora apiculata*	Scalariform	Scalariform	-	-	+	+
3	*Bruguiera cylindrica*	Scalariform	Scalariform, Transitional	-	-	-	+
4	*Bruguiera gymnorrhiza*	Scalariform	Scalariform, Transitional	-	+	-	+
5	*Bruguiera sexangula*	Scalariform	Scalariform, Transitional	-	+	-	-
6	*Kandelia candel*	Scalariform	Scalariform, Transitional	-	-	-	-
7	*Ceriops tagal*	Scalariform	Scalariform, Opposite	-	-	-	+
8	*Avicennia officinalis*	Simple	Alternate	+	+	+	+
9	*Avicennia marina*	Simple	Alternate	+	+	+	-
10	*Sonneratia alba*	Simple	Alternate	+	+	-	+
11	*Sonneratia apetala*	Simple	Alternate	+	+	-	-
12	*Sonneratia caseolaris*	Simple	Alternate	+	+	-	+
13	*Excoecaria agallocha*	Simple	Alternate	+	-	-	+
14	*Aegiceras corniculatum*	Simple	Alternate	+	+	-	-
15	*Heritiera littoralis*	Simple	Alternate	-	+	-	+
16	*Lumnitzera racemosa*	Simple	Alternate	+	+	-	-
17	*Xylocarpus granatum*	Simple	Alternate	+	+	-	+

5. DISCUSSION

The Mangroves are considered as the most endangered coastal ecosystem. Eighty percent of the mangroves in West coast of India were open mangrove with canopy density of 10-40 % and twenty percent of the area were moderately dense mangroves with canopy density of 40-70%.

The mangroves of the West Coast are considered to occur as fragmented patches. Wood blocks as well as increment core samples of true mangroves of 17 species were collected from 10 sites from this fragmented patch (Fig. 1). These species were distributed in 11 genera and 8 families (Table 2). Different scientists (Naskar and Mandal, 1987; Naskar, 2004) have reported 20 true mangroves distributed in 11 genera and 8 families (Annexure II) in the West Coast of India. Among the 8 different families of true mangrove species recorded in the current study, there was representation of more members from Rhizophoraceae family (41 %) followed by Lythraceae (17 %) and Acanthaceae (12 %). The remaining families viz. Meliaceae, Combretaceae, Euphorbiaceae, Myrsinaceae and Malvaceae represented only one member each (6 %). Systematic studies on the wood anatomical details of West Coast mangroves has not been attempted so far. The present study revealed interesting wood anatomical properties of mangrove species and also developed an IAWA based anatomical key will be helpful for the identification of mangrove species of West Coast of India. Because of the stressful and highly variable environmental condition, the mangroves developed some strategies and adaptation during the process of evolution. These special morphological and physiological adaptations make it possible for the mangrove species to survive in these conditions in contrast to their upland relatives. The modification of xylem hydrological structure of mangrove wood helps to balance safety versus efficiency of water transport system. These modifications of wood structure due to ecological conditions is the driving force for evolution of wood anatomy. Thus the wood anatomy of mangrove species encompasses a wide range of specialization. Important findings of the studies are discussed below.

5.1. Wood anatomical features of mangrove species

Rhizophora spp. comprises of the species. Growth rings were absent in both species of Rhizophora viz. *Rhizophora mucronata* and *Rhizophora apiculata*. Other studies also reported that growth rings were absent in *Rhizophora mucronata* (Van vliet, 1976, Janssonius, 1950; Wheeler, 2011) and *Rhizophora apiculata* (Van vliet, 1976; Wheeler, 2011). In contrast to this, in Kenya annual growth rings were found in *Rhizophora mucronata* but ring boundaries were indistinct (Yanez Espinosa and Flore, 2011). Verheyden *et al.* (2004) suggested that wood anatomical features in *Rhizophora mucronata* could be a potential proxy for past environmental conditions, in particular, temporal changes in soil water salinity. In the present study 60-85% solitary vessel percentage were reported in *Rhizophora* spp. A similar trend was reported by Van vliet (1976) in *Rhizophora* spp. The tangential vessel diameter of *Rhizophora* spp. were recorded as 63 to 130 µm with vessel frequency in the range between 12-13/mm^2 and perforations scalariform in oblique end walls, with 6-7 thick bars in the present study. Contrast to this in Javan mangroves, the tangential diameter and vessel frequency of *Rhizophora mucronata* were recorded 45 to 105 µm and 45 to 50/mm^2 (Janssonius, 1950) which is more than that of present study. A study conducted by Van vliet (1976) in mangrove species revealed that vessel frequency and vessel diameter of *Rhizophora apiculata* range between 14 to 18/mm^2 and 101 to122 µm respectively while in the case of *Rhizophora mucronata,* it ranges between 63 to 97 µm and 550 to 1180 µm respectively. In Kenya, the vessel frequency of *Rhizophora mucronata* recorded up to 30/mm^2 and vessel diameter of 70 µm in the dry season (Schmitz *et al.*, 2006). Vidyasagaran *et al.* (2014) reported moderately numerous to numerous with large vessels in *Rhizophora mucronata*. Similar trend of vessel bar number were observed by Van vliet (1976). Prismatic crystals and globular inclusions are present in procumbent ray cells of *Rhizophora mucronata* and *Rhizophora apiculata* in the present study (IAWA key no.138). Similar trend was reported by (Van vliet, 1976; Wheeler, 2011). Frequently non septate fibre with simple to minutely bordered pit and infrequently and septate fibre was observed in *Rhizophora mucronata* (IAWA key no.31, 32) but only non septate fibre were observed in *Rhizophora apiculata* (IAWA key no.31, 32). However, Wheeler (2011) reported the presence of non septate fibres in both the species while Van vliet, (1976) reported both septate and non septate fibres in *Rhizophora mucronata* and *Rhizophora apiculata* respectively. Fibres were long with thick wall and thin to thick wall were found in the present study (IAWA key no.31, 32,) while thick wall to very thick wall fibre were found in other studies (Wheeler, 2011; Van vliet, 1976). Emerhi (2012) studied the fibre properties of *Rhizophora racemosa* and *Rhizophora harrisonii* and reported the suitability of this species for paper and pulp manufacturing. Rays multiseriate cells up to 8 cells wide with 2.2mm height was ohserved for *Rhizophora mucronata* and 1.3 mm height for *Rhizophora apiculata* whereas Van vliet (1976) recorded ray height recorded up to 4.3mm.

The samples collected from the genera *Bruiguiera* sp comprised of *Bruguiera gymnorrhiza, Bruguiera cylindrica* and *Bruguiera sexangula.* All the three species showed diffuse porous wood with indistinct growth rings. Similar trends were observed by Van vliet (1976) in the same species. It can be noted that *Bruguiera sexangula* has more vessel frequency and vessel grouping than *Bruguiera gymnorrhiza* and *Bruguiera cylindrica* but vessel diameter was observed to be less in *Bruguiera sexangula.* It is a considered view that greater the frequency of vessel, smaller the diameter and greater the chance for grouping of vessels. In Javan mangrove species the vessel frequency of *Bruguiera gymnorrhiza* was 25/mm^2 (Janssonius, 1950) which is a greater value than the current study. The change in vessel frequency is due to the variation of salinity in the mangrove ecological conditions. Vessel occlusions like tyloses and tannins were present in *Bruguiera* spp. Presence of tyloses were reported in other studies also (Van vliet, 1976; Wheeler, 2011).

In the case of *Kandelia* and *Ceriops,* the growth rings were indistinct in both the species. Vessel density of *Ceriops* spp. is very numerous but in *Kandelia candel* it is numerous. Similar observations were reported by other scientists (Van vliet, 1976; Wheeler, 2011). Vessel plates are scalariform while lateral wall pitting is scalariform and transitional in both the species *Kandelia candel* and *Ceriops tagal.* Axial parenchyma observed in *Kandelia candel* was banded and in *Ceriops tagal* it is vasicentric scanty and aliform. Simple and bordered compound vessel ray pits were reported in both the species. Wheeler (2011) also reported the similar trend of observation in vessel ray pits in both the species.

Successive cambium was present in both *Avicennia officinalis* and *Avicennia marina.* Robert *et al.* (2011) reported that the wood anatomy of *Avicennia* is characterized by anomalous uniform growth rings which are however not correlated with the age of the tree. They indeed have ecological significance which seems strongly related to water limited environment. A preliminary study on six *Avicennia marina* trees in Gazi Bay, Kenya showed the non-annual nature of their growth layers (Schmitz *et al.*, 2007). Vessel grouping is high in *Avicennia* spp. However (Wheeler, 2011 and Schmitz *et al.*, 2007) observed high vessel grouping in *Avicennia* spp. Short, numerous vessels with vestured pit were found in both *Avicennia* spp in present study. A high vessel frequency optimizes the water transport under stressful conditions by allowing a more efficient bypass of air-filled vessels and by leaving more vessels functional for the same number of embolized vessels (Schmitz *et al.*, 2006). However helical structure has not so far been reported in vessels of woods of Acanthaceae (Carlquist, 1988) whereas in the present study it is reported in *Avicennia marina*. Yellow gummy inclusions in sclereids were reported in both *Avicennia* spp. in the present investigation. However (Panshin, 1932) observed orange gummy deposits in many cells of *Avicennia marina*. The occurrence of this vessel inclusions might help to prevent the spread of embolism.

From the observation made, the characters shown by *Sonneratia* includes growth ring boundaries indistinct or absent, radially flattened fibre, simple perforation and alternate vestured pit. A similar trend was reported by Rao *et al.* (1987). Most specialized homogeneous procumbent cells were common in three *Sonneratia spp.* The procumbant cells are more efficient at radial translocation of ions and storage of photosynthates. This might be released into cavitated vessel through pits and refill embolism in *Sonneratia* spp. Vessel occlusions like gum and crystals were reported in all the *Sonneratia* spp. in the present study. *Sonneratia* spp. have no axial parenchyma. Similar observations were made by Bass and Zweypfenning (1979) and Rao *et al*. (1987). The fibres constitute most of the ground tissue.

The data on wood anatomy of *Heritiera littoralis* showed both advanced and primitive characters. In the present investigation *Heritiera littoralis* was found to have short, medium vessels with low frequency, dark gum like deposits in rays and homogeneous specialized rays. Chattaaway (1937) also reported the same in *Heritiera littoralis.* Both apotracheal and paratracheal axial parenchyma were observed in the present investigation. Chattaway mentioned this apotracheal diffuse aggregate parenchyma as metatracheal parenchyma with one or two cells wide. Wheeler (2011) also reported diffuse aggregate parenchyma in *Heritiera littoralis.* Short narrow numerous vessels with high vessel grouping were observed in *Xylocarpus granatum, Excoecaria agallocha*, *Aegiceras corniculatum* and *Lumnitzera racemosa.* Septate fibre with simple to minute bordered pit and helical structure associated with vessel is considered as vasicentric tracheids were found in *Xylocarpus granatum*. Crystals were reported in non-chambered parenchyma and ray cells in *Xylocarpus granatum.* Negi *et al*. (2003) also observed the similar trend. Laticifers tube were reported in *Excoecaria agallocha.* The same line of observation was made by Mennega (2005). Heterogeneous type II to type III rays were seen in *Lumnitzera racemosa* and *Xylocarpus granatum* and most advanced homogeneous type II and type III rays were reported in *Excoecaria agallocha* and *Aegiceras corniculatum.*

5.2. Variability and diagnostic value in mangrove species

A number of wood anatomical characters have good diagnostic value on true mangrove species. However, some wood anatomical characters are rather variable and are not or only rarely diagnostic. For eg. a character like absence of growth rings has has no diagnostic value since these rings were not present in all species studied. In the species studied, however the growth rings distinction were observed in *Lumnitzera racemosa* and successive cambial ring distinction were seen in Acanthaceae members such as *Avicennia officinalis* and *Avicennia marina.* The vessel frequencies of mangrove genera vary from 5-165/mm^2 and shows strong overlap among species. *Aegiceras corniculatum* has high vessel frequency which shows variation from other species. Thus, numerous narrow vessels is considered as the diagnostic feature of mangrove species. The vessel length of all mangrove species ranging from small to medium length shows diagnostic value but only one species, viz. *Rhizophora mucronata* had long vessel element and shows much different from other species. Exclusively scalariform vessels were observed in Rhizophoraceae mangrove members and all other mangrove species were observed with simple plates. In the former group, the vessel bar varies between 6-12 and bar width ranges from 10-19 μm but in latter group perforations were absent. Thus scalariform plate with vessel bars is the diagnostic feature of Rhizophoraceae mangrove genera and in other mangrove genera with simple plates are the diagnostic feature. All types of lateral wall pitting were observed in mangrove species including scalariform, transitional, opposite and alternate pit is a good diagnostic feature. However, scalariform, transitional and opposite were observed in Rhizophoraceae mangrove members and alternate pit were reported in the remaining mangrove species. Vertically unilateral compound vessel ray pit includes bordered, half bordered and simple pit were observed in Rhizophoraceae mangrove member is of a good diagnostic value. But in the remaining mangrove species simple compound pits were of good diagnostic value. Rays of mangrove species vary from heterogenous type II to homogeneous type III. The breakdown area of rays were observed only in *Aegiceras* (Plate 419). Crystals are present in almost 65 percent of mangrove genera and is a good diagnostic feature. Vessel occlusions like tyloses, gums and tannins occurred in almost all the genera of mangrove and is considered as a diagnostic feature. Included phloem observed in *Avicennia* spp and *Lumnitzera racemosa* showed variability in mangrove genera. Vestured pits were recorded in almost all mangrove genera except Rhizophoraceae mangrove genera and *Heritiera littoralis* is a good diagnostic feature. Laticifers tubes were present only in *Excoecaria agallocha.* Helical thickenings were observed in mangrove members comprising *Avicennia marina, Aegiceras corniculatum, Xylocarpus granatum* and *Heritiera littoralis.* Fibre with minutely bordered to simple pit which were observed in almost all mangrove genera is a diagnostic feature. Only *Lumnitzera racemosa* recorded both bordered pit and simple pit in fibres show variability. Almost 70 percentage of true mangrove were seen with paratracheal vasicentric parenchyma, whereas, axial parenchyma is totally absent in *Sonneratia* spp and in *Bruguiera cylindrica.* Apotracheal parenchyma were recorded in *Aegiceras corniculatum, Heritiera littoralis* and *Lumnitzera racemosa.*

5.3. Ecoanatomical characterisation of mangrove genera

5.3.1. Vulnerability and mesomorphy

The ratio had been computed for 17 true mangrove species. Notably the vulnerability ranged from 0.27 for *Aegiceras corniculatum* to 31 for *Heritiera littoralis*. Vulnerability index is said to be indicative of sensitivity of a species to the risks of embolisms. A low value for vulnerability ratio could indicate safety of vessels (Givinish, 1986; Carlquist, 2001). More numerous the vessels per sq. mm. the lesser are the chance of disabling of a given number of vessels by air embolisms formed under water stress and serious impairment of conduction in a plant. High vulnerability values would indicate efficient conduction of water with wide infrequent vessels. *Aegiceras corniculatum* has numerous to more numerous vessel and are mostly found towards the seaward side in the present investigation. The vessel density was seen less in *Heritiera littoralis* and it is considered as a freshwater mangrove.

Mesomorphy was said to be the measure of water availability of the species with high values being typically for the species related to mesic ecology (Givinish, 1986; Carlquist, 2001). In the case of mesomorphic ratio, *Heritiera littoralis* (12418) was found to be of higher value and *Aegiceras corniculatum* (80) recorded with lower value. *Heritiera littoralis* is considered as fresh water mangrove as it had more mesomorphic ratio compared to other species. According to mesomorphic ratio of *Aegiceras corniculatum,* the wood is more xeric in nature.

5.3.2. Helical thickenings

The occurrence of helical wall thickenings in vessel elements of mangrove genera seems hardly related to ecological preference. Helical thickenings were observed in mangrove members comprising *Avicennia marina, Aegiceras corniculatum, Xylocarpus granatum* and *Heritiera littoralis.* The helical thickenings in mangrove species might help to store more water during stress conditions. Helical thickenings might aid in refilling of embolized vessels or in some way might diminish danger of cavitation or increase the wall strength (Carlquist 1975; Zimmermann 1983). The citation of helical thickenings in desert and chaparral shrubs by Webber (1936) underlines the relationship between helical thickenings and drought.

5.3.3. Successive cambium

Avicennia spp. showed distinct pattern of successive cambium. Patchy growth via successive cambia may offer a functional advantage under xeric and fluctuating environmental conditions as seen in the mangrove environment. Therefore, the formation of growth layers seems to be influenced by local environmental factors such as soil water salinity and seasonal climate. In addition, the proportion of phloem tissue increased slightly in connection with the salinity of the site (Schmitz et al., 2007). In agreement with these findings, Carlquist (2001) and Fahn and Shchori (1967) found that dispersed phloem tissue over the entire stem offers a functional advantage to trees growing under xeric conditions. The functional advantage of such a three-dimensional phloem network lies in its proposed role in embolism repair and water storage (Mauseth and Plemons-Rodriguez, 1997; Salleo *et al.*, 2004; Scholz *et al.*, 2007).

5.3.4 Vessel grouping

The average solitary vessel percentage of mangrove species was recorded as 30%. This indicates high vessel grouping in mangrove genera. High vessel grouping more probable with high vessel density, can also bring a functional advantage because it allows water to bypass air-filled vessels by alternative pathways created by the intervessel pits of touching vessels in a vessel group (Baas *et al.*, 1983; Zimmermann, 1983; Yanez-Espinosa *et al.*, 2011; Lopez *et al.*, 2005).

5.3.5. Axial parenchyma

According to Beeckman (2016), parenchyma plays an important role in embolism repair. Almost 70 percentage of true mangrove had paratracheal axial parenchyma in the present study. Due to saline stress condition in mangrove environment, an increase of osmotically active components are being released into cavitated conduits or surrounding cells and thus refilling the conduits would take place. In the past, it was suggested that abundant paratracheal parenchyma could help to refill air-filled vessels or aid in the recovery from embolism (Salleo *et al.,* 2004). The same trend was explained by Clearwater and Goldstein (2005) under drought conditions. The high amount of paratracheal axial parenchyma addressed by Beeckman (2016) in many tropical hardwoods suggests that this tissue plays an important role in the water balance.

5.3.6. Inclusions

Crystals are present in almost 65 percent of mangrove genera. Calcium oxalate crystals are formed as a result of ionic imbalance in a mangrove environment. Plant crystal idioblasts may function as a means of removing the oxalate which may otherwise accumulate in toxic quantities (Franceschi and Horner, 1980). Wheeler *et al.* (2007) showed that there is a general trend of increasing incidence of crystals from temperate to tropical regions, and far relatively high occurrences in regions that are largely xeric. Vessel occlusions like tyloses, gums and tannins occurred in almost all the genera of mangroves. Vessel occlusion by tyloses or gums plays an important role in preventing the spread of embolism. Both biotic and abiotic stresses have reported to cause vessel occlusion (Stevenson *et al.*, 2004; Sun *et al.*, 2011; Davison, 2014).

5.3.8. Vestured pit

Vestured pits have been reported in about 52 % of mangrove members, the vestured pit were reported. The vestures might help to prevent rupturing of the deflected pit membranes when pressure drops occur between adjacent vessel elements after air embolism. Carlquist (1982) hypothesized that cavitation might be less frequent because of the presence of vestures. Cavitation and the subsequent formation of air bubbles in embolized vessels substantially reduce the hydraulic conductivity of xylem (Milburn 1993). Vestures would trap small air bubbles and help to dissolve the trapped gas volume so that normal water transport is restored (Carlquist, 1982).

5.4. Ecoanatomical wood features of mangrove species

Multiple studies have demonstrated the strong correlations between ecology and wood anatomy within woody clades or entire floras (Carlquist, 2001; Baas *et al.*, 2004; Wheeler *et al.*, 2007). Tomlinson (1986) noted that the wood of mangrove species typically has a high number of narrow vessels, which are less vulnerable to cavitation, causing a safer sap stream. Furthermore, short vessel elements could also contribute to the safety of the sap stream in mangroves, which experience strongly negative pressures in their vessels due to the saline, physiologically dry, environment (Carlquist, 1977). The ecoanatomical wood features of seventeen true mangroves compared with its data from the nearest terrestrial relative of each mangrove genera either from the same family or same order are discussed hereunder.

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The comparison of ecoanatomical wood features of Rhizophoraceae mangrove members and their upland relative shows that mangrove wood anatomy is more related to xeric nature of upland relatives than mesic nature. The vessel frequency of Rhizophoraceae mangrove members shows numerous narrow vessels with smaller diameter. However, the terrestrial relative *Cassiporea guianensis* is said to occur in dry conditions and its vessels are also numerous (30-47/mm^2) with smaller diameter (66 µm) and the mesic species *Carallia brachiata* with vessel frequency of 13/mm^2 with larger diameter. The vessel grouping of mangrove species is more compared to its terrestrial relative. Janssonius (1950) described mangrove community as xeromorphic. In his work he compared the mangrove species with non mangrove species. The vessel frequency of former is much larger and diameter of individual vessels are smaller. The hydraulic conductivity is determined by the combination of both vessel frequency and vessel diameter (Chaot *et al.,* 2007). Shorter, narrower vessels can be cited as an indicative of xeromorphy (Carlquist, 1975). High degree of vessel grouping is the most common feature in arid regions. The vessel perforation plates of Rhizophoraceae mangrove members are scalariform whereas its terrestrial relative has simple plates. It can be inferred that mangrove genera of Rhizophoraceae have retained their scalariform perforation plates as a means of support to prevent their vessels from collapsing when they are submitted to high negative pressure. Rhizophoraceae is monophyletic and evolved from an ancestor that had scalariform perforation plates in its wood. Scalariform perforations were retained in descendants because they are adaptively neutral (Frost, 1930).

The number and width of vessel bar of Rhizophoraceae mangrove genera varies within the species. Some Rhizophoraceae have few but wide and conspicuously bordered bars (Metcalfe and Chalk, 1950; Van vliet, 1976). Carlquist (1975) claimed that such bars have selective value to prevent deformation and prevent vessel deformation. *Rhizophora mucronata* and *Rhizophora apiculata* had less number of bars with more bar width when compared to other species. The few bar with thick wall could aid some mechanical function, such as resistance to deformation under tension. As these two species are under the front line of mangrove zonation, they have to face more saline environmental stress. Carlquist (1966) reported that vessel elements having a few or no bars on their perforation plates represent a more favorable adaptation to dry environmental conditions than perforation plates with numerous and closely spaced bars.

The ecoanatomical wood features such as vessel frequency, vessel diameter and vessel grouping of *Avicennia* spp. is more related to its dry habitat terrestrial relative *Thunbergia spp.* than its moist habitat terrestrial relative *Tectona grandis* (Table 16). According to APG III classification *Avicennia* spp. belongs to Acanthaceae family. Vestured pits were observed in *Avicennia* spp and *Thunbergia* spp while it is absent in *Tectona* spp. In *Avicennia* spp. this vestures might help to prevent rupturing of the deflected pit membranes when pressure drops occur between adjacent vessel elements after air embolism due saline stress while in *Thunbergia* spp this vestures trap the air bubbles due water stress during dry condition. The vessels are small, numerous and more numerous in *Avicennia* spp. and *Thunbergia* spp. while vessels are large and less dense in *Tectona grandis* eventhough the three species belong to the same order Lamiales.

In Lythraceae also ecoanatomical wood features of the mangrove members are more related to their dry habitat terrestrial relatives. In such species, the vessel density distribution of mangroves with narrow numerous vessels, the pattern is similar to dry habitat *Lagerstroemia microcarpa.* The moist terrestrial relative *Duabanga molluccana* has low frequency and long wide vessels with less vessel grouping. *Sonneratia* spp. occurs in mangrove habitats and is adapted to saline condition hence in physiologically dry conditions, it shows smaller vessels with higher frequency (Rao *et al.,* 1987). The wider vessels lead to a higher hydraulic conductivity because the flow rates per vessel increase with the cross-sectional area of the lumen (Poorter *et al.,* 2008). Thus wider vessels are more efficient but have much more chance to cavitate, while smaller vessels 155 are mostly safer because they have smaller pit membrane areas per vessel that reduce the risk of air-seeding and consequently cavitation. Conduit dimensions can be influenced by environmental factors, such as water deficit (Anfodillo *et al.,* 2006) or even by high salinities, indicating that the smaller vessels of the mangroves are a response to their environmental conditions. Vestured pits were observed in mangrove species and are absent in the nearest terrestrial relatives. Vessel grouping is observed to be more in mangrove species. Vessel grouping is advantageous to saline stress condition. In saline stress condition there is a chance of vessel failure by air embolism. Carlquist (1984) claimed that in specialized wood this vessel grouping offers another kind of safety in which if any vessel is disabled, the conductive process can be transferred to an adjacent vessel. When compared to mangrove species *Excoecaria agallocha* and relatives, *Hura* spp. from moist habitat and *Bridelia retusa* from dry habitat, the vessel frequency is low but vessels are small while vessel grouping is high. The wood characters of *Excoecaria agallocha* are more resemblance to *Bridelia retusa* from dry habitat than *Hura* spp from moist habitat. The vessel length of all species are in the same range.

In the case of the mangrove species *Aegiceras corniculatum* the vessel frequency is very high with small vessel dimension and short vessels compared to its nearest terrestrial relative *Myrsine sandwicensis*. However the vessel grouping are relatively high in *Aegiceras* compared to its terrestrial relative. *Aegiceras* can easily be distinguished from other Myrsinaceae members by the presence of relatively narrow vessels, a relatively high vessel density and short vessel elements. There are also other morphological features in *Aegiceras* that are typical of Myrsinaceae, such as the presence of versatile anthers, viviparous fruits with exalbuminous seeds, and unitegmic ovules (Stahl and Anderberg, 2004). However, molecular data show that *Aegiceras* falls within a well supported clade including all other woody taxa of Myrsinaceae studied (Kallersjo *et al.,* 2000). *Aegiceras corniculatum* was observed mostly in seaward zone along with Rhizophoraceae members.

From the ecoanatomical wood features of *Heriteria littoralis* the vessel frequency, vessel diameter, vessel length and vessel grouping are almost similar to its nearest terrestrial relative. *Heriteria littoralis* is seen in the landward area of mangrove habitat. However it is a freshwater mangrove, during high tide it is subjected to saline stress. The helical thickening in vessel elements is present in *Heriteria littoralis* and it is absent in its terrestrial relative *Argyrodendron trifoliolatum.* The excessive negative pressure in the xylem sap are periodically subjected to embolism. The helical structure increases surface area of walls of vessel elements and increases the efficiency of hydraulic conductivity and thus decreasing the risk of embolism. Carlquist (1984) also supported the statement in relation to xeric environment. According to the major trends of specialization in secondary xylem of dicotyledons (Yatsenko- Khmelevskyi, 1954) helical thickening are interpreted as the most advanced character.

The ecoanatomical features such as vessel frequency, vessel diameter and vessel grouping of *Lumnitzera racemosa* has more resemblance with xeromorphic terrestrial relative *Anogeissus latifolia* than its mesic relative *Terminalia nitens.* The ecoanatomical vessel features of *Xylocarpus granatum* with short narrow, numerous vessel have resemblance with its terrestrial relative *Azadirachta indica* which is a xeromorphic species. The helical thickening and vestured pit is present in *Xylocarpus granatum* but not observed in *Azadirachta indica.* The vessel length of mangrove genera and their terrestrial relatives recorded not so much variation. High vessel frequency and narrow vessels in *Lumnitzera* was reported by Van vliet (1979).

The ecoanatomical wood characters of mangrove genera are more related to their xeric wood nature of their upland relatives. These characters specialize according to the ecological condition. In mangroves these specialized wood character help to localize air embolism inside the xylem and maintain the hydraulic balance. Plasticity of wood anatomical characters with respect to ecological condition is one of the physiological adaptations of mangrove species to withstand the change in climatic conditions, raise in hydrological regimes and Tsunami.

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5.5. Evolutionary trend in wood anatomy of mangrove species

Some ecological trends were well established for ecological wood anatomy and have been suggested to be one of the main force of wood evolution through adaptation. Nevertheless, the wood of mangrove families has neither been fully described nor adequately interpreted ecologically and evolutionarily. In order to establish an evolutionary trend of mangrove species it is necessary to mention the features recognized for trend of evolution (Carlquist, 2001). The trends in evolution are evident in a number of features which are listed in the Table 25. The most primitive mangrove family in the current investigation was found to be Rhizophoraceae. Eventhough Rhizophoraceae mangrove genera and *Excoecaria agallocha* belongs to the same order Malpighiales according to APG III classification (APG, 2009) the former had 70-90 % primitive characters while it is absent in *Excoecaria agallocha.* The other mangrove genera comprising *Avicennia* (20 %), *Aegiceras* (20%), *Heritiera* (10%), *Lumnitzera* (30%) and *Xylocarpus* (30%) lower level percent of primitiveness and it is absent in *Sonneratia* spp. and *Excoecaria agallocha* (Table 28). However, the level of specialization was reported to be less in Rhizophoraceae (20-45 %) and in other mangrove species specialization level was reported to be 70-75 % (Table 29). The evolutionary trend observed in mangrove genera are discussed here under.

5.5.1 Vessel width and vessel bar

In the present investigation Rhizophoraceae members had scalariform vessel plates while the remaining members had simple plates. Scalariform vessel plate is considered to be more primitive than simple plates (Frost, 1930; Carlquist, 2001). Rhizophoraceae mangrove genera (*Rhizophora, Bruguiera, Ceriops* and *Kandelia)* has scalariform plates. *Rhizophora mucronata* and *Rhizophora apiculata* had less number of bars and more bar width than *Ceriops, Kandelia* and *Bruguiera.* Reduction in number

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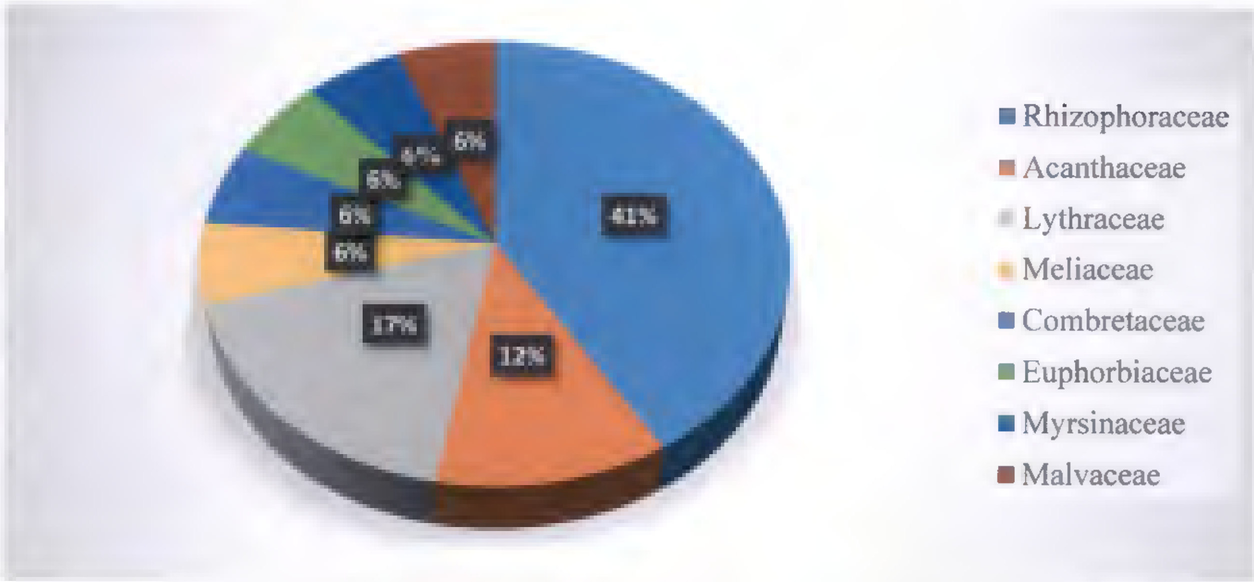

Fig. 2 Pie chart showing proportion of true mangrove members present in each family

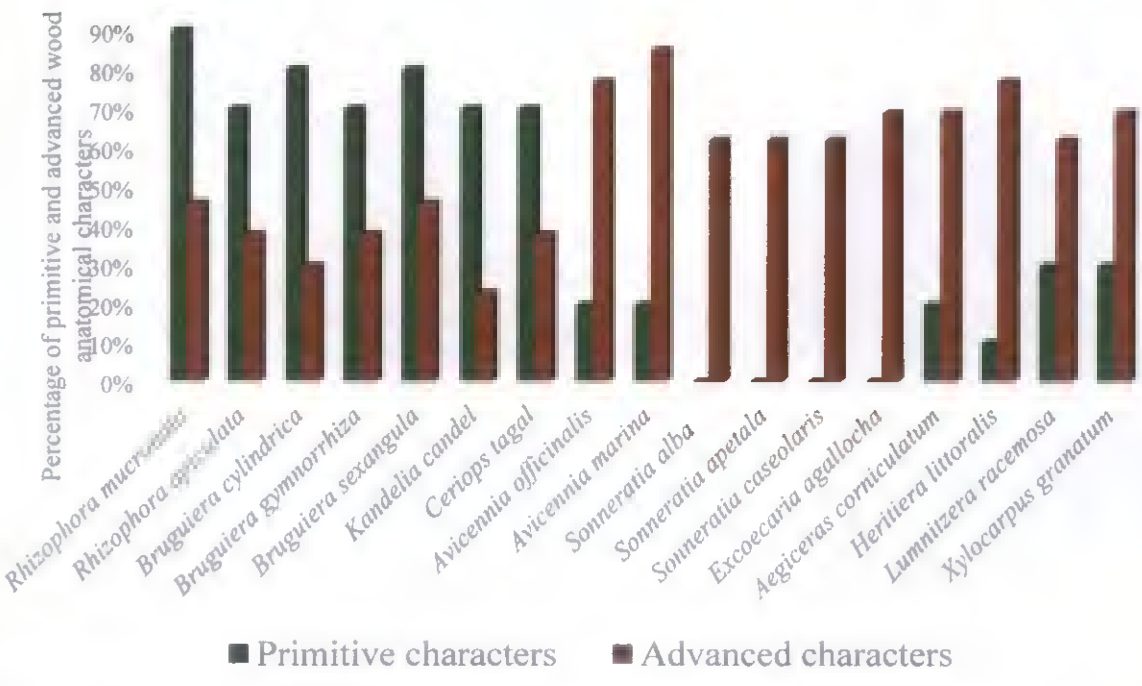

Fig. 3. Heterobatmy in mangrove species

of vessel bars and increase in bar width is considered as a primitive condition (Frost, 1930). Hence, the genus *Rhizophora* has more primitive vessel bar.

5.5.2 Vessel length

The vessel length of true mangroves range from long vessels to medium to short vessels. Only five per cent of true mangroves studied had long vessels and rest had medium to short vessels. Length of the vessel element decreases from primitive to highly specialised stage (Frost 1930; Carlquist 2001). According to evolutionary trend, *Rhizophora mucronata* had the longest vessels and was considered as the most primitive and *Avicennia officinalis, Avicennia marina* and *Aegiceras corniculatum* had the shortest vessel which is considered as the most advanced stage.

5.5.3 Vessel frequency

The evolutionary trend of vessel frequency showed that the most primitive one were *Heritiera littoralis* and *Excoecaria agallocha.* The most specialized vessels are reported in *Avicennia officinalis, Avicennia marina* and *Sonneratia* spp. According to Frost (1930) and Carlquist (2001), highly specialized structures have narrow and small vessels.

5.5.4. Vessel grouping

Vessel grouping is the characteristic of mangrove genera and it is reported in almost all genera. Solitary vessels are more primitive than vessels having group or clusters (Frost 1930; Yatsenko-Khmelevskiy, 1948; Carlquist 2001). This trend can be postulated to be an adaptation to water stress, because the vessel groups provide the bypass water conduits in the case of an embolism of some vessels (Zimmermann, 1983; Carlquist, 1987; Sperry, 2003). This hypothesis on the adaptive value of vessel grouping was recently demonstrated in experiments (Lens *et al.*, 2011).

5.5.5. Lateral wall pitting

Mangrove genera showed all possible types of lateral wall pitting. Scalariform lateral wall pitting is primitive, and the sequence should be from scalariform, to transitional, to opposite, culminating in the highly specialized alternate arrangement of circular pits. The evolutionary trend of lateral wall pitting showed Rhizophoracea members with most primitive type of pitting includes scalariform, transitional and opposite (Table 28) while majority of vessel members in mangrove genera had highly advanced alternate lateral wall pitting (Table 29).

5.5.6. Nature of apertures of perforation

The most primitive type of perforations such as bordered and half bordered pit were present in Rhizophoraceae mangrove genera and in *Lumnitzera racemosa* only bordered pit was observed while the other had the most advanced one, the simple pits (Table 28). According to Frost (1930) the primitive fully bordered aperture of a scalariform perforation gradually loses its border as the perforation becomes specialized.

5.5.7. Inclination of the end wall

The inclination of the end wall changes from the highly inclined position to the transverse position (Frost, 1930). In the mangrove genera highly inclined to transverse end wall is seen. The most primitive type of oblique end wall was seen in Rhizophoraceae mangrove genera and the remaining mangrove genera had highly specialized transverse end walls (Table 28). The vessel segment is frequently subjected to collapsing pressures, due to tension of the liquid column. The transverse end wall, is better adapted to resist crushing forces than an oblique brace.

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5.5.8. Rays

Rays in mangrove genera are quite varied which possess a mixture of homocellular and heterocellular to exclusively homocellular rays. In the current study the most primitive type heterogeneous type II rays to the most advanced homogeneous type III rays were seen in different species (Table 27). The primitive type of rays heterogeneous type II were present in *Lumnitzera racemosa* and *Xylocarpus granatum.* Heterogeneous type III rays were observed in Rhizophoraceae members (*Rhizophora, Bruguiera, Ceriops* and *Kandelia*) and *Avicennia* members (*Avicennia officinalis* and *Avicennia marina*). Homogeneous type II were seen in *Aegiceras corniculatum* and *Heritiera littoralis.* Homogeneous type III were reported in *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris.* Hence the mangrove species *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris* are the most advanced one. Regarding ray evolution, Kribs (1935) suggested that the most primitive condition was that of woods with both multiseriate and uniseriate rays co-occurring, with both rays being high and heterocellular in composition. According to (Kribs, 1935), ray evolution involved a gradual decrease in height and number of upright and square cells as seen in longitudinal section, eventually evolving into a homocellular ray.

5.5.9. Axial parenchyma

Almost 70 percentage of true mangrove has paratracheal vasicentric paranchyma. All rhizophoraceae mangrove genera had these advanced characters (Table 26), whereas axial parenchyma is totally absent in *Sonneratia* spp which is a primitive condition. Rao *et al.* (1987) recorded similar trend in *Sonneratia* spp. Apotracheal parenchyma were reported in three species viz. *Aegiceras corniculatum, Lumnitzera racemosa* and *Heritiera littoralis* which is a primitive one. For axial parenchyma, the primitive type of axial parenchyma was inferred as apotracheal scanty or diffuse, evolving toward progressively larger volumes of parenchyma within the stem and in association with the vessels i.e. paratracheal parenchyma (Kribs 1937; Carlquist, 1961).

According to Pace and Angyalossy (2013) in Bignoniaceae, scanty axial parenchyma is the ancestral clades that later evolved vasicentric and aliform parenchyma.

5.5.10. Fibre

In all mangrove genera the fibre tissue is highly specialized with few minutely bordered to simple pits. Helical appearance present on fibres shows specialization. Carlquist (2001) reported helical structure in libriform fibres. Both septate and non septate fibre were observed in mangrove genera. Minute pits with non septate fibre is the advanced stage (Carlquist, 2001). According to Pace and Angyalossy (2013) nonseptate fibers are derived from ancestors with septate fibers.

Almost 76 percent of mangrove species showed heterobatmy-coexistence of progressive and ancestral characters in the same organism as a result of different rate of their evolutionary specialization (Fig. 3). Thus the development of wood anatomical characters in mangrove genera was an example of heterobatmy. Wroblewska (2015) also observed heterobatmy in the primitive angiosperm family Magnoliaceae. Lower degree of specialization could be observed in Rhizophoraceae genera and all other mangrove members recorded more specialization. The primitive characters recorded more in Rhizophora genera is totally absent in *Sonneratia spp.* and *Excoecaria agallocha.* Eventhough the genus *Rhizophora* and *Excoecaria agallocha* belong to the primitive order Malpighiales, the former showed more primitive characters and in the latter it is totally absent. Thus in phylogenetic tree according to wood anatomy classification there is a need to shift *Excoecaria agallocha* from the primitive mangrove order to more advanced mangrove order.

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Table 25. Evolutionary trend in wood anatomy (as reported by several authors)

Anatomical traits	Evolutionary trend	References
Vessel element	Scalariform vessel plate is more primitive than simple plates	Frost (1930), Carlquist (2001)
Vessel length	Length of the vessel element decreases from primitive to highly specialised stage	Frost (1930), Carlquist (2001)
Vessel frequency	Highly specialized structure have narrow and small vessels	Frost (1930), Carlquist (2001)
Vessel arrangement	Solitary vessels are more primitive than vessels having group or clusters	Frost (1930), Carlquist (2001)
Vessel bars	Reduction in vessel bars shows specialisation	Frost (1930)
Vessel bar width	The width between the bars increases with specialization of the vessel segment	Frost (1930)
Lateral wall pitting	Scalariform lateral intervascular pitting is primitive, and the sequence should be from scalariform, to transitional, to opposite, culminating in the highly specialized alternate arrangement of circular pits	Frost (1930), Carlquist (2001)
Nature of apertures of perforation	The primitive fully bordered aperture of a scalariform perforation gradually loses its border as the perforation becomes specialized	Frost (1930)

Anatomical traits	Evolutionary trend	References
Inclination of end wall	The inclination of the end wall changes from the highly inclined position to the transverse position as the scalariform perforation develops into the porous perforation	Frost (1930)
Rays	Ray evolution involved a gradual decrease in height and number of upright and square cells as seen in longitudinal section, eventually evolving into a homocellular ray	Kribs (1935)
Axial parenchyma	The primitive type of axial parenchyma was inferred as apotracheal scanty or diffuse, evolving toward progressively larger volumes of parenchyma within the stem and in association with the vessels (paratracheal)	Kribs (1937)
Vestured pit	Presence of liplike structure on alternate polygonal pit is an advanced character	Frost (1930), Carlquist (2001)
Vasicentric tracheid	Vasicentric tracheids can occur in woods with fiber-tracheids or libriform fibre	Frost (1930), Carlquist (2001)
Helical thickenings	Helical thickenings in secondary vessel elements shows specialization	Frost (1930)

Table 26. Variation in axial parenchyma type in mangrove genera

Mangrove species	**Absent**	**Diffuse**	**Diffuse in aggregate**	**Vasicentric scanty**	**Vasicentric abundant**	**Aliform**	**Aliform confluent**	**Banded parenchyma**
Rhizophora mucronata	-	-	-	+	+	-	-	-
Rhizophora apiculata	-	-	-	+	-	-	-	-
Bruguiera cylindrica	+	-	-	+	-	-	-	-
Bruguiera gymnorrhiza	-	-	-	+	+	-	-	-
Bruguiera sexangula	-	-	-	+	+	-	-	+
Kandelia candel	-	-	-	-	-	-	-	-
Ceriops tagal	-	-	-	+	-	+	-	-
Avicennia officinalis	-	-	-	+	-	+	-	-
Avicennia marina	-	-	-	+	-	-	-	-
Sonneratia alba	+	-	-	-	-	-	-	-
Sonneratia apetala	+	-	-	-	-	-	-	-
Sonneratia caseolaris	+	-	-	-	-	-	-	-

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Mangrove species	Absent	Diffuse	Diffuse in aggregate	Vasicentric scanty	Vasicentric abundant	Aliform	Aliform confluent	Banded parenchyma
Excoecaria agallocha	-	-	-	-	-	-	-	+
Aegiceras corniculatum	-	+	-	+	-	-	-	-
Heritiera littoralis	-	-	+	-	-	-	-	-
Lumnitzera racemosa	-	+	-	+	+	-	-	-
Xylocarpus granatum	-	-	-	+	-	-	-	+

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Table 27. Different types of rays in true mangrove species

Mangrove species	Heterogeneous type I	Heterogeneous type II	Heterogeneous type III	Homogeneous type I	Homogeneous type II	Homogeneous type III
Rhizophora mucronata	-	-	+	-	-	-
Rhizophora apiculata	-	-	+	-	-	-
Bruguiera cylindrica	-	-	+	-	-	-
Bruguiera gymnorrhiza	-	-	+	-	-	-
Bruguiera sexangula	-	-	+	-	-	-
Kandelia candel	-	-	+	-	-	-
Ceriops tagal	-	-	+	-	-	-
Avicennia officinalis	-	-	+	-	-	-

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Mangrove species	Heterogeneous type I	Heterogeneous type II	Heterogeneous type III	Homogeneous type I	Homogeneous type II	Homogeneous type III
Avicennia marina	-	-	+	-	-	
Sonneratia alba	-	-	-	-	-	+
Sonneratia apetala	-	-	-	-	-	+
Sonneratia caseolaris	-	-	-	-	-	+
Excoecaria agallocha	-	-	-	-		+
Aegiceras corniculatum	-	-	-	-	+	-
Heritiera littoralis	-		-	-	+	-
Lumnitzera racemosa	-	+	-	-	-	-
Xylocarpus granatum	-	+	+	-	-	-

Table 28. Primitive wood anatomical characters of true mangrove species

Species	Scalariform vessel plate	Scalariform, transitional and opposite pitting	Long vessel length	Bordered and half bordered pit	Oblique end wall	Heterogeneous type I, type II and type III	Axial parenchyma absent or scanty	Apotracheal parenchyma	Vessel bar	Septate fibre
Rhizophora mucronata	+	+	+	+	+	+	+	-	+	+
Rhizophora apiculata	+	+	-	+	+	+	+	-	+	-
Bruguiera cylindrica	+	+	-	+	+	+	+	-	+	+
Bruguiera gymnorrhiza	+	+	-	+	+	+	+	-	+	-
Bruguiera sexangula	+	+	-	+	+	+	+	-	+	+
Kandelia candel	+	+	-	+	+	+	-	-	+	+
Ceriops tagal	+	+	-	+	+	+	+	-	+	-
Avicennia officinalis	-	-	-	-	-	+	+	-	-	-
Avicennia marina	-	-	-	-	-	+	+	-	-	-

Species	Scalariform vessel plate	Scalariform, transitional and opposite pitting	Long vessel length	Bordered and half bordered pit	Oblique end wall	Heterogeneous type I, type II and type III	Axial parenchyma absent or scanty	Apotracheal parenchyma	Vessel bar	Septate fibre
Sonneratia alba	-	-	-	-	-	-	-	-	-	-
Sonneratia apetala	-	-	-	-	-	-	-	-	-	-
Sonneratia caseolaris	-	-	-	-	-	-	-	-	-	-
Excoecaria agallocha	-	-	-	-	-	-	-	-	-	-
Aegiceras corniculatum	-	-	-	-	-	-	+	+	-	-
Heritiera littoralis	-	-	-	-	-	-	-	+	-	-
Lumnitzera racemosa	-	-	-	+	-	+	-	+	-	+
Xylocarpus granatum	-	-	-	-	-	+	+	-	-	+

Table 29. Advanced wood anatomical characters of true mangrove species

Species	Simple vessel plate	Alternate pitting	Medium to short vessel length	Vestured pit	Simple pit	Transverse end wall	Homogeneous type I, type II and type III rays	Paratracheal abundant	Simple fibre pit	Helical thickening	Vessel grouping	Solitary vessel outline	Non septate fibre
Rhizophora mucronata	-	-	+	-	+	-	-	+	+	-	+	-	+
Rhizophora apiculata	-	-	-	-	+	-	-	+	+	-	+	-	+
Bruguiera cylindrica	-	-	-	-	+	-	-	-	+	-	+	-	+
Bruguiera gymnorrhiza	-	-	-	-	+	-	-	+	+	-	+	-	+
Bruguiera sexangula	-	-	-	-	+	-	-	+	+	-	+	+	+
Kandelia candel	-	-	-	-	+	-	-	-	+	-	+	-	-
Ceriops tagal	-	-	-	-	+	-	-	+	+	-	+	-	+
Avicennia officinalis	+	+	-	+	+	+	-	+	+	-	+	+	+
Avicennia marina	+	+	-	+	+	+	-	+	+	+	+	+	+

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Species	Simple vessel plate	Alternate pitting	Medium to short vessel length	Vestured pit	Simple pit	Transverse end wall	Homogeneous type I, type II and type III rays	Paratracheal abundant	Simple fibre pit	Helical thickening	Vessel grouping	Solitary vessel outline	Non septate fibre
Sonneratia alba	+	+	-	+	+	+	+	-	+	-	+	-	-
Sonneratia apetala	+	+	-	+	+	+	+	-	+	-	+	-	-
Sonneratia caseolaris	+	+	-	+	+	+	+	-	+	-	+	-	-
Excoecaria agallocha	+	+	-	+	+	+	+	-	+	-	+	+	-
Aegiceras corniculatum	+	+	-	+	+	+	+	-	+	+	+	-	-
Heritiera littoralis	+	+	-	+	+	+	+	-	+	+	+	+	-
Lumnitzera racemosa	+	+	-	+	+	+	-	-	+	+	+	-	-
Xylocarpus granatum	+	+	-	+	+	+	-	-	+	+	+	+	-

5.6. Perforated Card Key based on the IAWA list of microscopic card features for mangrove identification

5.6.1. *Rhizophora mucronata* Lam.

2, 5, 15, 20, 31, 32, 41, 47, 54, 58, 61, 65, 66, 69, 70, 72, 78, 79, 83, 93, 97, 98, 102, 106, 109, 110, 115, 136, 138, 152, 159, 160, 169, 171, 172, 173,176, 189, 192, 194, 196, 197, 198

5.6.2. *Rhizophora apiculata* Blume

2, 5, 15, 20, 31, 32, 41, 47, 53, 56, 58, 61, 66, 69, 70, 72, 78, 79, 93, 97, 98, 102, 110, 115, 136, 138, 152, 159, 189, 169, 170, 173, 176, 189, 192, 194, 196, 197

5.6.3. *Bruguiera cylindrica* (L.) Druce

2, 5, 14, 15, 20, 31, 32, 41, 47, 53, 56, 58, 61, 65, 66, 67, 69, 72, 75, 78, 93, 97, 98, 102, 109, 110, 115, 136, 159, 169, 170, 173, 189

5.6.4. *Bruguiera gymnorrhizza* (L.) Poir.

2, 5, 10, 13, 16, 20, 30, 31, 32, 33, 41, 47, 53, 56, 60, 61, 64, 66, 67, 69, 70, 72, 75, 78, 92, 93, 97, 98, 106, 107, 110, 115, 137, 138, 159, 168, 169, 170, 172, 173, 189, 192, 194, 196 ,197

5.6.5. *Bruguiera sexangula* (Lour.) Poir

2, 5, 10, 12, 15, 20, 31, 32, 33, 41, 48, 53, 61, 65, 66, 67, 69, 70, 72, 78, 79, 97, 98, 102, 107, 108, 110, 115,169, 170, 171, 173, 189, 192, 194, 196, 197

5.6.6. *Kandelia candel* (I.) Druce

2, 5, 11, 14, 15, 20, 31, 32, 41, 48, 53, 61, 65, 70, 72, 85, 86, 93, 97, 98, 102, 106, 107, 110, 115, 120, 159, 160, 169, 171, 173, 189, 193, 196, 197, 206, 207

5.6.7. *Ceriops tagal* (Perr.) Robinson

2, 5, 10, 14, 15, 20, 31, 32, 34, 41, 48, 53, 58, 61, 62, 66, 70, 72, 78, 80, 82, 83, 93, 97, 98, 102, 108, 109, 110, 115, 136, 137, 152, 169, 170, 173, 176, 189, 192, 195, 196, 197

5.6.8. *Avicennia officinalis* Lamark

2, 5, 7, 10, 12, 13, 22, 23, 29, 41, 47, 52, 61, 66, 69, 72, 78, 79, 80, 83, 92, 97, 98, 102, 103, 109, 115, 133, 137, 152, 144, 145, 151, 152, 154, 155, 169, 170, 173, 189, 194, 200

5.6.9. *Avicennia marina* Vierth

2, 5, 7, 10, 12, 13, 22, 23, 29, 41, 48, 52, 61, 66, 69, 72, 78, 79, 92, 97, 98, 103, 109, 116, 133, 144, 145, 166, 169, 167, 173, 176, 189, 194, 200

5.6.10. *Sonneratia alba* Sm

2, 5, 10, 13, 19, 23, 29, 30, 31, 32, 33, 34, 41, 48, 53, 58, 60, 61, 62, 66, 68, 71, 72, 75, 96, 104, 116, 109, 136, 137, 138, 152, 159, 160, 169, 173, 178, 180, 189, 194, 197

5.6.11. *Sonneratia apetala* Buch.-Ham

2, 5, 10, 13, 19, 23, 29, 30, 31, 32, 33, 34, 41, 48, 53, 58, 60, 61, 62, 66, 68, 71, 75, 96, 104, 116, 109, 116, 159, 160, 169, 170, 189, 194, 197

5.6.12. *Sonneratia caseolaris* (L.) Engl

2,5,13,19, 23, 29, 30, 31, 32, 33, 34, 42, 47, 53, 58, 60, 61, 62, 66, 68, 71, 72, 75, 96, 104, 116, 109, 136,138, 159, 160, 169,172, 173,176, 189, 193, 194,197

5.6.13. *Heritiera littoralis* Dryand

2, 5, 12, 13, 22, 31, 42, 46, 53, 56, 58, 61, 66, 68, 72, 77, 78, 79, 91, 92, 97, 98, 102, 103, 104, 110, 115, 120, 122, 142, 168, 169, 170, 171, 172, 173, 175, 176, 178, 179, 189, 192, 194, 196, 197

5.6.14. *Xylocarpus granatum* J.König

2,5,12,13,22,29,30,41,47,53,58,60,61,62,65,68,72,78,89,92,93,97,103,106,107,115,120.136,137,138,141,168,169,171,172,173,178,179,180,189,196

5.6.15. *Excoecaria agallocha.* L.

2, 5, 10, 12, 13, 22, 23, 29, 30, 32, 41, 47, 53, 58, 60, 61, 66, 68, 72, 86, 92, 96, 103, 104, 109, 116, 132, 136, 138, 159, 168, 169, 170, 171, 173, 189, 193, 199

5.6.16. *Aegiceras corniculatum* Blanco

2,5,7,10,13,22,23,29,30,36,40,50,52,57,58,60,61,62,66,68.71,76,78,91,92,97,98,104,115,120,168,169,171,172,173,174,175,176,190,194,200

5.6.17. *Lumnitzera racemosa* (L.) Gaertn.

1, 5, 10, 13, 22, 29, 30, 32, 33, 34, 41, 48, 53, 60, 65, 66, 68, 72, 75, 76, 78, 91, 96, 105, 116, 168, 169, 171, 172, 173, 174, 175, 176, 178, 179, 180, 189, 194, 196, 197

6. SUMMARY

Wood blocks as well as increment core samples of 17 true mangroves were collected from ten sites of West Coast of India in the present investigation. The species were identified using IAWA list of card key microscopic features for hardwood wood identification. Perforated card key based on the IAWA list of microscopic card features for mangrove species identification was prepared. The ecoanatomical wood features of true mangrove species were studied and compared with data from the nearest terrestrial relative of each mangrove genera. Finally the evolutionary trend of mangrove wood anatomy was studied. The summary of the investigations are listed below.

1. Among the 8 families of true mangrove species studied in the current investigation, there was representation of more members from Rhizophoraceae family (41 %) followed by Lythraceae (17 %) and Acanthaceae (12 %). The remaining families comprising Meliacea, Combretaceae, Euphorbiaceae, Myrsinaceae and Malvaceae represented one member each (6 %).
2. Growth rings were absent in 82 % of mangrove species collected whereas the distinct rings were seen in *Lumnitzera racemosa* and successive cambial rings were seen in Acanthaceae members such as *Avicennia officinalis* and *Avicennia marina*.
3. Majority of mangrove genera had small vessel diameter (88 %) and high vessel frequency (95 %).
4. The vessel length of all mangrove species ranged from small to medium except *Rhizophora mucronata* which had long vessel element.

5. Exclusively scalariform vessels with vessel bars were observed in Rhizophoraceae mangrove members and all other mangroves species had simple plates.
6. Scalariform, transitional and opposite lateral wall pitting were observed in Rhizophoraceae mangrove members and alternate pit were reported in other mangrove species.
7. Vertically unilateral compound vessel ray pit including bordered, half bordered and simple pit were observed in Rhizophoraceae mangrove member whereas in other mangrove species simple compound pits were recorded.
8. Rays of mangrove species varied from heterogenous type II to homogeneous type III.
9. The breakdown area of rays were observed only in *Aegiceras corniculatum.*
10. Crystals were present in almost 65 percent of mangrove genera.
11. Vessel occlusions like tyloses, gums and tannins occurred in almost all the genera of mangroves.
12. Vestured pits were recorded in almost all mangrove genera except Rhizophoraceae mangrove genera and *Heritiera littoralis.*
13. Laticiferous tube, were present only in *Excoecaria agallocha.*
14. Helical thickenings were observed in mangrove members comprising *Avicennia marina*, *Aegiceras corniculatum, Xylocarpus granatum* and *Heritiera littoralis.*
15. Fibre with minutely bordered to simple pit were observed in almost all mangrove genera
16. Almost 70 percentage of true mangrove were seen with paratracheal vasicentric parenchyma whereas axial parenchyma is totally absent in *Sonneratia spp* and in *Bruguiera cylindrica.*

17. Apotracheal parenchyma was recorded in *Aegiceras corniculatum, Heritiera littoralis* and *Lumnitzera racemosa.*
18. Vulnerability ratio ranged from 0.27 for *Aegiceras corniculatum* to 31 for *Heritiera littoralis.*
19. In the case of mesomorphic ratio *Heritiera littoralis* (12418) was found to be of higher value and *Aegiceras corniculatum* (80) were recorded a lower value.
20. The average solitary vessel percentage of mangrove species was 30%.
21. The comparison of ecoanatomical wood features of mangrove members and its upland relative shows that mangrove wood anatomy is more related to xeric nature.
22. The most primitive mangrove family in the current investigation was found to be Rhizophoraceae (70-90 %).
23. The remaining mangrove genera comprising *Avicennia* (20%), *Aegiceras* (20%), *Heritiera* (10%), *Lumnitzera* (30%) and *Xylocarpus* (30%) showed less percent of primitiveness and is absent in *Sonneratia* spp. and *Excoecaria agallocha.*
24. The level of specialization was reported to be less in Rhizophoraceae (20-45 %) and in remaining mangrove genera 70-75 % of primitive character were reported.
25. According to evolutionary trend, *Rhizophora mucronata* had the longest vessel and can be considered as the most primitive while *Avicennia officinalis, Avicennia marina* and *Aegiceras corniculatum* with the shortest vessel considered as the most advanced stage.
26. Evolutionary trend showed that of vessel frequency showed the most primitive one was in *Heritiera littoralis* and *Excoecaria agallocha.* The most specialized vessels were reported in *Avicennia officinalis, Avicennia marina* and *Sonneratia spp.*

27. The evolutionary trend in lateral wall pitting showed that Rhizophoracea members were the most primitive type of pitting which included scalariform, transitional and opposite while majority of vessel members in mangrove genera had highly advanced alternate lateral wall pitting.
28. The most primitive type of perforations such as bordered and half bordered pit were present in Rhizophoraceae mangrove genera and only bordered pit was observed in *Lumnitzera racemosa* while the remaining genera had the most advanced one, the simple pits.
29. The most primitive type of oblique end wall was seen in Rhizophoraceae mangrove genera and in the other mangrove genera highly specialized transverse end wall has seen.
30. Primitive type of rays viz., heterogeneous type II rays were present in *Lumnitzera racemosa* and *Xylocarpus granatum* while heterogeneous type III rays were observed in Rhizophoraceae members (*Rhizophora, Bruguiera, Ceriops and Kandelia*) and *Avicennia* members (*Avicennia officinalis* and *Avicennia marina*).
31. More specialized homogeneous type II rays were seen in *Aegiceras corniculatum* and *Heritiera littoralis* and homogeneous type III rays were reported in *Sonneratia alba, Sonneratia apetala* and *Sonneratia caseolaris.*
32. Almost 76 percent of mangrove species showed heterobatmy

ECOANATOMICAL CHARACTERISATION AND DEVELOPMENT OF ANATOMICAL KEY OF SELECTED MANGROVE SPECIES OF WEST COAST OF INDIA

By

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(2013-27-101)

ABSTRACT

Submitted in partial fulfillment of the requirement for the degree of

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2017

ABSTRACT

The present investigation focused on the ecoanatomical characterisation of the wood of 17 selected true mangroves collected from 10 locations in the Western Coast of India. A total of 221 characters listed in the IAWA (International Association of Wood Anatomists) list of card key features were studied for each species as there is a felt need for creating databases of mangrove wood anatomy which allows to quantify the relative amount of intra- and interspecific variation, as well as variation within and between the mangrove genera. Mangrove wood from West Coast of India is characterised by diffuse-porosity, scalariform to opposite vessel wall pitting, scalariform perforations with few bars or large number of bars. Most mangrove family members were found to have simple perforations, septate or non septate fibres with distinctly to minutely bordered pits, bordered, half bordered to simple pits, paratracheal parenchyma, apotracheal and banded parenchyma. Heterocellular to homocellular rays with mostly procumbant cells with one or several marginal row of square/upright cells was also observed in these mangrove genera. Short numerous vessels with small dimension and vessel grouping were also common. The most advanced characters like vestured pit, helical thickening, crystals and vessel occlusions were present in majority of the samples. A perforated card key based on the IAWA list of microscopic card features for mangrove identification was also prepared. The development of an IAWA based anatomical key will be helpful for the identification of mangrove species based on wood anatomy.

The ecoanatomical characters such as vessel diameter, vessel frequency, vessel grouping, type of vessel plate, lateral wall pitting, type of pits of true mangrove species were studied and compared with data from their nearest upland relative. The ecoanatomical features of wood of mangrove species are correlated with xeromorphic nature of their upland relatives. Because of the highly variable and stressful environmental condition, the mangroves developed certain strategies and adaptations

during their evolution. These special morphological and physiological adaptations made it for the mangrove species to survive in these conditions in contrast to their upland relatives. A safe hydraulic architecture is only one of the alternative ways for a plant to be able to survive in water stress situations. The modification of xylem hydrological structure of mangrove wood helps to balance safety versus efficiency of water transport system. These modifications of wood structure due to ecological conditions are the driving force to evolution of wood anatomy. Thus the evolution of mangrove genera has been shown to be likely driven by environmental condition and not by phylogeny.

The general pattern of wood anatomy of mangrove genera of different families indicates convergent evolution. These trends of wood anatomy in mangrove species provide new examples of phenotypic plasticity in angiosperms. To ensure safety, certain primitive structures such as bordered pits, scalariform vessel plate, scalariform, transitional, opposite lateral wall pitting and vessel bars still persist in the true mangrove genera of the present investigation. Thus the development of wood anatomical characters in mangrove genera were an example of heterobatmy. The presence of mostly primitive wood character states suggest an unbroken occupancy of stressful habitat by its ancestral genera. Mangrove occurs in different families in which the gamut of wood specialization ranges from advanced to highly advanced features. Rhizophoraceae members were found to be the most primitive ones with less specialization whereas the other mangrove species were found to have highly advanced wood anatomical characters.

Annexure I. IAWA list of card key microscopic features for hardwood identification (Wheeler, 2011)

Growth Rings

1. Growth ring boundaries distinct
2. Growth ring boundaries indistinct or absent

Vessels

Porosity

3. Wood ring-porous
4. Wood semi-ring-porous
5. Wood diffuse-porous

Vessel arangement

6. Vessels in tangential bands
7. Vessels in diagonal and / or radial pattern
8. Vessels in dendritic pattern

Vessel groupings

9. Vessels exclusively solitary (90% or more)
10. Vessels in radial multiples of 4 or more common
11. Vessel clusters common

Solitary vessel outline

12. Solitary vessel outline angular

Perforation plates

13. Simple perforation plates
14. Scalariform perforation plates
15. Scalariform perforation plates with <= 10 bars
16. Scalariform perforation plates with 10 - 20 bars
17. Scalariform perforation plates with 20 - 40 bars
18. Scalariform perforation plates with >= 40 bars
19. Reticulate, foraminate, and / or other types of multiple perforation plates

Intervessel pits: arrangement and size

20. Intervessel pits scalariform
21. Intervessel pits opposite
22. Intervessel pits alternate
23. Shape of alternate pits polygonal

24. Minute - <= 4 µm
25. Small - 4 - 7 µm
26. Medium - 7 - 10 µm
27. Large - >= 10 µm
28. Range of intervessel pit size(µm)

Vestured pits

29. Vestured pits

Vessel - ray pitting

30. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell
31. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular
32. Vessel-ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical (palisade)
33. Vessel-ray pits of two distinct sizes or types in the same ray cell
34. Vessel-ray pits unilaterally compound and coarse (over 10 µm)
35. Vessel-ray pits restricted to marginal rows

Helical thickenings

36. Helical thickenings in vessel elements present
37. Helical thickenings throughout body of vessel element
38. Helical thickenings only in vessel element tails
39. Helical thickenings only in narrower vessel elements

Tangential diameter of vessel lumina

Mean tangential diameter of vessel lumina

40. <= 50 µm
41. 50 - 100 µm
42. 100 - 200 µm
43. >= 200 µm
44. Mean,+/- Standard Deviation,n=x
45. Vessels of two distinct diameter classes, wood not ring-porous

Vessels per square millimetre

46. <= 5 vessels per square millimetre
47. 5 - 20 vessels per square millimetre
48. 20 - 40 vessels per square millimetre
49. 40 - 100 vessels per square millimetre
50. >= 100 vessels per square millimetre
51. Mean,+/- Standard Deviation,n=x

Mean vessel element length

52. <= 350 µm
53. 350 - 800 µm
54. >= 800 µm
55. Mean,+/- Standard Deviation,n=x

Tyloses and deposits in vessels

56. Tyloses common
57. Tyloses sclerotic
58. Gums and other deposits in heartwood vessels

Wood vesselless

59. Wood vesselless

Tracheids and fibres

60. Vascular / vasicentric tracheids present

Ground tissue fibres

61. Fibres with simple to minutely bordered pits
62. Fibres with distinctly bordered pits
63. Fibre pits common in both radial and tangential walls
64. Helical thickenings in ground tissue fibres

Septate fibres and parenchyma-like fibre bands

65. Septate fibres present
66. Non-septate fibres present
67. Parenchyma-like fibre bands alternating with ordinary fibres

Fibre wall thickness

68. Fibres very thin-walled
69. Fibres thin- to thick-walled
70. Fibres very thick-walled

Mean fibre lengths

71. <= 900 µm
72. 900-1600 µm
73. >= 1600 µm
74. Mean,+/- Standard Deviation,n=x

Axial parenchyma

75. Axial parenchyma absent or extremely rare

Apotracheal axial parenchyma

76. Axial parenchyma diffuse
77. Axial parenchyma diffuse-in-aggregates

Paratracheal axial parenchyma

78. Axial parenchyma scanty paratracheal
79. Axial parenchyma vasicentric
80. Axial parenchyma aliform
81. Axial parenchyma lozenge-aliform
82. Axial parenchyma winged-aliform
83. Axial parenchyma confluent
84. Axial parenchyma unilateral paratracheal

Banded parenchyma

85. Axial parenchyma bands more than three cells wide
86. Axial parenchyma in narrow bands or lines up to three cells wide
87. Axial parenchyma reticulate
88. Axial parenchyma scalariform
89. Axial parenchyma in marginal or in seemingly marginal bands

Axial parenchyma cell type / strand length

90. Fusiform parenchyma cells
91. Two cells per parenchyma strand
92. Four (3-4) cells per parenchyma strand
93. Eight (5-8) cells per parenchyma strand
94. Over eight cells per parenchyma strand
95. Unlignified parenchyma

Ray width

96. Rays exclusively uniseriate
97. Ray width 1 to 3 cells
98. Larger rays commonly 4 - to 10 seriate
99. Larger rays commonly > 10-seriate
100. Rays with multiseriate portion(s) as wide as uniseriate portions

Aggregate rays

101. Aggregate rays

Ray height

102. Ray height > 1 mm

Rays of two distinct sizes

103.Rays of two distinct sizes

Rays: cellular composition

104. All ray cells procumbent

105. All ray cells upright and / or square

106. Body ray cells procumbent with one row of upright and / or square marginal cells

107. Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells

108. Body ray cells procumbent with over 4 rows of upright and / or square marginal cells

109. Rays with procumbent, square and upright cells mixed throughout the ray

Sheath cells

110. Sheath cells

Tile cells

111. Tile cells

Perforated ray cells

112. Perforated ray cells

Disjunctive ray parenchyma cell walls

113. Disjunctive ray parenchyma cell walls

Rays per millimetre

114. <= 4 / mm

115. 4-12 / mm

116. >= 12 /mm

Wood rayless

117. Wood rayless

Storied structure

118. All rays storied

119. Low rays storied, high rays non-storied.

120. Axial parenchyma and / or vessel elements storied

121. Fibres storied

122. Rays and / or axial elements irregularly storied

Secretory elements and cambial variants

Oil and mucilage cells

124. Oil and / or mucilage cells associated with ray parenchyma

125. Oil and / or mucilage cells associated with axial parenchyma

126. Oil and / or mucilage cells present among fibres

Intercellular canals

127. Axial canals in long tangential lines

128. Axial canals in short tangential lines

129. Axial canals diffuse

130. Radial canals

131. Intercellular canals of traumatic origin

Tubes / tubules

132. Laticifers or tanniniferous tubes

Cambial variants

133. Included phloem, concentric

134. Included phloem, diffuse

135. Other cambialvariants

Mineral inclusions

Prismatic crystals

136. Prismatic crystals present

137. Prismatic crystals in upright and / or square ray cells

138. Prismatic crystals in procumbent ray cells

139. Prismatic crystals in radial alignment in procumbent ray cells

140. Prismatic crystals in chambered upright and / or square ray cells

141. Prismatic crystals in non-chambered axial parenchyma cells

142. Prismatic crystals in chambered axial parenchyma cells

143. Prismatic crystals in fibres

Druses

144. Druses present

145. Druses in ray parenchyma cells

146. Druses in axial parenchyma cells

147. Druses in fibres

148. Druses in chambered cells

Other crystal types

149. Raphides

150. Acicular crystals

151. Styloids and / or elongate crystals

152. Crystals of other shapes (mostly small)

153. Crystal sand

Other diagnostic crystal features

154. More than one crystal of about the same size per cell or chamber

155. Two distinct sizes of crystals per cell or chamber

156. Crystals in enlarged cells

157. Crystals in tyloses

158. Cystoliths

Silica

159. Silica bodies present

160. Silica bodies in ray cells

161. Silica bodies in axial parenchyma cells

162. Silica bodies in fibres

163. Vitreous silica

Non-anatomical information

Geographical distribution

164. Europe and temperate Asia (Brazier and Franklin region 75)

165. Europe, excluding Mediterranean

166. Mediterranean including Northern Africa and Middle East

167. Temperate Asia (China), Japan, Russia

168. Central South Asia (Brazier and Franklin region 75)

169. India, Pakistan, Sri Lanka

170. Burma

171. Southeast Asia and Pacific (Brazier and Franklin region 76)

172. Thailand, Laos, Vietnam, Cambodia (Indochina)

173. Indomalesia: Indonesia, Philippines, Malaysia, Brunei, Papua, New Guinea, and Solomon Islands

174. Pacific Islands (including New Caledonia, Samoa, Hawaii, and Fiji)

175. Australia and New Zealand (Brazier and Franklin region 77)

176. Australia

177. New Zealand

178. Tropical mainland Africa and adjacent islands (Brazier and Franklin region 78)

179. Tropical Africa

180. Madagascar & Mauritius, Réunion & Comores

181. Southern Africa (south of the Tropic of Capricorn) (Brazier and Franklin region 79)

182. North America, north of Mexico (Brazier and Franklin region 80)

183. Neotropics and temperate Brazil (Brazier and Franklin region 81)

184. Mexico and Central America

185. Carribean

186. Tropical South America

187. Southern Brazil

188. Temperate South America including Argentina, Chile, Uruguay, and S. Paraguay (Brazier and Franklin region 82)

Habit

189. Tree

190. Shrub

191. Vine / liana

Wood of commercial importance

192. Wood of commercial importance

Specific gravity

193. Basic specific gravity low, <= 0.40

194. Basic specific gravity medium, 0.40-0.75

195. Basic specific gravity high, >= 0.75

Heartwood colour

196. Heartwood colour darker than sapwood colour

197. Heartwood basically brown or shades of brown

198. Heartwood basically red or shades of red

199. Heartwood basically yellow or shades of yellow

200. Heartwood basically white to grey

201. Heartwood with streaks

202. Heartwood not as above

Odour

203. Distinct odour

Heartwood fluorescent

204. Heartwood flourescent

Water & ethanol extracts: fluorescence & colour

205. Water extract fluorescent

206. Water extract basically colourless to brown or shades of brown

207. Water extract basically red or shades of red

208. Water extract basically yellow or shades of yellow

209. Water extract not as above

210. Ethanol extract fluorescent

211. Ethanol extract basically colourless to brown or shades of brown

212. Ethanol extract basically red or shades of red

213. Ethanol extract basically yellow or shades of yellow

214. Ethanol extract not as above

Froth test

215. Froth test positive

Chrome Azurol-S test

216. Chrome Azurol-S test positive

Burning splinter test

217. Splinter burns to charcoal

218. Splinter burns to a full ash: Colour of ash bright white

219. Splinter burns to a full ash: Colour of ash yellow-brown

220. Splinter burns to a full ash: Colour of ash other than above

221. Splinter burns to a partial ash

Annexure II. True mangroves of the West Coast in India based on the publications of different workers (Naskar and Mandal, 1987; Naskar, 2004)

Sl No.	Scientific Names of Species	Nature of the plants	Family
1.	*Rhizophora mucronata*	Tree	Rhizophoraceae
2	*Rhizophora apiculata*	Tree	Rhizophoraceae
3	*Ceriops tagal*	Shrub	Rhizophoraceae
4	*Ceriops decandra*	Shrub	Rhizophoraceae
5	*Kandelia candel*	Tree	Rhizophoraceae
6	*Bruguiera gymnorrhiza*	Tree	Rhizophoraceae
7	*Bruguiera cylindrica*	Tree	Rhizophoraceae
8	*Bruguiera parviflora*	Tree	Rhizophoraceae
9	*Xylocarpus granatum*	Tree	Meliaceae
10	*Cynometra ramiflora*	Shrub	Fabaceae
11	*Lumnitzera racemosa*	Tree	Combretaceae
12	*Avicennia officinalis*	Tree	Acanthaceae
13	*Avicennia alba*	Tree	Acanthaceae
14	*Avicennia marina*	Tree	Acanthaceae
15	*Avicennia marina Var.accutissima*	Tree	Acanthaceae
16	*Excoecaria agallocha*	Tree	Euphorbiaceae
17	*Aegiceras corniculatum*	Tree	Myrsinaceae
18	*Sonneratia alba*	Tree	Lythraceae
19	*Sonneratia caseolaris*	Tree	Lythraceae
20	*Sonneratia apetala*	Tree	Lythraceae

Annexure III. Different types of Mangroves distributed along the Indian Coast and their area (Source: FSI, 2015)

Sl No.	State/UT	Very Dense Mangrove (Km^2)	Moderately Dense Mangrove (Km^2)	Open mangrove (Km^2)	Total (Km^2)
1	Andhra Pradesh	0	129	238	367
2	Goa	0	20	6	26
3	Gujarat	0	174	933	1,107
4	Karnataka	0	3	0	3
5	Kerala	0	5	4	9
6	Maharashtra	0	79	143	222
7	Orissa	82	95	54	231
8	Tamil Nadu	1	18	28	47
9	West Bengal	990	700	416	2,106
10	Andaman & Nicobar Islands	399	168	50	617
11	Daman & Diu	0	0	3	3
12	Puducherry	0	0	2	2
Total		**1,472**	**1,391**	**1,877**	**4,740**

Annexure IV. Details of the relationship between mangrove genera and nearest upland relatives from various literatures

Mangrove genera	Nearest upland relative	Method	Gene/DNA	References	Habit
Rhizophora, Ceriops, Kandelia, Bruguiera	*Cassiporea guianensis*	MP	*rbcL, rbcL/atpB-rbcL/trnL-trnF/ nrDNA*	Schwarzbach and Ricklefs ,2000	Tree
	Carallia brachiata	MP	*rbcL, rbcL/atpB-rbcL/trnL-trnF/ nrDNA*	Schwarzbach and Ricklefs, 2000	Tree
Avicennia officinalis Avicennia marina	*Thumbergia spp.*	MP/ML	*rbcL, trnL intron, trnL-trnF space,nr DNA*	Schwarzbach and McDade, 2002	Vines
	Tectona spp.	MP/ML	*rbcL, trnL intron, trnL-trnF space,nr DNA*	Schwarzbach and McDade, 2002	Tree
Sonneratia alba, Sonneratia apetala, Sonneratia caseolaris	*Duabanga spp.,*	MP	*nr DNA*	Shi *et al.*, 2000	Tree
	Lagerstroemia	MP	*nr DNA*	Shi *et al.*, 2000	Tree

Mangrove genera	Nearest upland relative	Method	Gene/DNA	References	Habit
Excoecaria agallocha	*Hura spp., Bridelia spp.*	MP	*rbcL, atpB, matK* and *18SrDNA*	Tokuoka and Tobe, 2006	Tree
Aegiceras corniculatum	*Myrsine spp,*	MP	*atpB, ndhF and rbcL and DNA*	Kallersjo, 2000	Tree
Lumnitzera racemosa	*Anogeissus, Terminalia*	MP/ML	*nr DNA, rbcL*	Tan *et al.*, 2002	Tree
Heritiera littoralis	*Argyrodendron*	MP	*Chloroplast Gene ndhF*	Wilkie *et al.*,2006	Tree
Xylocarpus granatum	*Azadirachta*	MP	*rcbL*	Muellner *et al.,2006*	Tree

Annexure V. Details of nearest terrestrial relatives and ecoanatomical features of Rhizophoraceae mangrove genera for the study

Mangrove genera	Nearest terrestrial relative	Ecoanatomical characters	Habitat	References
Rhizophora, Ceriops, Kandelia, Bruguiera	*Cassiporea guianensis*	Solitary vessel percentage, vessel frequency, vessel diameter, vessel length, nature of perforation plates	Dry habitat	Van vliet (1976)
	Carallia brachiata	Solitary vessel percentage, vessel frequency, vessel diameter, vessel length, nature of perforation plates	Semi evergreen forest	Van vliet (1976)

Annexure VI. Details of ecoanatomical features of Lytheraceae mangrove members and its terrestrial relatives

Mangrove genera	Nearest terrestrial relative	Ecoanatomical characters	Habitat	References
Sonneratia alba, Sonneratia apetala, Sonneratia caseolaris	*Duabanga molluccana*	Vessel frequency, vessel diameter, vessel length, solitary vessel percentage	Alluvial and wet sites	Rao *et al.*, (1987)
	Lagerstroemia microcarpa	Vessel frequency, vessel diameter, vessel length, solitary vessel percentage	Dry habitat	Baas and Zweypfenn Ing (1979)

Annexure VII. Details of ecoanatomical features of Acanthaceae mangrove members and its terrestrial relatives

Mangrove genera	Nearest terrestrial relative	Ecoanatomical characters	Habitat	References
Avicennia officinalis, Avicennia marina	*Thumbergia alata*	Vessel frequency, vessel diameter, vessel length, vessel grouping	Dry habitat	Carlquist (1988)
	Tectona grandis		Moist habitat	Hussain and Nasir (2012).,Ahmed and Chun (2011)

Annexure VIII. Details of ecoanatomical features of mangrove species *Excoecaria agallocha* and its terrestrial relatives

Mangrove genera	Nearest terrestrial relative	Ecoanatomical characters	Habitat	References
Excoecaria agallocha	*Hura spp.*	Vessel frequency, vessel diameter, vessel length, solitary vessel percentage	Wet habitat	Mennega (2005)
	Bridelia retusa		Dry habitat	Nair *et al.* (1981)

Annexure IX. Details of ecoanatomical features of mangrove species *Aegiceras corniculatum* and its terrestrial relatives

Mangrove genera	**Nearest terrestrial relative**	**Ecoanatomical characters**	**Habitat**	**References**
Aegiceras corniculatum	*Myrsine sandwicensis*	Vessel frequency, vessel diameter, vessel length, solitary vessel percentage	Wet habitat	Lens *et al.* (2005)

Annexure X. Details of ecoanatomical features of mangrove species *Heritiera littoralis* and its nearest terrestrial relatives

Mangrove genera	**Nearest terrestrial relative**	**Ecoanatomical characters**	**Habitat**	**References**
Heritiera littoralis	*Argyrodendron trifoliolatum*	Vessel frequency, vessel diameter, vessel length, solitary vessel percentage	Drier parts of rainforest	Chattaway (1937) Wheeler (2011)

Annexure XI. Details of ecoanatomical features of mangrove species *Lumnitzera racemosa* and its nearest terrestrial relatives

Mangrove genera	Nearest terrestrial relative	Ecoanatomical characters	Habitat	References
Lumnitzera racemosa	*Anogeissus latifolia*	Vessel frequency, vessel diameter, vessel length, solitary vessel percentage	Dry deciduous forest	Van vliet,1979
	Terminalia nitens		Wet forest	

Annexure XII. Details of ecoanatomical features of mangrove species *Xylocarpus granatum* and its nearest terrestrial relatives

Mangrove genera	Nearest terrestrial relative	Ecoanatomical characters	Habitat	References
Xylocarpus granatum	*Azadirachta indica*	Vessel frequency, vessel diameter, vessel length,vessel grouping	Dry deciduous habitat	Anoop *et al.* (2005); Nair (1988)

Plate 18.a. Knee roots of *Bruguiera sexangula* b. Knee roots of *Bruguiera gymnorrhiza* c. Knee roots of *Ceriops tagal* d. Horizontal roots of *Excoecaria agallocha*

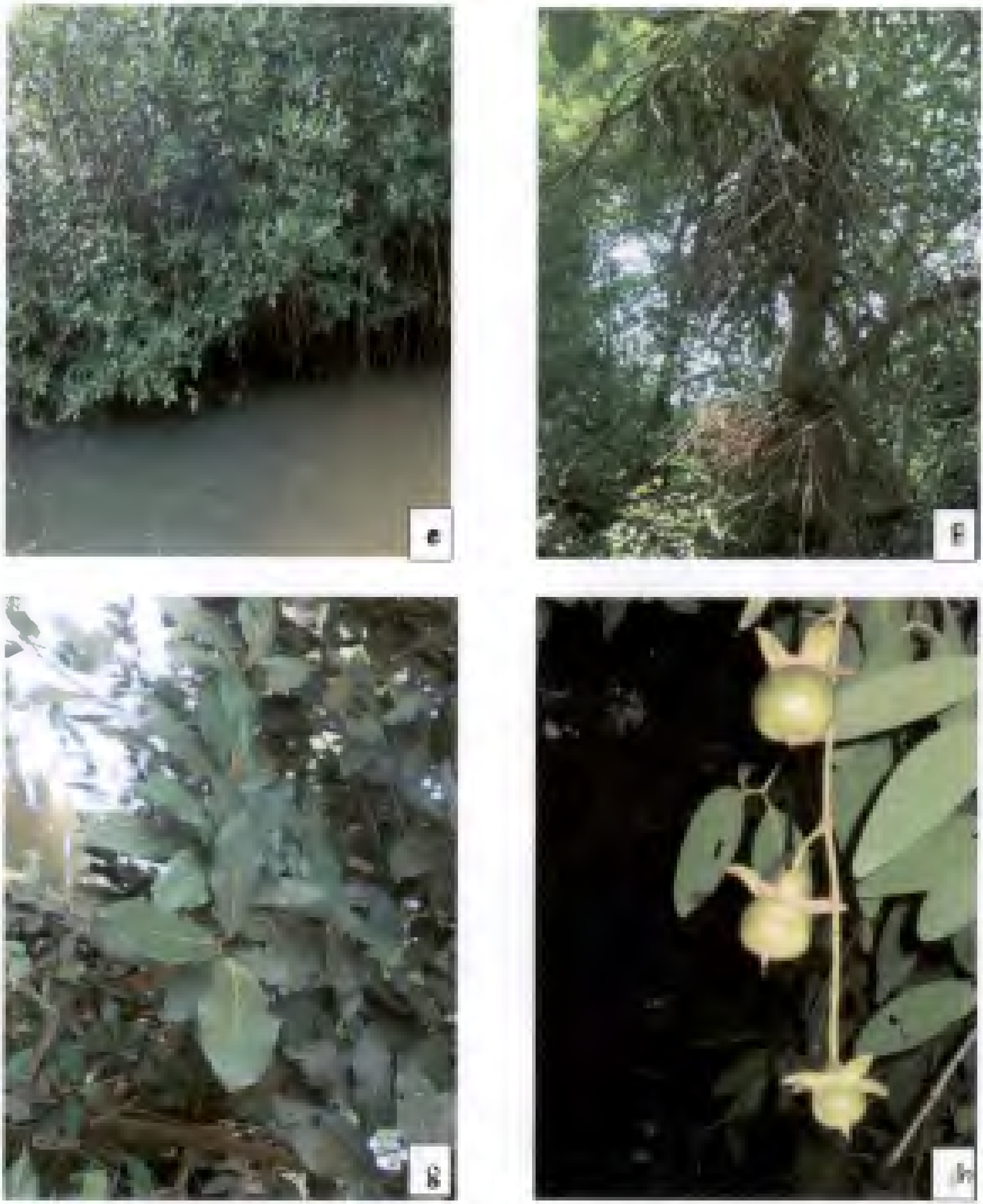

Plate 18. e. Patches of *Rhizophora apiculata* f. Aerial roots of *Avicennia marina* g. *Heritiera littoralis* tree h. Fruit of *Sonneratia apetala*

Plate 18. i. Pneumatophores of *Sonneratia caseolaris* j. Fruit of *Sonneratia alba* k. Tree of *Lumnitzera racemosa* l. Patch of *Bruguiera cylindrica*

Plate 18. m. Stilt and prop roots of *Rhizophora mucronata* n. Fruits of *Xylocarpus granatum* o. Pneumatophores of *Sonneratia alba* p. Pneumatophores of *Avicennia officinalis*