Indian Mangroves

Insights, Interventions and Implications

A Handbook

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION, DEHRADUN

(An Autonomous body of Ministry of Environment, Forest and Climate Change, Government of India)

INDIAN MANGROVES:
INSIGHTS, INTERVENTIONS AND IMPLICATIONS

A HANDBOOK

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
P.O. New Forest, Dehradun - 248 006

www.icfre.gov.in

PATRON

Dr. Suresh Gairola, IFS
Director General

EDITORS

Ms. Kanchan Devi, IFS
Deputy Director General (Extension)

Shri Vipin Chaudhary, IFS
Former Deputy Director General (Extension)

Dr. Shamila Kalia
Assistant Director General (Media & Extension)

Shri Ramakant Mishra
Chief Technical Officer (Media & Extension)

Published by

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Processed and Realization
Print Vision
41-C, Rajpur Road, Dehradun
(+91) 135 2741702 | printvisionddn@gmail.com | www.printvisionindia.com

Foreword

Dr. Suresh Gairola, IFS
Director General
Indian Council of
Forestry Research and Educatrion

ICFRE with its Headquarters at Dehradun is an apex body in the national forestry research system that promotes and undertakes need based forestry research and extension. The Council that came into being in 1986 has a pan India presence with its 9 Regional Research Institutes and 5 Centers in different bio-geographical regions of the country. Since then research in different fields of forestry has been a major focus of ICFRE.

There is an earnest need to present its research findings to the stakeholders in a simple and lucid manner, to improve the visibility and relevance of ICFRE. Therefore it was decided that the information available on the technologies, processes, protocols and practices developed by ICFRE be published in the form of operational manuals/user manuals. It is also desirable that the manual should be a comprehensive national level document depicting extent of knowledge in applicable form.

Accordingly, 18 scientists of ICFRE were nominated as National Subject Matter Coordinators (NSMCs) to carry out the task on the specified subject. These NSMCs were assigned the task to select and nominate nodal officers from other Institutes of ICFRE as well as other organizations if necessary, collect and collate the information on the subject from various sources in coordination with the nodal officers of ICFRE institutes.

I take pride in informing that, during the International Decade of Biodiversity (2010 – 2020) ICFRE launched some important research projects in mangroves such as species recovery and habitat restoration in the country. These activities were formulated and fielded with inputs, consultation and participation of the State forests departments of Kerala, Tamilnadu and Andamans. Species recovery programmes through human assisted reproduction were successfully conducted in RET taxa such as *Bruguiera sexangula* and *Ceriops decandra* in technical collaboration with the state Governments of Kerala and Tamilnadu respectively. Presently, ICFRE looks forward in harnessing the productivity potential of putative Rhizhophora hybrids in collaboration with Tamilnadu Forest Department. In future, I trust, deploying hybrid planting stock could bring in enhanced productivity particularly, those being developed in the hyper saline zones.

I congratulate the efforts made by the authors and I am sure that this publication will prove effective to all the people working towards the conservation and sustainable management of Indian Mangroves in the country.

Dr. Suresh Gairola

Preface

Mangroves are global assets, across ages these genetic resources have continued to serve to the benefit of the human society. Mangroves are among the most productive as well as highly threatened ecosystems. Globally, hypersalinity in the estuaries due to diversion of upstream of rivers is a major concern. This appears to be a major extinction vortex to the upkeep and maintenance of overall mangrove management. The mangroves are implicated in term of overall physiology, photosynthesis and productivity and most importantly reproduction. In several locations, across the mangrove zones those species surviving very high salinity range only survive and often vegetations lack diversity and get to become monospecific stands. Deploying unconventional mangrove FGRs (Forest Genetic Resources) is a strategy to improve productivity. During the period 2010 – 2019, the Institute of Forest Genetics and Tree Breeding, Coimbatore in participation with the states of Tamilnadu, Kerala and Andmans conducted certain unique and innovative exercises. An attempt was made to conduct species recovery programs and restoration ecology studies. Studies of basic nature such as quantifying reproductive behaviour to highly applied aspect such as controlled pollination were successfully conducted in Bruguiera sexangula (In Ernakulam, Kerala) and Ceriops decandra (In Pichavaram, Tamilnadu). These said studies are pivotal to comprehend the genetics and breeding aspects and increasing the physical size of the population. Further, studies were also conducted on the microbiological aspects to improve the nursery quality of planting stock of RET species. This manual also highlights the status of Mangroves in the Andamans and Nicobar. Most disciplines discussed are first of its kind with reference to Critical Ecosystems. It is hoped that knowledge building exercises on the said aspects would improve in conservation and management of mangroves.

Dr. B. Nagarajan
Scientist G
Institute of Forest Genetic & Tree Breeding (IFGTB)
Coimbatore

COMPILED BY

- Dr. B. Nagarajan — Institute of Forest Genetic & Tree Breeding
  Scientist G — Coimbatore

CONTRIBUTORS AS NODAL OFFICERS AT VARIOUS INSTITUTES

- Dr. A. Karthikeyan, Scientist F — IFGTB, Coimbatore
- Dr. A. Shanthi, Scientist D — IFGTB, Coimbatore
- Dr. P. Ragavan — Senior Research Scholar*
- Dr. N. B. Siva Priya — Senior Research Scholar
- Shri.M. Utchimahali — Senior Research Scholar
- Shri. K. Haribabu — Field Assistant

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INTRODUCTION

1 INTRODUCTION

According to The Convention of Biological Diversity (CBD), individual countries are responsible for conservation and sustainable use of their biological diversity (UNEP 1992). Oldfield *et al.*, (1998) estimated that about 10% of the world's 1, 00,000 of trees species are under threat and about 1000 species are critically endangered and may face extinction. In most of these species the processes of reproduction remains unknown. Understanding Forest Genetic Resources (FGR) is gaining importance among tropical countries (Changtragoon 2001, Rao *et al.*, 2001, Ved *et al.*, 2001). Resource cataloguing at ecosystem and population levels is recognized to be extremely essential in formulating conservation, domestication and bio-prospecting programs (Batis and Vazquez-Yanes 1996, Ganeshiah *et al.*, 2001). Studies in Asia indicate that FGRs are on a rapid decline trend and in some regions their future looks jeopardized (FAO 1999, ITTO/RCFM 2000). Initiative to estimate forest genetic resources with proper action plan is the need of the hour in Asia (Rao and Koskela, 2001). Among the FGRs, wetland, particularly the Mangroves one of the most fragile ecosystems of our country are the least comprehended with reference to conservation and management.

The Ramsar convention (1971) defines that *"Wetlands are area of marsh, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six meters"*. In a wider perspective wetlands are shallow hydrological body that stores water for most part of the year and recedes below the surface level during the dry season. In terms of vegetations dynamics wetland biotic community undergoes temporal changes from aquatic/marshy to mesophytic types. Mangroves are a complex hydrological and biogeochemical system and are recognized as distinct ecosystems between the terrestrial and aquatic zones.

Mangroves are unique marine wetland ecosystems found in the inter-tidal coastal regions of the tropics and subtropics of the globe. They are not only among the most productive but most threatened ecosystems in the world due to natural and demographic pressures (Kathiresan, 2002; Roy and Krishnan 2005; Proffitt *et al.*, 2006). The global mangrove cover is estimated to be about 200,000 km^2 (Spalding *et al.*, 1997). India accounts about 424 400 ha of mangroves (FSI 1988 cited in FAO).Owing to natural calamities, climatic change and anthropogenic pressure over the past twenty years approximately 35% of the world's total mangrove area has been lost (Valiela *et al.*, 2001). Mangrove vegetations constitute approximately eighty species belonging to twenty families (Duke, 1992). The better known taxa are the members of Rhizophoraceae namely *Rhizophora, Bruguiera, Ceriops and Kandelia*. These taxa are listed under various IUCN threat categories that require conservation programs (Rao *et al.*, 1994). As mangroves propagate through only sexual reproduction their maintenance and recovery depends on the propagule production, dispersal and establishment (Tomlinson, 1986).

Indian mangroves can be broadly divided into three types East Coast Deltaic (Chidhambaram, 2004) and West Coast Non-Deltaic (Rao *et al.*, 1999) and Island mangroves (Rao and Krishnan, 2005). The East coastal mangroves are protected by forest agencies while, in the West Coast most are of private ownership. The mangroves in Kerala are highly localized with high species richness when compared to other locations of our country in the West Coast (Chand Basha 1992). Ramachandran *et al.* (1986) observed that the mangroves of Kerala were degraded and grew in isolated patches. Chand Basha (1992) and Mohanan (1999) estimated it to be *"less than 50 sq. km"* and listed a total of 32 mangrove species. Although, habitat fragmentation and over exploitation are the more apparent casual factors, failure of reproductive processes to cope with environmental changes could also be the fundamental reason for species loss (Moza and Bhatnagar, 2007). In the recent past only a few studies have been conducted on reproduction of mangroves (Duke, 1990, Clarke and Myerscough 1991; Sun *et al.*, 1998; Drexler 2001; Coupland *et al.*, 2005; Coupland *et al.*, 2006; Raju *et al.*, 2006).

The Convention on Wetlands signed in Ramsar, Iran in 1971 is an Inter-Governmental Treaty which provides the framework of national action and international cooperation for the conservation of wetlands. India a signatory to the Ramsar Convention was a member to the Standing Committee Members (SCM) during the periods 1993-1996 and 1999-2002. It has also contributed to the Committee on Communication, Education and Public Awareness (CEPA) during the period 1999-2002. According to the Ramsar Convention's mission *"the conservation and wise use of wetlands by national action and international cooperation as a means to achieving sustainable development throughout the world"*.

The Ramsar Convention has twelve articles dealing with definitions of wetlands, designation and classification, usage, establishment of nature reserve, research, monitoring, management and international cooperation. The criteria for identifying or recommending wetland inland or coastal wetlands to the convention depend on the following criteria:

Criterion 1: If it supports vulnerable, endangered or critically endangered species or threatened ecological communities.

Criterion 2: It should support plant/animal population that is important for maintaining the biological diversity of a particular bio-geographic region.

Criterion 3: If it supports a plant/animal species at a critical stage in their life cycle.

Criterion 4: If it regularly supports over a bird visitation census of over 20,000 or more water birds.

Criterion 5: If it supports 1% of the individuals in a population of one species or subspecies of water birds.

Criterion 6: If it supports a significant proportion indigenous species or subspecies of fishes.

Criterion 7: If it is a spawning ground of migratory path of fishes

Criterion 8: Increased possibilities for recreation, eco-tourism, educational opportunities and conservation of heritage.

About 154 nations are parties to the convention tally for 1634 wetland sites totalling 145.73 million hectare are included in the Ramsar List of Wetlands of International importance. India has designated twenty five wetlands as Ramsar sites which is equal to 1.5% of the total sites in the world. Only three enlisted sites namely East Kolkata (West Bengal), Bhitarkanika (Orissa) and Point Calimere (Tamil Nadu) have coastal wetlands that host mangroves in them.

Mangroves are an important bulkhead against climate change; they afford protection to coastal areas from tidal waves and cyclones and are among the carbon rich forests in the tropics (Cornforth *et al.*, 2013). Interestingly, the economic worth of mangroves was estimated less than 50 US cents/hectare (Pearson, 1914) in the beginning of the century. However, the present bionomics worth of mangroves is over 90,000 US $/hectare. (Costanza, 2014) Ironically, such precious ecosystems are among the world's most threatened biomes. In the 1970s and drying of mangroves on large scale across the globe was first noted (Jimenez *et al.*, 1985). Over the past three decades or so, global warming has been reported to increase surface evaporation, increase seawater intrusion and unpredictable freshwater flow have challenged the already threatened ecosystem. Hypersalinity appears to be the main extinction vortex, particularly in the deltaic mangroves (Adeel and Pomeroy, 2002).

To overcome localized elimination of mangrove population recently in 2010 the Indian Council of Forestry Research and Education initiated Species Recovery Program (SRP) in true mangroves. Species such as *B.sexangula* a very critically endangered taxon in Kerala and *Ceriops decandra* an Globally Near Threatened (GNT) category species in Tamilnadu. Currently, a comprehensive Species Centred Approach (SCAP) is being adopted that consists of control pollination and biotechnological interventions. It is certain appears that reproductive bottleneck posed to the species could be overcome by deployment of human assisted reproduction and regeneration.

Mangrove is perhaps unique in that it stands a universal forest type that varies in of floristic composition depending on the geomorphology of the location. The management of global mangrove resources is confronted with commonest problems such as inadequate fresh water flow, land diversion for commercial marine food, sea level rise and most importantly induced hypersalinity. Among the vortices, it appears that hypersalinity is the major environmental impediment to the overall genetic diversity and floristic composition of mangroves. Most forests are climaxing in to a single species forest stands. The multi-stakeholders lists are endless and growing are ever in utilising mangroves resources. However, creating them are always a challenge. The technical and intellectual capabilitites to tackle field problems is equally challenging. It could be highly prudent at this juncture to establish working groups at National, Regional and Global levels to pursue strategies that would govern research, management and legal requirements to sustain the mangrove ecosystems.

In this field manual we present the case studies carried out by ICFRE institutions across the country in tackling and strategies that are prudent in conserving and managing mangroves.

2

HISTORY, FOREST TYPES AND CURRENT STATUS

2 HISTORY, FOREST TYPES AND CURRENT STATUS

Globally, the geographic regions that lie between 24° 00 N - 38° 00 S in the tropics and subtropics and that support intertidal wetland forests or vegetations are referred to as *"Mangroves"* (Chapman, 1976) (Tomlinson, 1986) (Duke, 1992) and (Duke et al, 1998). They found exclusively either in the equatorial zone or in the tropical summer rainfall zone and only patchy mangrove vegetations are found in subtropical and temperate zones. The said aspects indicate that distribution of mangroves is limited by the temperature thresholds (Selvam & Karunagaran, 2004). These areas receive annual preceipitation of 1000-3000mm with annual temperature ranges 26º-35º C.

The term mangroves is commonly referred to both individual species and to the entire ecosystem. Mangroves are known to grow in over 123 countries (Hamilton and Casey 2016) and occur in geo-morphologically similar locations with highly varying floristic compositions depending on the salinity attributes of the region. Normally, Higher the salinity which the region, lower the among floristic diversity is known exists within the vegetations. The estimated global cover of mangroves is about 150,000 km^2. Regionally, over 40% of the global mangroves are in the South and South East Asian regions. India is bestowed with 45.8% of the mangrove cover in the South East Asian territory (World Atlas of Mangroves, 2010). India is estimated to have about 3% of the total mangrove cover in the world and spread over an area of 4920 km^2 (FSI, 2017). The mangrove cover in India has increased by 21.63% over 30 years at 0.72% increase rate per year in India (Kathiresan, 2018).

In India, the mangrove cover is 57% in the east coast, 30% in the west coast and 13% is within the Andaman Nicobar and Lakshadweep islands. Sundarbans, West Bengal in the East Coast and Gujarat in the West coast are the major vegetations in India extending 43% and 23% of the total mangrove cover in India respectively (SFR, 2015). Indian mangrove habitats are classified into three major groups namely, Deltaic (East Coast), Non-Deltaic (West Coast) and Island (Andaman Nicobar and Lakshadweep). The mangrove cover in the east coast is higher than that of the west coast. This is mainly due to the formation of deltaic regions by the rivers like Ganges, Brahmaputra, Mahanadhi, Godavari, Krishna and Cauvery. The rivers Narmada and Tapti form wetlands in the west coast that facilitate mangroves in Maharashtra and Gujarat.

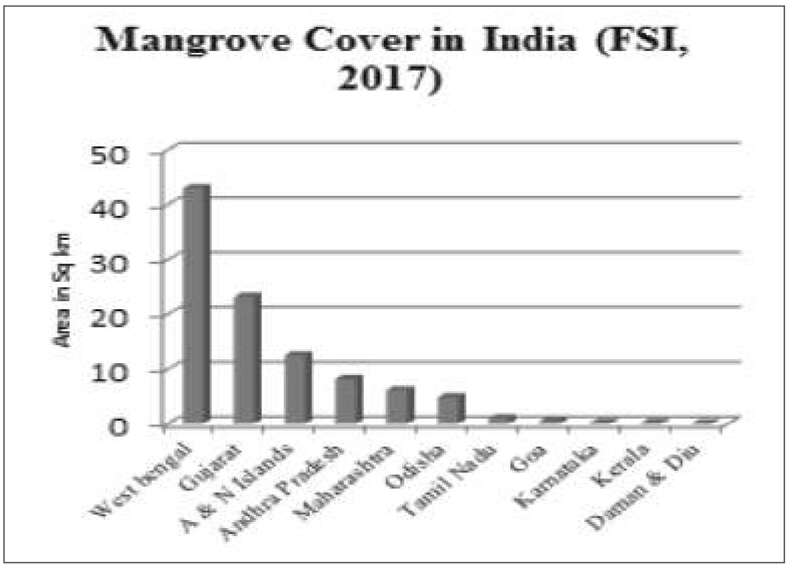


Fig 1. *Casuarina growing along with paddy in coastal Tamil Nadu*

Mangroves are very unique group of plants that are adapted to survive hostile conditions. They are naturally adapted to thrive under demanding physical and eco-physiological conditions such as hyper salinity, extreme heat, tidal actions, high velocity winds and anaerobic, marshy soil profiles. The taxa such as *Avicennia, Aegiceras,* and *Ceriops* have salt glands on their leaf surface through which they excrete excessive salts. Plants such as *Excoecaria, Sesuvium* and *Sueada* are capable of storing the salts in their leaves. Species such as *Rhizhophora* use roots as their bio-filters to remove excessive salts.

Breathing roots or pneumatophores is a unique adaptation seen in species such as *Avicenia* and *Sonneratia*, through which oxygen passively diffuses. The genus *Bruguiera* and *Ceriops* have knee roots or cable roots to support and also play an important role in preventing soil erosion. Stilt roots are supporting function is common in *Rhizophora* which helps in strong anchorage to overcome tidal movements. *Vivipary* is an interesting adaptation exhibited by the family Rhizophoraceae. The embryo continues to grow on the mother plants for periods varying from 3-12 months depending on the species and is released as seedlings commonly referred to as hypocotyls. This adaptation is advantageous to zygotes as not being lost as seeds to nature. Seedlings being released with defined shoot and root system assures higher rate, of survival and thus also gaining, as greater reproductive success.

Mangrove ecosystems support an array of biodiversity and services. They act as niche for several other groups of organisms like algae, migratory birds etc. Globally, there are about 74 species of true mangroves species within 27 genera belonging to 20 families (Ward *et al.* 2016). Being the third largest country for mangrove biodiversity, India has the highest record of species richness in mangrove ecosystems of the world with 4107 species including 925 species of plants of which 44 are true mangroves and 3182 taxa of fauna (Kathiresan, 2018).

Mangrove vegetations support detritus food cycle and it accrues accumulation of organic and inorganic nutrients constantly. As a geo-morphological structure mangrove adds to land accretion by trapping fine sediments that flow in to estuaries and deltas through Riverine flow and thus arresting coastal erosion. Water salinity transition, habitat provisioning and nutrition make mangroves as a universal hatchery or nurseries to most fish and crustacean lives. The deadly Tsunami of 2004 exhibited the real value in terms of protection to the globe. Most villages closer to dense mangrove vegetation faced least physical damage. Since then mangroves are being treated as very valuable global green assets. Several countries have improved their mangrove forest covers through systematic coastal afforestation programs.

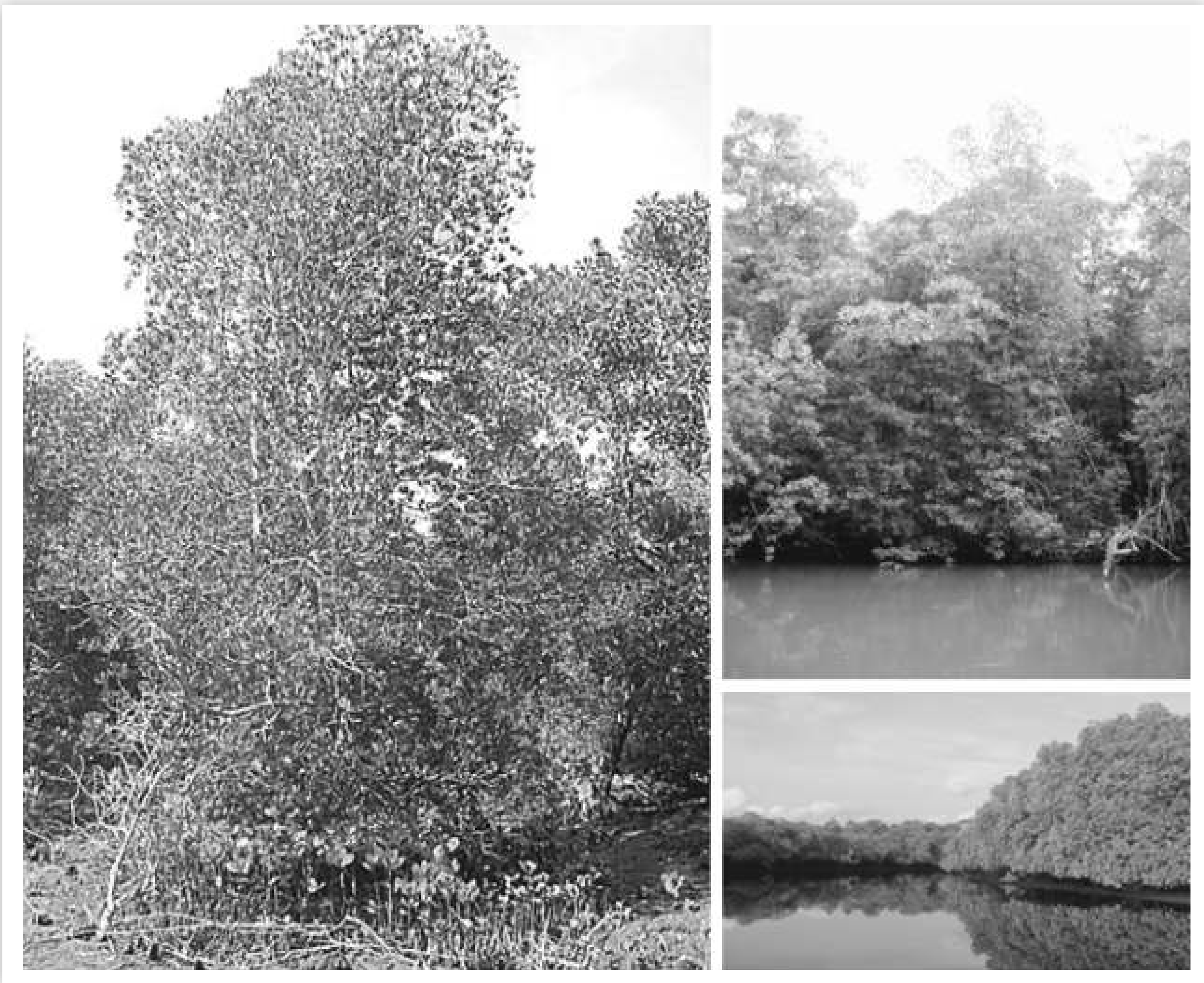
Champion and Seth (1968) in their classical work on forest types of India, categorised mangroves as Tidal Swamp Forests with the nomenclature type 4B. Mangroves are further classified as 4B (Littoral forests) TS1 (Tidal Swamp Forests – Mangrove Scrub) and TS2 (Tidal Swamp Forests – Mangroves Forests). The authors found that the Indian mangroves varied so much in such short distances and that a general description for this type was difficult. They described that the finest forest was found on ground which is flooded at every high tide with only moderately brackish water, and is an evergreen closed high forest to about 30 m with an under wood of younger trees of the same species or others. They found that mangroves were commonly two storied owing to the prevalence of trees whose height was only 5-10 m. The soil was bare mud, wherein masses of regeneration covered the surface. Floristically, it was found that species composition were relatively few and were gregarious; practically all taxa were with evergreen with simple coriaceous leaves. Grasses were rare and climbers were usually a few with fairly numerous epiphytes. Mangrove forests are considered as one of the most productive ecosystems and are source of energy in the coastline habitats (Snedaker, 1978). They support both aquatic and terrestrial flora and fauna. The ecosystem services of these ecotone vegetations are protect coastlines from erosion, and storms, cyclones and high tidal waves, also they also serve as sink and source of nutrients and minerals for other inshore marine habitats. (Fosberg 1971, Barbier *et al.*, 2008, Das & Vincent, 2009).

The natural wealth or green capital of any country directly depends upon its untapped bio recourses. In terms of biological diversity, India is one among the richest countries. However, increasing human population along with habitat destruction, over exploitation, increasing rates of pollution are the major threats to losses caution our biodiversity wealth. For instance, the developing fast and highly populated metro cities on costal line and vanishing mangrove wealth have been vanishing constantly (Sandilyan, 2014). Developing strategies. The scientific management of mangrove forests was implemented in 1892 in our country (Chaudury and Chaudury 1994). During 1976 National Mangrove Committee (NMC) was established in the Ministry of Environment and Forest, for advising the government on scientific basis of the mangrove management. The Indian Forest Act (1927) and Wild life Protection Act (1972) are the major legal frameworks in India which protects the biodiversity. The Indian Forest act 1972 has declared Sundarbans as reserve area (Naskar and Mandal, 1999). The coastal regulation zone (CRZ) notice under the Environment protection act 1986 is providing various levels of management strategies to mangrove ecosystems (Bhatt *et al.*, 2013).

The Joint Forest Management (JFM) programs by MS Swaminathan Research (MSSRF) Foundation along with the State Forest Departments (SFDs) have successfully demonstrated afforestation in states like Tamil Nadu Andrapradesh and Odisha. following the irrepairable Tsunami 2004 peoples attitude towards coastal conservation has certainly improved. Tamil Nadu has added 2162 ha of mangrove plantations were raised during 2005 – 2007 (Sreedharan and Sekar 2013).

3

ECOLOGY



3 ECOLOGY

Recently, studies have indicated that *B. sexangula* a true mangrove belonging to Rhizhophoraceae is exclusively pollinated by sunbirds (*Nectarinia zeylonica* and *N. asiatica*) (Nagarajan *et al.*, 2009) and they face severe pollen limitation (Krishnamoorthy *et al.*, 2013. In the case of *B. parviflora* Pollinated by butterflies very little information is available on the pollination behavior and breeding systems. It is conflicting to observe that disappearance of forests in tropics comes at a time when our knowledge on their reproduction, structure and dynamics is woefully inadequate (Hubbel and Foster 1992; Owens, 1993). Precise information on reproductive patterns in tropical ecosystems is scarce and their determining factors are still debated (Borchert 1983; De Bie *et al.*, 1998). Quantitative data on phenology, floral characteristics and pollination are important in understanding breeding systems (Gitiru *et al.*, 2002). Thus, understanding reproductive processes is a prerequisite for genetic amelioration, conservation and rational management of genetic resources (Congdon and Herbohn, 1993; Aronson *et al.*, 1994).

In this chapter, we try to highlight the following aspects in true mangroves belonging to the viviparous true mangrove taxon Rhizophoraceae:

- Phenological variations
- Floral Biology and Breeding Systems
- Pollinator visitation and limitation
- Reproductive fitness and Success

Comprehending plant reproduction and breeding system is a prerequisite to long term conservation efforts (Moza and Bhatnagar, 2007). Among tropical ecosystems mangroves seems to the least probed in terms of reproduction (Tomlimson *et al.,* 1979; Tomlimson, 1984). Rhizhophoraceae representing the true mangroves is the only taxon among plantae wherein sexual reproduction is obligatory through a process called *vivipary*. In the past studies of phenology in mangrove associates conducted elsewhere have indicated that plant populations have significant latitudinal effect in the process of reproduction (Duke 1990a and 1990b, Duke 1992). Studies have also shown that reproductive events were relatively synchronous among trees at a particular latitude and this was constant among years (Clarke and Myerscough, 1991). However, the reproductive behavior of individual trees is known to vary across flowering years (Nagarajan *et al.*, 2013). Individual trees and populations are switch know to from reproductive to a non-reproductive state across years. such phenological behaviour has been recorded in *Ceriops* and *Bruguiera* populations, that are classified as RET taxa in the East and West Coasts of India (Krishnamoorthy *et al.*,2010 Nagarajan *et al.*, 2010, Pandiarajan *et al.*, 2010 and Sophia *et al.*, 2010).

PHENOLOGICAL VARIATIONS

Habitat fragmentation, over exploitation are the more apparent casual factors, for depletion of mangrove reproduction however, failure of reproduction towards coping environmental changes is also a the major reason for species loss (Moza and Bhatnagar, 2007). Globally, In mangroves only a few studies have been conducted on the phenology (Duke, 1990, Clarke and Myerscough 1991; Sun *et al.*, 1998; Drexler 2001; Coupland *et al.*, 2005; Coupland *et al.*, 2006; Raju *et al.*, 2006). Rajendran and Sanjeevi (2004) provided the most exhaustive account on the phenology of true and mangrove associates. Almost, in all the taxa dealt by them clear variation on the flowering behaviour across latitudes was Such a trend was also observed by Duke (1990) in the mangroves of Australian.

Clarke and Myerscough (1991) could correlate that, reproductive events were relatively synchronous among trees at particular latitude and these pattern was constant across years. However, it needs to be noted that behaviour of certain individual trees varied highly between years. (Clarke and Myerscough 1991) reflected that such patchy flowering may promote out breeding or simply reflect change in sediment resources availability It was observed that in Pitchavaram, Tamilnadu every species had its own reproductive pattern. Such distinct reproductive behaviour among species within an ecosystem reduces competition in sharing pollinators, nutrients and substrate for the propagules to establish. Kumar (1992), noted that prominent phenological variations among the populations in the Indian mainland and Andaman Islands.

In India, it is reported that the East and West Coast populations of *B. cylindrica* vary in their phenological output (Sophia *et al.*, 2013). It is observed that the reproductive phenology of the East Coast populations is tuned to South West monsoon the west coast populations are in harmony with North East monsoon. Among the Bruguieras *B. cylindrica* was the earliest to flower and the fastest in terms of fruit maturation and dispersal (Nagarajan *et al.*, 2010).

FLORAL BIOLOGY AND BREEDING SYSTEMS

The positioning of inflorescences is unique in Rhizophoraceae; they are borne sub-terminally wherein reproductive shoots develop only from the second and third nodes immediate to the meristamatic tips. There is a clear spatial and temporal separation of sexual phases within and among flowers in an inflorescence (Nagarajan *et al.*, 2008). In general flowers are bisexual, strongly protandrous and dichogamous that produce enormous amounts of pollen (Table 1). Such kind of pollen ovule ratio is normally seen only in anemophilous taxa. Taxa adapted to Entromophilous species produce flowers in shades of white and creamish yellow, not showy and not adapted to any kind of specialist pollinator syndrome. In *B. cylindrica* mature flower buds measure 4-6 mm in length; 3-4mm breadth with 1 cm^2 corolla when fully open. 1cm in breadth when fully open and in *Ceriops* mature flower buds measure 4-5 mm in length; 3-4mm breadth, 0.7 cm in breadth when fully open. In *B. cylindrica* each reproductive shoot produces 6-18 flowers. Flowers are in axillary cymes, small (2.5 cm in length), creamish yellow in colour, not showy, bisexual, strongly protandrous, dichogamous and short lived (>or = 4 days). Flowers are scented (attractants to Thrips) and floral life lasts for 3-6 days (Sophia *et al.*, 2013). Based on entomophilous adaptations and moderate reproductive success it can be well inferred that *C. decandra* seedlings are lorgly outcrossed products. On the contrary, *B. cylindrica* pollinated by thrips, (an intra floral pollinator) promotes geitonogamy leading to the production of selfed offsprings. Recent studies on genetic indicate high levels of genetic relatedness within and among populations of *Ceriops* (Sun *et al.*, 1998).

In terms of entomophilous species such as *B. cylindrica* total flower life was 3-4 days, followed by *C. decandra* (6-8 days) and *C. tagal* (8-10 days). Pollen is dispatched for about a day in *B. cylindrica* and for more than 2 -3 days in *Ceriops*. The stigma is receptive on the second day in *Bruguiera* and on the third day in *Ceriops*. Well hydrated stigmas amidst completely dried and dehydrated anther mass is a common expression in highly protandrous species. In ornithophilous taxa, such as *B. gymnorhiza* and *B. sexangula* reproductive shoots consists only 2-4 flowers arranged in two nodes also in immediate second node to the main stem. The flowers are large varying 1.75 – 2.0 cm in length having a deep calyx cup that stores about 25-40 µl of thin nectar with a life of about 14 – 20 days

(Nagarajan *et al.*, 2008). The number of anthers/flower varies from 20-24. Each anther sheds 70,000-80,000 pollen grains (Krishnamoorthy *et al.*, 2013). The pollen is bi-nucleate and storable over three months at 4^o C. Both species exhibit very high pollen fertility of about 95%. The pollen ovule ratio is very high. In *B. sexangula* and *B. gymnorhiza* after the anther being tripped by the avian visitor pollen is released explosively as small clumps on to the beaks and heads (Nagarajan and Jesubalan 2012).

Diverse floral features, high pollen out put, very high pollen to ovule ratio and low reproductive success noticed in *Bruguiera* and *Ceriops* places them amongst highly out crossing woody perennials. It is interesting to note that despite having multiple ovule system (4-6) only one ovule succeeds in developing in to a propagule.

Allen and Duke (2006) noted that *B. gymnorhiza* had very long reproductive maturation period of 1-2 years from flower emergence to dispersal of mature hypocotyls. In the Indian mainland and Andamans it is found that *Rhizhophora* propagules mature over a period of 8-10 months to develop on mother plants, whereas in *B. cylindrica* and *C. decandra* it is 3-6 months (Kumar 1992; Nagarajan *et al.*, 2008). In *Ceriops decandra* fruits remain dormant after fertilization for over 3-4 months. Else where similar reproductive behaviour was reported in *Ceriops australis* (Coupland *et al.*, 2006). However, Raju *et al.*, (2006) reported that *C. decandra* populations found in Coringa, India develop propagules immediately after fruit set. But our field observations on the populations at Pitchavaram, Tamilnadu indicate that there is a certain dormant post fertilisation period. In B. cylindrica the period of propagule maturation is 3-4 months and in the case of bird pollinated *B. gymnorrhizha* and *B. sexangula* the propagules mature over a period of 6-8 months.

POLLINATOR VISITATION AND LIMITATION

Studies on pollen biology in *Bruguiera, Ceriops* and *Rhizophora* indicate higher pollen sterility compared to outbreeding woody perennials (Nagarajan *et al.*, 2006). This could be due to the possibilities of inbreeding depression or a mere response to higher salinity and lower influx of freshwater (Nagarajan *et al.*, 2013). Recently, studies on breeding system and reproductive biology in the taxa *Bruguiera* and *Ceriops* have thrown light on different pollination syndromes. Interestingly species such as *Rhizophora* that are fairly abundant even the process of pollination is yet to be comprehended. Interestingly, it is noted *B. cylindrica* pollinated by thrips shows the higher reproductive success (Sophia *et al.*, 2013) and the bird pollinated taxon *B. sexangula* shows the least reproductive fitness (Krishnamoorthy *et al.*, 2013). It appears that pollinator limitation is very high in ornithophilous species compared to entomophilous taxa (Naarajan *et al.*, 2013). In Kerala once rarely seen *B. parviflora* is not traceable in any of wetlands in the Travancore and Kannur region. Owing to pollinator limitation many species.

In case of *C. decandra* pollinator visitation was from 08.00 to 18.00 hours. Wild solitary bees (*Nomia* and *Allodape*) were the major visiting group (Fig. 4). No social bees could be recorded, however large pollinators like *Xylocopa* were recorded. Forage timing among bees varied 3-5 seconds. Large numbers of thrips (*Thysanoptera*) were found residing within *B. cylindrica* flowers (usually 2-4). *B. sexangula* and *B. gymnorrhiza* are pollinated by sunbirds (*Nectarinia asiatica* and *N. zoylonica*). The birds usually forage in pairs; visits are random and performed throughout the day. Usually 4-6 visits were recorded an hour. The visit of the birds is continuous and random in nature. However, in the case of *B. gymnorrhiza* during the month of October *Apis dorsata* and *Ceratina* were also recorded (Nagarajan *et al.*, 2010).

REPRODUCTIVE FITNESS AND SUCCESS

Pre-Emergent Reproductive Success (PERS) values indicate the total number of progeny produced by a plant within a flowering season. Taxa with high values of PERS indicate high levels of selfing while low levels indicate high out crossing (Wiens *et al.*, 1987). Values obtained in *B. cylindrica, C. decandra,* and *C. tagal* are indicative of high outcrossing nature. Among the true mangroves *B. cylindrica* adapted to thrips pollination exhibits the highest reproductive success followed by *B. gymnorrhiza* and *B. sexangula* (Table). It can be broadly inferred that the least reproductively successful mangrove species are the ornithophilous taxa.

DISCUSSION

Studies and detailed information on reproductive success at individual tree and population level are not available in any of the mangrove species in India. In mangroves the high level of heterozygosity within population confirms random movement of pollen (Lakshmi *et al.*, 2001). All *Bruguiera* species have explosive pollen release but that to main agents trigger the process, insects in small flowered species, birds in the large flowered species, (Tomlinson, 1979). We observed that *B. cylindrica* pollinated by thrips. Also the species has about 85% pollen fertility. But there is a need to document more information on plant-pollinator interaction.

Generally, the one ovule develops in to seedling out of the six or four ovules may due to inadequate fertilization, expression of lethal alleles in fertilized embryos, competition among sibling embryos and control of maternal investment (Fennar and Thompson, 2005). Maturing ovules are known to produce growth regulators which in turn stimulate fruit development. Likewise, young fruits with a greater number of developing ovules are more apt to mature, presumably because they produce more growth regulators and consequently grow faster than ovaries with fewer developing ovules (Stephenson 1981).Based on total output of flowers, fruits and seeds, high reproductive fitness is observed. Problems do occur during the post zygotic phases where in propagules fail to establish in to seedlings. In seed plants, post emergent reproductive success represents the stages in the life cycle from seed germination to reproductive nodule and fertilization (Wiens *et al.*, 1987) Further, a high level of pollen sterility could lead to genetic bottleneck. The process of gamete development, pollination, endosperm and embryo development and other reproductive features can provide important clues regarding the reproductive constraints of plants that need conservation (Moza and Bhatnagar 2007).

Field and excutive staff dealing with the above said aspects were trained during the year 2011-2013 and recently during 2017, in the Andaman and Nicobar Islands through extension programs.

4

PHENOLOGY, POLLINATION AND BREEDING SYSTEMS

4 PHENOLOGY, POLLINATION AND BREEDING SYSTEMS IN MANGROVES

Mangrove vegetations constitute approximately eighty species belonging to twenty families (Duke, 1992). The better known taxa are the members of Rhizophoraceae namely *Rhizophora, Bruguiera, Ceriops* and *Kandelia*. These are listed under various IUCN threat categories that require conservation programs (Rao *et al.*, 1994). Among tropical ecosystems mangroves remain poorly understood in terms of life history traits (Tomlinson *et al.*, 1979). Quantifying levels of reproduction is a prerequisite to effective genetic resource management (Congdon and Herbohn 1993, Aronson *et al.*, 1994). As mangroves propagate only through sexual reproduction their maintenance and recovery depends on propagule production, dispersal and establishment (Tomlinson, 1986).

Although habitat fragmentation and over exploitation are the more apparent casual factors, failure of reproductive processes to cope with environmental changes could also be the fundamental reason for species loss (Moza and Bhatnagar, 2007). In the recent past only a few studies have been conducted on reproduction of mangroves (Duke, 1990, Clarke and Myerscough 1991, Sun *et al.*, 1998, Drexler 2001, Coupland *et al.*, 2005, Coupland *et al.*, 2006, Raju *et al.*, 2006).

In this chapter, we have attempt in quantifying the following aspects in natural populations of *Rhizophora apiculata, R. mucronata Bruguiera cylindrica* and *Ceriops decandra*:

- Phenology
- Floral Biology
- Pollination biology
- Reproductive success

MATERIALS AND METHODS

Study site

The Study site, Pitchavaram is located between the Vellar River in north, Coleroon River in the south and Uppanar in the west (Chidambaram 2005) (Table 1). The part near the Coleroon estuary is pre-dominated with mangrove vegetation, while the northern part near the Vellar estuary is dominated by mud flats. The tides are semi-diurnal and varying in amplitude from about 15 to 100 cm in different regions during different seasons, reaching a maximum during monsoon and post monsoon and a minimum in summer (Kathiresan 2002). The rise and fall of the tidal waters is through a direct connection with the sea at the Chinnavaikkal mouth and also through the two adjacent estuaries and the depth in water channels range from about 0.3 to 3 m (Kathirasen 2002).

Target species

The species *Rhizophora mucronata, R. apiculata, Bruguiera cylindrica* and *Ceriops decandra* belong to the family Rhizophoraceae. These are referred to as true mangrove species and are viviparous in nature.

Phenology

Studies were carried out in forty individuals in each of the said species in different islets. Ten branches in each of the plants were tagged for observing bud initiation, flower production and fruit set.

Floral Biology

Time and duration of anthesis, flower life and pollen output was quantified according to methods described by Dafni (1992). Flower from the period of opening to drying up of the stigma tip was recorded.

Pollen fertility

Pollen was collected from different flower positions for testing fertility using differential staining method (Alexander 1969). Pollens were smeared with a drop of stain and left undisturbed over night. Pollen with pink stained cytoplasm will be scored as viable while those with green stained cytoplasm will be treated as aborted. Standard procedures were used to analyze pollen grains morphology. (Radford *et al.,* 1974)

Pollen Ovule ratio

P/O ratio = Number of pollen grains in a flower/ Number of ovules in a flower was calculated using procedures developed by Cruden (1977).

Plant pollinator interaction

Pollinator behaviour in plants and their effectiveness in pollination were studied according to standard procedures described by Dafni (1992).

Reproductive success

Pre-emergent Reproductive Success (PERS) was derived from fruit to flower ratio and seed to ovule ratio using the following formula (Wiens *et al.*, 1987)

PERS = Fruit/flower ratio X Seed/ovule ratio

RESULTS

Phenology

Among the four species *B. cylindrica* was the earliest to flower and fastest to mature fruits within a period of 12 weeks. *C. decandra* flowered one month latter to *B. cylindrica* which was followed by Rhizophoras (Table 2).

Inflorescence architecture and Flowering behaviour

Inflorescences are cymes borne opposite in axils of the second and third immediate nodes proximal to Cymes bear 2 flowers in *R. apiculata*, 3 flowers in *B. cylindrica*, 4 flowers in *C. decandra* and *R. mucronata*. A reproductive shoot contains 12-18 flowers in *B. cylindrica*, 16-24 flowers in *C. decandra* and 12–16 flowers in case of *R.*

apiculata and *R. mucronata*. Flowers within an inflorescence or in a reproductive shoot do not bloom simultaneously.

Floral biology

Flowers were in shades of white, not showy and not found adapted to any kind of specialist pollinator syndrome. They are bisexual, protandrous and produce enormous amounts of pollen (Table 2). *B. cylindrica* had the least duration of flower life (3-4 days), followed by *C. decandra* (6-8 days) and *Rhizhophora* (8-10 days). The dichogamous are strongly protandrous with pollen dispatches for about a day in Bruguiera and for more than 2 -3 days in Ceriops. In Rhizophora pollen is dispatched over 3-4 days as anthers open continuously. The stigma is receptive on the second day in *Bruguiera*, day three in *Ceriops* and beyond 4 days in Rhizophora. Well hydrated stigmas within completely dehydrate anther mass is common sight among Rhizophoraceae taxa.

Pollen biology

Flowers produced plenty of pollen also the pollen to ovule ratio was also very high among species (Table 2). Pollen fertility varied considerably among species (Table 2). Infertile pollen was smaller in size as well.

Plant Pollinators

In *B. cylindrica* large numbers of thrips were found within flowers. Seldom visits by wasps and solitary bees were also recorded. In case of *C. decandra* there pollen vector started visiting 08.00 – 18.00 hours. Wild solitary bees were the major visitor group. No social bees could be recorded. Occasionally large pollinators like *Xylocopa* were also recorded. Forage timing of bees varied from 3-5 seconds.

Vivipary and seedling development

Development of viviparous seedling followed immediately after fruit set in *Bruguiera* and *Rhizhophora*. However, in *C. decandra* after a dormancy period of 16-18 weeks fruits started maturing in to propagules.

Reproductive success

Flower to fruit ratio varied among species, in terms of reproductive success *B. cylindrica* showed the highest and the lowest was of *R. apiculata* (Table 3).

Discussion

In the past studies on mangrove reproductive phenology have indicated latitudinal effect on flowering (Duke 1990a and 1990b). Pitchavaram mangroves are among the southern most latitudes in India, Rajendran and Sanjeevi (2004) have recorded that flowering phenology in Pitchavaram is highly seasonal and unique from rest of the mangrove locations in the country.

Clarke and Myerscough (1991) found reproductive events in mangroves were relatively synchronous among trees at particular latitude and this was constant among years. However, the reproductive status of individual trees highly varied between years. Individual trees and clusters did switch synchronously from reproductive to a non -reproductive state across years. A similar phenological trend was observed in the present study. Such patchy flowering may promote out breeding or simply reflect change in sediment resources availability (Clarke and Myerscough 1991). It was observed that in Pitchavaram every species had its own reproductive niche. Such distinct reproductive behaviour among species within an ecosystem reduces competition in sharing pollinators, nutrients and substrate for propagules to establish.

Inflorescence architecture is unique in Rhizophoraceae; they are borne sub-terminally wherein reproductive shoots develop only in the second and third nodes immediate to the meristamatic tips of vegetative branches. There is a clear spatial and temporal separation of sexual phases within and among flowers in an inflorescence. Even though the Rhizophoraceae taxa investigated in this study reveal entomophily, characteristics such as production of small sized pollen in large quantities and high pollen to ovule ratio reflect anemophilous breeding system.

The pollen fertility observed in *Bruguiera, Ceriops* and *Rhizophora* is comparatively lower to the values reported in other out breeding woody perennials (Nagarajan *et al.*, 1998, Nagarajan *et al.*, 2006). This could be due to the possibilities of inbreeding depression. In terms of pollinators all the three species showed different group of insect visitors. *Bruguiera cylindrica* flowers were pollinated by thrips while *Ceriops decandra* was visited by diverse taxa of insect visitors belonging to *Hymenoptera* and *Lepidoptera*. In the case of *Rhizophora* even though occasional bee and wasp visits were noted their pollination accomplishment remains unclear.

It is interesting to note that despite having multiple ovule system (4-6) only one ovule succeeds in developing in to a propagule. Allen and Duke (2006) noted that *B. gymnorhiza* had very long reproductive maturation period of 1-2 years from flower emergence to dispersal of mature hypocotyls. In this study it was found that propagules in *Rhizhophora* mature over a period of 8-10 months to develop on mother plants, whereas in *B. cylindrica* and *C. decandra* it was 3-6 months.

In *Ceriops decandra* after fruit set they remain dormant for the next 3-4 months. A similar reproductive behaviour was reported in *Ceriops australis* (Coupland *et al.*, 2006). However, Raju *et al.*, (2006) reported that in *C. decandra* populations found in Coringa, India develop propagules immediately after fruit set.

Diverse floral features, high pollen out put, very high pollen to ovule ratio and low reproductive success noticed in *Bruguiera, Ceriops* and *Rhizophora* places them amongst highly out crossing woody perennials. Based on entomphilous adaptations and moderate reproductive success it can be well inferred that *C. decandra* propagules are outcrossed products. On the contrary, *B. cylindrica* pollinated by thrips, an intra floral pollinator could promote geitonogamy. In *Rhizophora* no conclusive evidences could be drawn. In human assisted regeneration programs of Pitchavaram it is recommended that *B. cylindrica* propagules should not be sampled from a few individuals as it could bias towards selecting genetically related individuals. Instead if sampling is done from various clusters in different Islets genetically diverse material can be obtained. In case of *C. decandra* one or more individuals within a cluster can be sampled for plantation purposes. At this stage it can be only inferred that this could be due to bi-parental inbreeding or perhaps due to short distance travel by the propagules. However, recent studies on genetic markers contrarily indicate high levels of genetic relatedness within and among populations of *Ceriops* (Sun *et al.*, 1998). Further studies are required on these lines.

Table1. Details of the study site

Name of the location	Pitchavaram, Tamil Nadu, India
Geographical position	11º 24'N, 79º 47'E
Total mangrove area	1,100 ha.
Annual mean range temperature	20°C - 37°C
Vegetation type	Estuarine Mangrove
Floral composition	*Rhizophora apiculata, R. mucronata, Bruguiera cylindrica, Ceriops decandra, Sonneratia apetala, Avicennia marina, A. officinalis, Aegiceras corniculatum, Suaeda maritime, S.nudiflora, Arthrocnemum*

Table 2. Phenology and floral biology characteristics in the four Rhizophoraceae taxa

	B. cylindrica	*C. decandra*	*R. mucronata*	*R. apiculata*
Flowering period	March-April	April-May	October-December	September-November
Flower type	Entomophilous	Entomophilous	Anemophilous(?)	Anemophilous(?)
Colour	White	White	White	White
Symmetry	Actinomorphic	Zygomorphic	Actinomorphic	Actinomorphic
Odour	Present	Mild	Present	Absent
Nectar	Present	Present	Absent	Absent
Anthers/ Flower	16	10	8	8
Pollens/Anther	1690	24,000	50,000	NA
Ovules/ flower	4 -6	6	4	4
Pollen size (µm)	14 - 16	18-20	16-22	16-28
Pollen fertility	80%	65%	81%	79%
Pollen type	Spherical, smooth walled, tricolpate	Spherical, smooth walled, tricolpate	Spherical, smooth walled, tricolpate	Spherical, smooth walled, tricolpate
Stigma type	Wet, Bifid	Wet, Bifid	Bifid	Bifid
Pollen/ovule ratio	1:6750	1:40, 000	1:1,00,000	NA

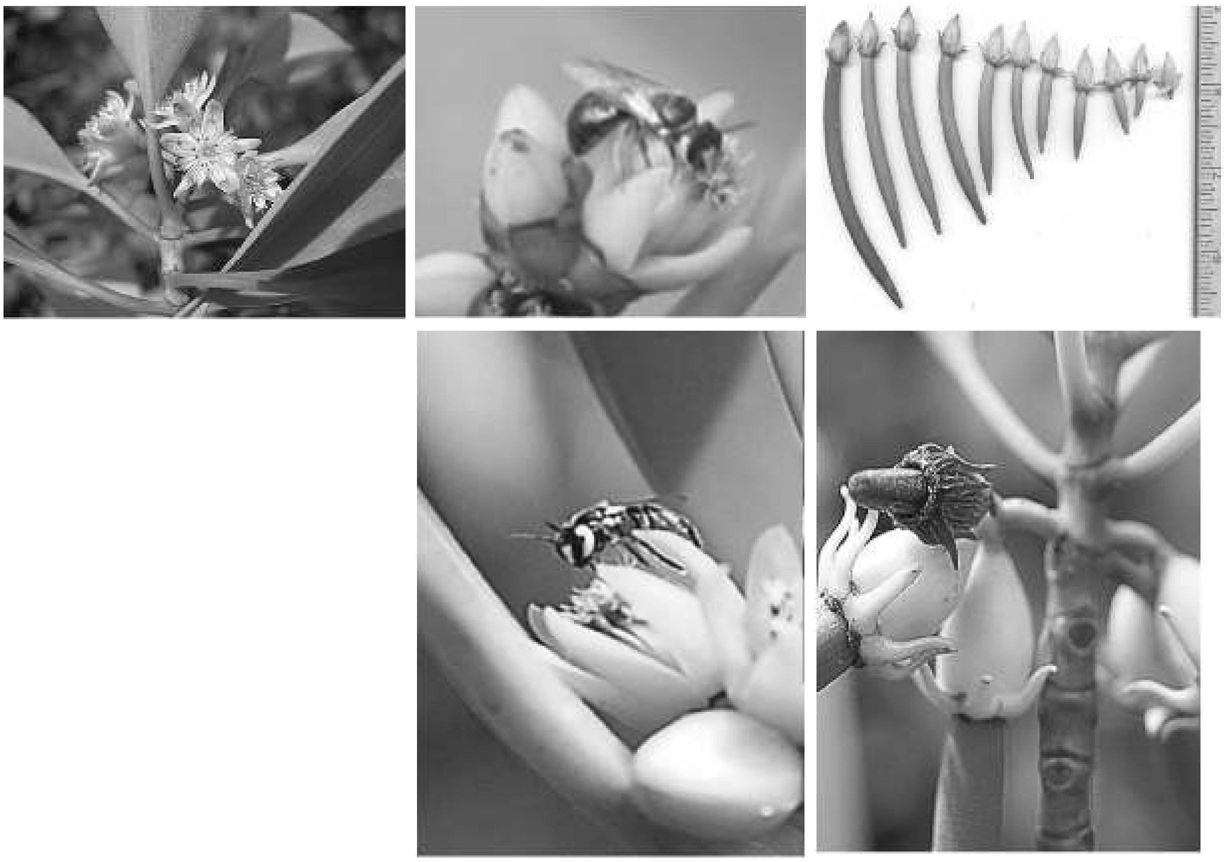
Table 3. Reproductive Success in different Rhizophoraceae taxa found in Pitchavaram mangroves

Species	Flower/fruit ratio	Seed / ovule ratio	PERS*
B. cylindrica	0.30	0.25	0.07
C. decandra	0.16	0.16	0.025
R. apiculata	0.25	0.25	0.06
R. mucronata	0.12	0.25	0.03

* - Based on Wiens *et.al.*, (1984)

5

GENETICS, POPULATION STRUCTURE AND BIOTECHNOLOGICAL INTERVENTIONS



5 GENETICS, POPULATION STRUCTURE AND MANAGEMENT

Variations in reproductive patterns in space and time have considerable influence in determining population structure (Loveless and Hamrick, 1984). In case of true mangroves it could be stated the ecological determinants for the low genetic diversity are:

- Breeding system promotes geitonogamy (related selfing),
- low pollen and seed travelling distance promotes tendency to develop family structure.

In the past, studies on gene diversity in mangroves have indicated low levels of intra population and inter-population variations (Parida *et al.*, 1995, Lakshmi *et al.*, 1997, Parani *et al.*, 1997, Parani *et al.*, 1998 Lakshmi *et al.*, 2001). Such a trend of high relatedness between geographically distant populations indicates the low levels of diversity in the founder populations of Mangroves (Jana and Deshmukh, 1994). It is very important to identify the visually observed diversity at the field level disembarking in to molecular approaches (Jana and Deshmukh, 1994) that could be deployed for conservation programs.

Restoration and Mangrove afforestation need be managed genetically so that adequate variation is ensured for the existing and the emerging populations.

It is well known that the 2004 *Tsunami*, implicated the life history traits of the coastal flora and fauna. Currently, it appears the coastal biome is restored to its equilibrium in terms of reproduction and regeneration. It would be highly desirable at this stage to acquaint knowledge both on the physical and genetic size of critical ecosystems like mangroves within our country. It would be also prudent to deploy recent biotechnological tools such as functional genotypes (Haplotypes) in assessing mangrove genetic resources.

Genetic diversity and population structures are very important for understanding the evolutionary history, breeding systems, geographical distributions and ecological requirements of species. In evolutionary studies, molecular markers that differentiate close species and their putative hybrids greatly increase our understanding of the genetic basis of speciation and the effects of introgression on species integrity.

Microsatellites are the most popular and versatile genetic marker which is codominant in nature and highly polymorphic with multitude of applications in population genetics, conservation biology, and evolutionary biology. These are the arrays of DNA sequences, consisting of tandemly repeating mono-, di-, tri-, and tetranucleotide units, which are distributed throughout the genomes.

HYBRID IDENTIFICATION OF MANGROVES THROUGH MICROSATELLITE MARKERS

Recently, during 2018-19, a study has been initiated by ICFRE on mangroves for comprehending genetic and adaptive variations in Rhizhophora species. Mcrosatellite primers were designed to comprehend the Rhizhophora hybrid complex. The species *Rhizhophora apiculata*, *R. mucronata* and hybrids (*Rhizhophora annamalaiana*) were discriminated by the amplification of SSR primers.

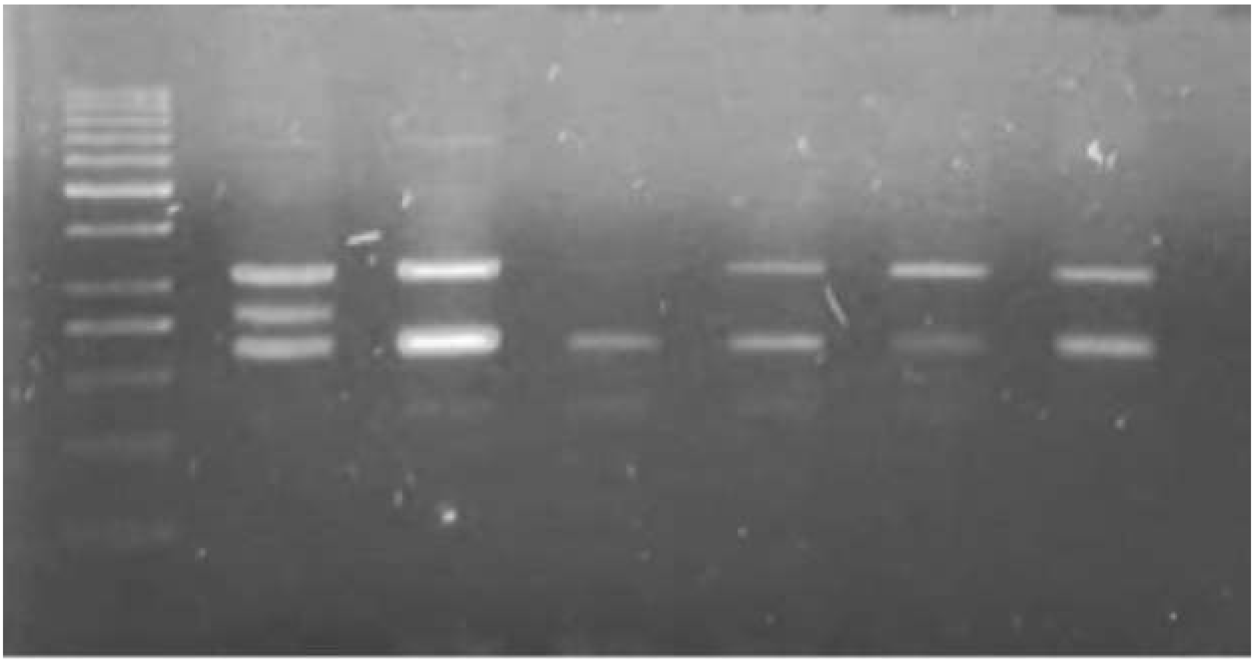


Fig SSR amplification in Mangroves Lane 1 0bp ladder, Lanes 2,3- *R. mucronata,* Lanes 4,5- hybrids & lanes 6 & 7 *R. apiculata*

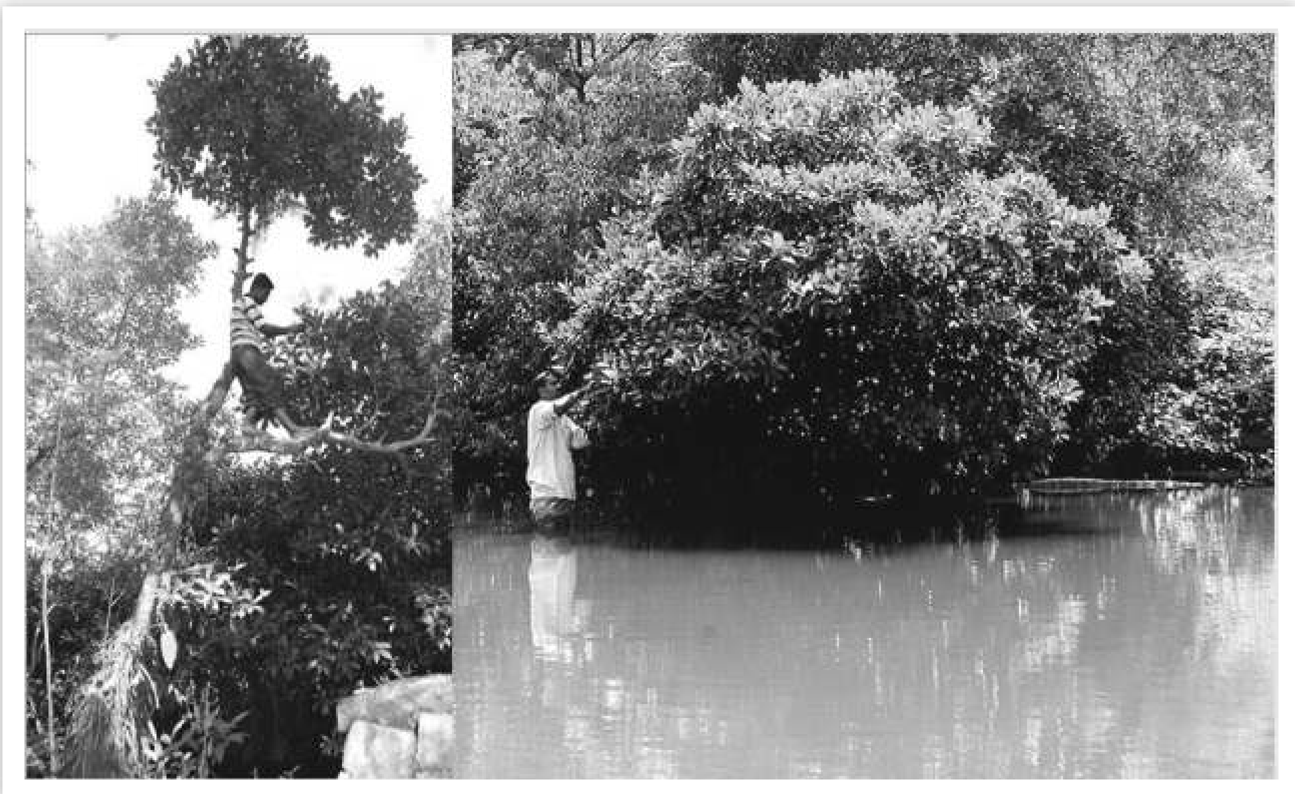
Globally, in the post tsunami it has been realized that the *Rhizhophora* complex is versatile resource in terms of accomplishing successful afforestation targets. The initial survival and establishment and the growth rate also is highly appreciable. The taxon *R. mucronata* appears to be much salt resilient compared to the other genetic resources. Further, It is also observed that *Rhizhophora* hybrids are much superior in terms of growth, resilience to hyper salinity and establishment compared to parental species *R. mucronata* and *R. apiculata*. Till date the superiority in biomass production in hybrids over parental species and their proportion is yet to be comprehended and quantified. This study could be a vital link to learn blue carbon sink and mitigation studies in future.

If *Rhizophora X hybrid* putative selections are confirmed with Haplotype specificity, region wise propagation populations with greater vigour and productivity could be short listed. Thus, annual afforestation targets concerning blue carbon fixation/mitigation could be dealt positively.

This approach will support systematic *in situ* conservation of the species. In future, *inlieu* to the current practice of deploying planting stocks on the basis of physical size could be replaced with genetic size.

6

SPECIES RECOVERY



6 SPECIES RECOVERY STUDIES IN MANGROVES

Globally extinction threats to tree species that are adapted to a particular pollination syndrome are notably higher. *Hortus Malabaricus* (= Green Garden of Malabar) by *Hendrick Van Rheede* a flora comprehending the West Coast written in the 16th century describes *Bruguiera sexangula* Poir. as a common taxon in its time. However, subsequent floristic surveys could not locate the species and the taxon was assumed 'locally extinct'. The team led by University of Calicut rediscovered the species in 2004. About twenty four individuals were located at the Panangad and Kumbalangi panchayaths in the Ernakulam District, Kerala. The rediscovery was published and the herbaria were deposited at the Calicut Herbarium between 2002- 2005.

It is conflicting to observe that disappearance of forests in tropics comes at a time when our knowledge on their reproduction, structure and dynamics is woefully inadequate (Hubbel and Foster 1992; Owens, 1993). Precise information on reproductive patterns in tropical ecosystems is scarce and their determining factors are still debated (Borchert 1983; De Bie *et al.*, 1998). Quantitative data on phenology, floral characteristics and pollination are important in understanding breeding systems (Gitiru *et al.*, 2002). Understanding reproductive processes is a prerequisite for genetic amelioration, conservation and rational management of genetic resources (Congdon and Herbohn, 1993; Aronson *et al.*, 1994).

B. sexangula a typical ornithophilous species in which pollinator limitation could be documented became an obvious choice for conducting species recovery studies. Field observations indicated that *B. sexangula*, was pollinated by sunbirds (*Leptocoma zeylonica* and *N. asiatica*) and they face severe pollen limitation (Krishnamoorthy *et al.*, 2009). In the East coasts, mangroves are protected by forest agencies while in the West Coast of India most are of private ownership. Kerala has a coastline of about 550 km with a stretch of backwaters and series of lagoons running parallel to the sea. Mangroves cover about 17 km^2 in the entire backwater system. The mangroves in Kerala are highly localized with high species richness when compared to other locations of our country (Chand Basha, 1992). Ramachandran *et al.*, (1986) observed that the mangroves of Kerala were degraded and grew in isolated patches. Chand Basha (1992) and Mohanan (1999) estimated it to be *"less than 50 km^2"* and listed a total of 32 mangrove species. Although habitat fragmentation and over exploitation are the more apparent casual factors, failure of reproductive processes to cope with environmental changes could also be the fundamental reason for species loss (Moza and Bhatnagar, 2007). In the recent past, only a few studies have been conducted on reproduction of mangroves (Duke, 1990, Clarke and Myerscough 1991; Sun *et al.*, 1998; Drexler 2001; Coupland *et al.*, 2005; Coupland *et al.*, 2006; Raju *et al.*, 2006).

Through reconnaissance survey about twenty five *B. sexangula* individuals were recorded in the panchayats of Kumbalam and Kumbalangi within the Ernakulam region. An attempt was made understand reproductive constraints if any and also to possible conduct species recovery by combining conventional tree breeding and biotechnological tools so that the species could be reintroduced in to its type habitat.

Target Organism

Bruguiera sexangula (Lour.) Poir. the study organism is a critically endangered taxon in India. IUCN places the taxon as vulnerable (B1, 2c, 2d). Within our Nation, it is distributed in Bhitrakanika (Odisha), Andaman group of Islands and Ernakulam in the West Coast of India. It is a diploid species with a chromosome number of 2n = 34. The fragmented populations of *B. sexangula* from Panangad and Kumbalangi were used as the genetic resource bases. Both locations are highly urbanized and most mangroves are under private ownership. At present there are twenty individuals in each of the locations. All individuals were mapped and documented using a handheld Geographical Positioning System (GARMIN Version-3.2).

Controlled pollination

Controlled pollination was carried out in five individuals across two locations. Depending on the receptivity 20-50 flowers were operated per day. All flowers were double dusted. Operated flowers were caged in paper bags (in size of 12x7 cm) and were tagged properly. Bags were removed on the third day and fruit set was recorded.


Fig 6.1. Performing controlled pollination

Genetic diversity studies

Seven individuals from each of the two populations were quantified for diversity studies using ISSR primers. About twenty different primer sequences were used. Gels were visualized using standard procedures and variations were recorded.

Plant Pollinator Interaction

B. sexangula is pollinated exclusively by sunbirds. In the present study we observed two species namely *Leptocoma zeylonica* (Purple Rumped Sunbird) and *Nectarinia asiatica* (Purple Sunbird). The birds usually forage in pairs. The bird visits are random in time and performed throughout the day sunrise (07.15-07.20) to set (17.15-17.30). In a given day the number of pollinator visit did not exceed 12 ± 3 visits in the case of *L. zeylonica* while with *N. asiatica* it was as minimal as 2 ± 1 in a given day. In certain days nil visits were also recorded. During the male phase pollen is dispatched as and when pollinators arrive in. Mechanical contact with the anther induces a trigger operation and pollen gets deposited a powdery clumps on the chest and heads of the pollinator. When the pollinator contacts the upper part of the perianth a tangential force is extended that splits the anther ventrally in the middle and top. The male phase of the flower extends 10-12 days during which pollen is liberated constantly. The species has a deep calyx cup that is filled with nectar

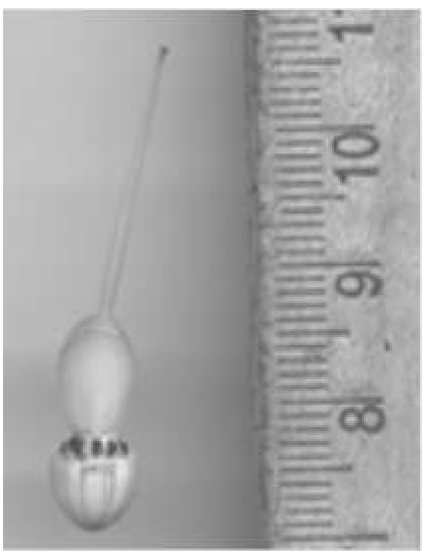


Fig 6.2. Only one embryo gets fertilized rest abort (see: shriveled black colored embryos in the bottom)

constantly (25-40µl). During the female phase the perianth withers off and nectar secretion continues. The chance of geitonogamy is extremely remote. As a rule in Rhizhophoraceae only one of the ovules develops in to a seedling.

Controlled Pollination

Pollen pistil interaction studies indicated very low pollen loading in the open pollinated flowers. Despite the flowers having a long life over twenty days and the female phase alone for nearly 15 days did not provide the desirable results. In both the fragments sunbird visits varied across the days. However, controlled pollination using cross pollen showed very high fruit set compared to self pollen and open pollination (Table 4). This is indicative that the species suffers even minimal visit of pollinator across days. This could be due to anthropogenic interference by means of urbanization. Studies also indicate that since the seed to ovule ratio is fixed in the plant breeding system it might not be possible to exponentially increase the same. The high PERS values of 0.043 – 0.05 obtained under self pollination indicates that in a given season all propagules could be selfed products. However, since the PERS is exponentially high up to 0.14 with cross pollen it would be highly desirable to conduct crossing between spatially distant individuals.

Table 4. Flower/Fruit ratio and Seed/Ovule ration and PERS observed in five mother trees of Kumbalangi and Puduvyppu under open and controlled pollination methods.

Mother trees	Pollination method	Flower/fruit ratio	Seed/ovule ratio	PERS*
K/MT-1	Open Pollination	0.01	0.16	0.001
	Cross pollination	0.90	0.16	0.144
	Self Pollination	0.27	0.16	0.043
K/MT-2	Open pollination	0.01	0.16	0.001
	Cross pollination	0.78	0.16	0.124
	Self pollination	0.32	0.16	0.051
K/MT-3**	Open Pollination	0.00	0.00	0.00
	Cross Pollination	0.00	0.00	0.00
P/MT-1	Open Pollination	0.02	0.16	0.004
	Cross Pollination	0.88	0.16	0.140
	Self Pollination	0.27	0.16	0.043
P/MT-2	Open Pollination	0.02	0.16	0.003

(PERS; Pre Emergent Reproductive Success – Values in accordance to Wiens et al., 1987;
** - The individual is has a continuous inundated habit flowering noticed but fails to set propagules)

It was also noted while flowering was influenced owing to land compacting in the case of the mother tree P/MT-2 severe inundation was also equally a problem. The said individual flowered copiously in the years 2010 and 2011. However, efforts on controlled pollination led to nil setting. This is indicative that reproductive success could be influenced at pre zygotic stages also. At this stage it is inferred that selecting mother trees that are under highly land compacted and inundated conditions do not fail to flower. However, they fail to support seedling growth or vivipary. This could be an adaptation or a life history trait in itself that needs to be comprehended in future studies.

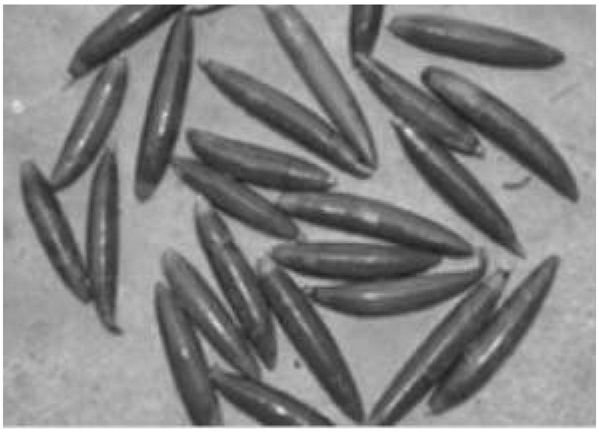


Fig 6.3. Control Pollinated Propagules

Fig 6.4. Viviparous propagules grown in nursery

Harvested propagules were maintained in the nursery at IFGTB for a period of 140 days and then were transferred to field. Under natural conditions mangrove seedlings are highly preferred by crustaceans for their herbivorous requirements. Thus seedlings those have gained over 8mm in collar girth were transferred. Seedlings grown over 1.2 feet showed very good after transplantation performance. Planting was carried out from Mid March to late April. Initial survival of over 90% was recorded.

Fig 6.5. Successfully established seedlings after six months of planting in Ernakulam

GENETIC VARIATION

The genome was tested with a set of 30 primers that are known to be polymorphic in mangrove taxa. However, in the present study only 39 ISSR products were traceable of which 18 were polymorphic. Based on a preliminary analysis it was found that variations were higher within the populations compared to between the populations. No population specific products could be traced among the seven individuals sampled in each of the population. Hence, based on spatial mapping control pollination studies were initiated. The low levels of genetic variations noticed between the populations could be owing to common co-ancestry.

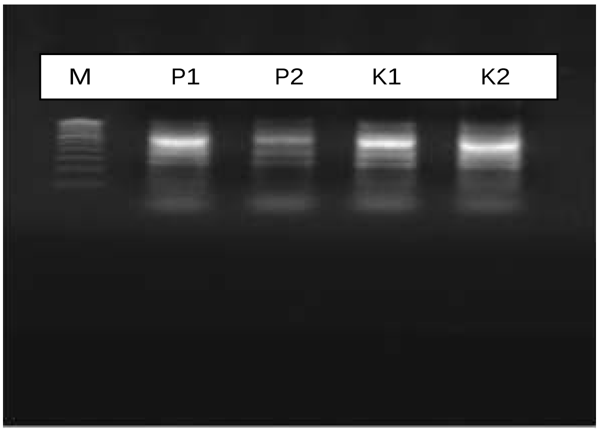


Fig 6.6. Gel photograph depicting high genetic relatedness among and within individuals belonging to the Panangad & Kumbalangi Populations chosen for controlled pollination.

Fig 6.7. Controlled Pollination work in *B. sexangula*

Table. List of ISSR primers and their details used for characterising B.sexangula populations

S.No.	Primer	Primer Sequence (5'-3')
1	UBC 807	AGAGACAGAGACAGAGT
2	UBC 808	AGAGACAGAGACAGAGT
3	UBC 810	GAGAGAGAGAGAGAGAT
4	UBC 816	CACACACACACACACAT
5	UBC 825	ACACACACACACACACT

SPECIES RECOVERY

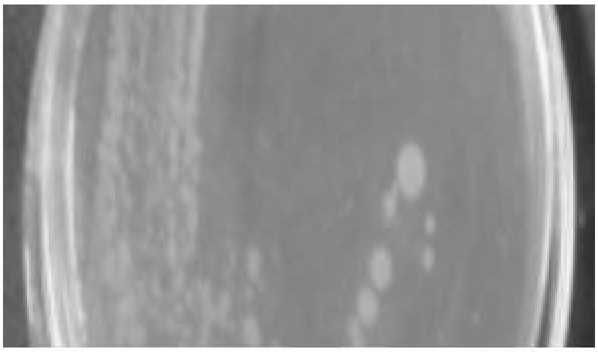
B. sexangula is an obligatorily ornithophilous taxa pollinated by *Nectarinia zeylonica* and *N. Asiatica.* With increasing sea levels ornithophilous mangroves like *B. sexangula* that grow colonize landward deserves our focus as their survival and regeneration is completely dependent on sunbirds. The pollen fertility observed in *B. sexangula* is comparable to the values reported in other out breeding woody perennials reported elsewhere (Nagarajan *et al.*,1998, Nagarajan *et al.*, 2006). Generally, in Rhizhophoraceae only one ovule develops in to seedling among six or four ovules this may due to inadequate fertilization, expression of lethal alleles in fertilized embryos, competition among sibling embryos and preferential maternal investment (Fennar and Thompson, 2005).

Studies on genetic diversity estimates conducted in different parts of the world often contradict. This could be largely owing to the sampling methods deployed by individual researchers and teams. In the case of *B. sexangula* the differences between the two local populations namely Kumbalangi and Panangad are very low. This could be owing to their origins being traced to highly related progenitor population. However, there is adequate variation within population and hence this can be used to continue controlled pollination. A major reproductive bottleneck noted was poor visitation of sunbirds (8 ± 3visits/day/tree). In peak flowering seasons 97% of senesced flowers showed no pollen deposition. Using DNA assay high level of genetic relatedness between and within the populations was confirmed. Studies on breeding behavior indicated that the species was adapted to mixed-mating. Control pollination resulted in 90% of fruit set. The propagules were allowed to mature for 160-180 days on trees and then were harvested and raised in nursery. Seedlings over one feet were reintroduced in to mangrove patches or developed as linear rows. About 400 individuals were successfully reintroduced until May, 2013. Over 90% of control pollinated propagules planted during July, 2012 have grown over 1 meter in height. In future, it seems control pollination and DNA marker diversity estimation could be effective synergistic tools in restoring RET mangroves that are constrained by genetic bottle neck.

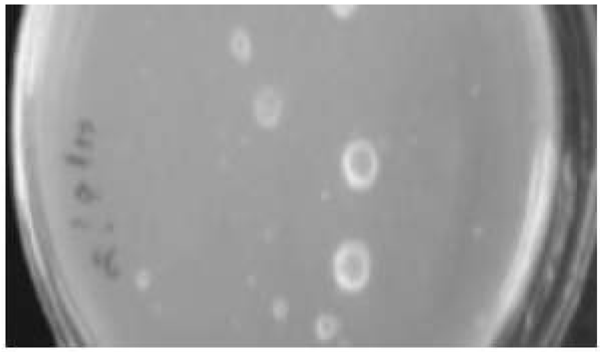
Fig 6.8. Planting of Control Pollinated Propagules

7

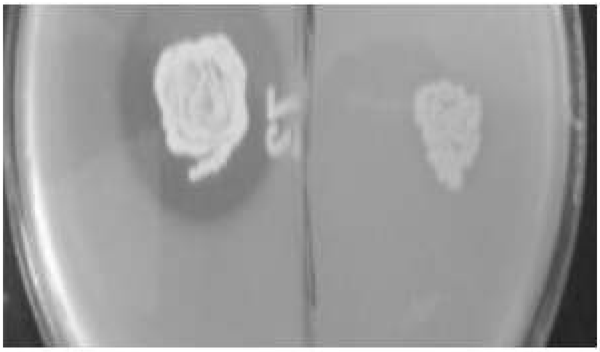
IMPROVING MANGROVE PLANTING STOCK



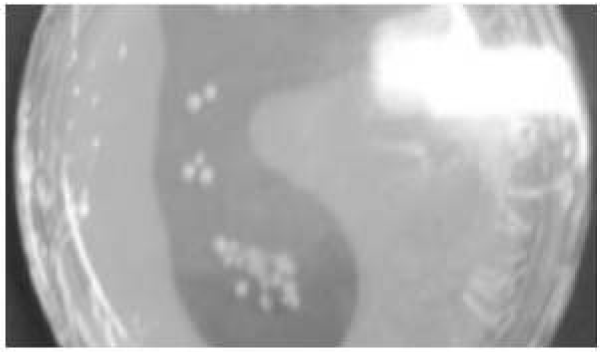
Azospirillum brasilense



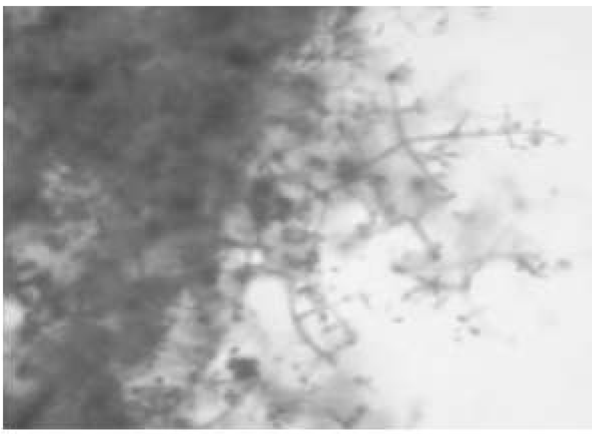
Azotobacter chrococcum



Bacillus megaterium

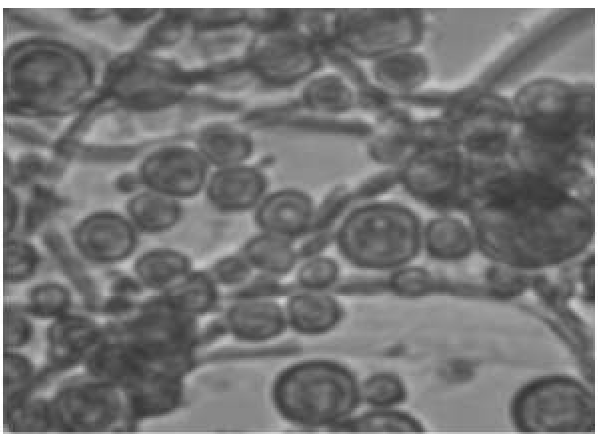


Fraturia aurantia

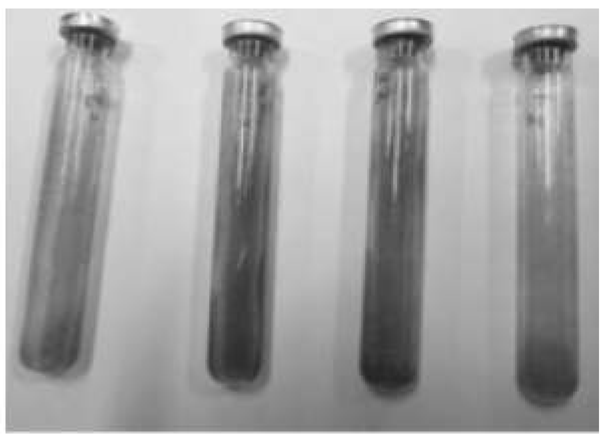


Trichoderma viride

Scutelopora calospora



Chlorococcum infusiforum



Methanogens

7 IMPROVING MANGROVE PLANTING STOCK

INTRODUCTION

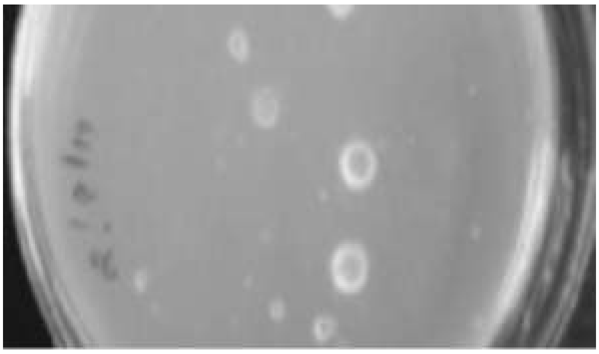
Mangroves are complex and dynamic ecosystems varying in salinity, water level and nutrient availability; they also contain diverse and distinct microbial communities by providing a unique ecological niche to different microbes which play various roles in nutrients recycling as well as various environmental activities Microbes play a key role in maintaining the productivity of mangroves in fact they also constitute the largest pool of metabolic pathways on Earth with potential biotechnological and environmental implications and also mangroves serve as an important part of estuarine food webs, producing large amounts of leaf litter which are quickly decomposed by microbes such as bacteria and fungi. Various groups of Bacteria like Nitrogen fixers, Phosphate and potassium solubilizers are prevalent in mangrove ecosystem out of which algae play a vital role in mangrove community food webs. Algal communities are unique to certain mangrove habitats and an understanding of their abundance may indicate the health of mangrove ecosystems. In buried marine sediments of mangroves the methanogens took part and play a vital role in methanogenesis. Archaea, representing third domain of life known to be dominated by mainly methanogens are the important methane source as where inhabit in extreme conditions like anaerobic zone of mangroves in which they contribute and maintain the biogeo chemical cycles. However, the benefits of microorganisms (in particular those associated with roots) to the productivity of mangroves and the roles they play in plant fitness, survival and overall ecosystem resilience have been not studied. Unveiling the diversity and structure of microbial communities in mangrove environments represents the first step towards a better understanding of their role in ecosystem functioning.

MICROFLORA IN MANGROVES

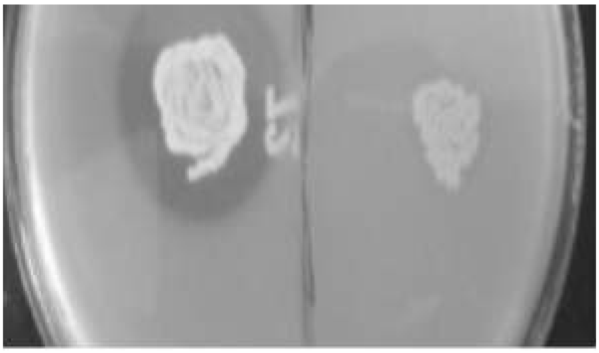
The microflora normally occurred in the rhizosphrere are bacteria, fungi, algae and rhizosphere microflora in *Bruguiera sexangula* and *Bruguiera cylindrical* at Panangadu and Kumbalangi, Kerala. The Methanogens Institute of Forest Genetics and Tree Breeding, Coimbatore studied the following microflora were isolated and recorded.

S. No.	Name of the Beneficial Microbes	Category
1	*Azotobacter chrococcum*	Nitrogen fixers
2	*Azospirillum brasiliense*	
3	*Bacillus megaterium*	Phosphate Solublizers
4	*Frateuria aurantia*	Potassium Mobilizers
5	*Trichoderma viride*	Fungi
6	*Microcystis auroginosa*	Algae
7	*Aphano capsa*	
8	*Chlorococcum infusiforum*	
9	*Chlorococcum citriforme*	
10	*Clostridium subterminale*	Metthanogens
11	*Methanogenic archaeon*	
12	*Glomus pustulatum,*	Arbuscular Mycorrhizal fungi
13	*Glomus deserticola*	
14	*Acaulospora foveata*	
15	*Scuatellospora calospora*	

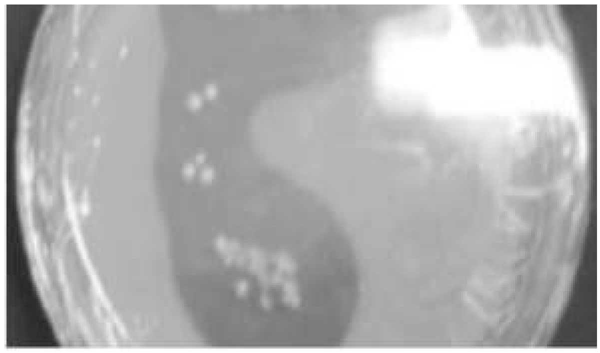
Azospirillum brasilense



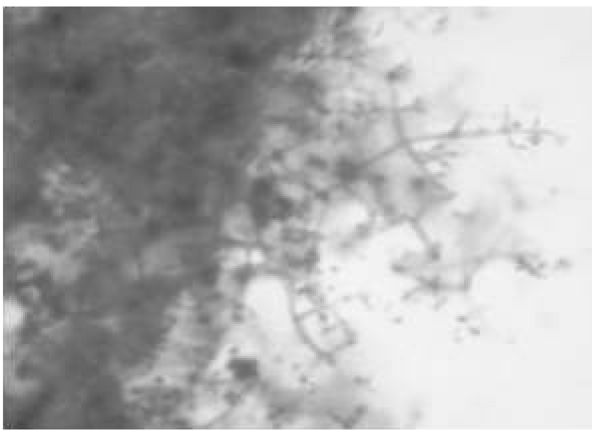
Azotobacter chrococcum



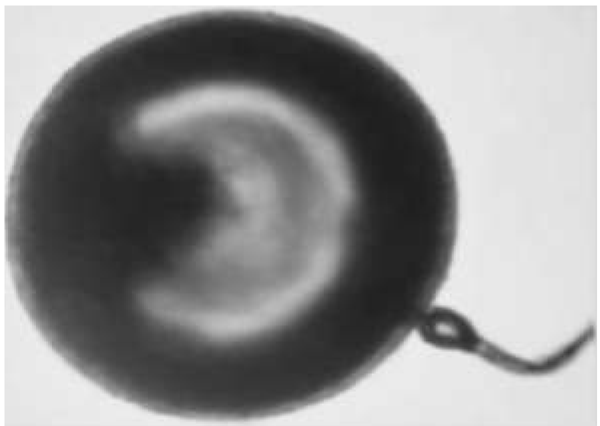
Bacillus megaterium



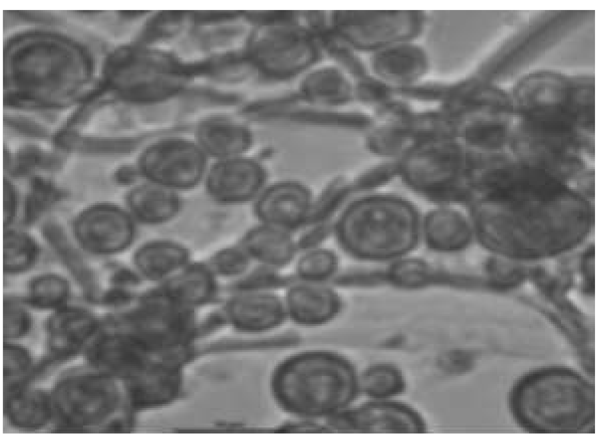
Fraturia aurantia



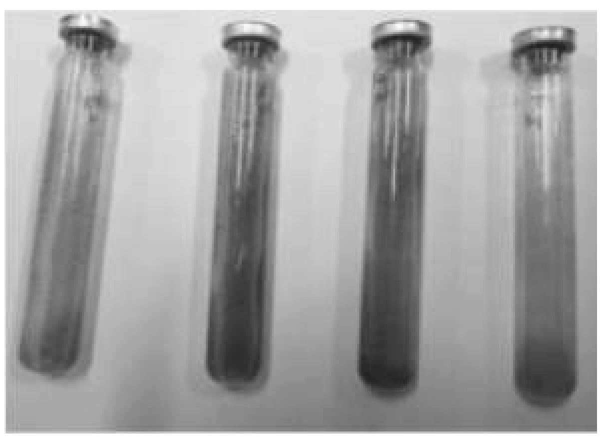
Trichoderma viride



Scutelopora calospora



Chlorococcum infusiforum



Methanogens

The physico – chemical properties of the rhizosphere soils of *B. sexangula* from Panangadu (10.2689200°N 76.166120°E) Kerala were assessed and showed a pH 6.53(±0.08), electrical conductivity 1.3mS (±0.001), Nitrogen 24.9 (±1.3) $mgKg^{-1}$, Phosphorus 20.1(±1.4) $mgKg^{-1}$, Potassium 19.2(±1.2) $mgKg^{-1}$, Bulk density 1.2 (±0.09) g/cc, Organic carbon 0.33 (±0.01)%, Calcium and Magnesium 0.42 (±0.01) and 0.03 (±0.005)Meq/100g, Copper, Zinc and Manganese 0.57(±0.03),0.7(±0.06) and 0.3(±0.06) ppm respectively. The physico – chemical properties of the rhizosphere soils of *B. cylindrica* from Kumbalangi (10.2689200°N 76.166120°E) Kerala were assessed and showed a pH 6.72(±0.015), electrical conductivity 2.13mS (±0.02), Nitrogen 30.7 (±0.36) $mgKg^{-1}$, Phosphorus 24.3(±0.11) $mgKg^{-1}$, and Potassium 20.3(±0.22) $mgKg^{-1}$, Bulk density 1.27 (±0.15) g/cc, Organic carbon 0.88 (±0.02)%, Calcium and Magnesium 0.61 (±0.018) and 0.04 (± 0.003)Meq/100g, Copper, Zinc and Manganese 4.7(±0.73),8.5(±0.14) and 11.1(±0.06) ppm respectively.

INOCULATION OF BENEFICIAL MICROBES IN MANGROVE PROPAGULES

Nursery experiments were carried at Silviculture nursery of Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore (11°01' N - 96°93' E; altitude 410m) with propagules of *B. sexangula* and *B. cylindrica* collected from Panangadu (11°01'06.2" N - 76°57'07.3" E) and Kumbalangi (11°01'06.2" N - 76°57'07.3" E) respectively. The efficiency of growth parameters and nutrient uptake was studied in propagules of *B. sexangula* and *B. cylindrica* inoculated with *Azotobacter chrococcum, Azospirillum brasilense, Bacillus megaterium* and *Frateuria aurantia* isolates of *B.sexangula* and *B.cylindrica*.

PROPAGATION OF MANGROVE PROPAGULES

The collected propagules of *B. Sexangula* and *B.cylindrica* were prior sterilized with 80% ethanol for 2 min followed by 0.1% $HgCl2$ for 10 min. Later the sterilized propagules were washed 10 times in sterile distilled water. This treated uniform length (15cm) propagules of *B. Sexangula* and *B.cylindrica* were placed in polybags (13?25cm) contains sterilized soil + sand (1:1v). The propagules in polybags were maintained in the nursery for 30days under shade house and watered twice per day for development of roots.

BENEFICIAL MICROBES

The beneficial isolated microbes such as *A. chrococcum, A. brasilense, B. megaterium* and *F. aurantia* were mass multiplied in their respective medium for nursery experiments. 12 treatments including control as shown below were replicated at 10 times using 5 propagules per treatment. These treatments were arranged in randomized block design in nursery at 32?c (± 1.2); 74 %(±2.6) RH conditions and watered twice daily. The seedlings of *B. Sexangula* and *B.cylindrica* were harvested with their entire root system intact, 6 months after inoculation of beneficial microbes. The root length, shoot length, collar diameter and number of leaves of treated each seedling were measured.

INOCULATION OF BENEFICIAL MICROBES IN MANGROVE SEEDLINGS

The beneficial microbes inoculated propagules of *B.sexangula* showed significantly improved growth and biomass than control propagules. The combined beneficial microbes *(Azotobacter chrococcum + Azospirillum brasilense + Bacillus megaterium + Frateuria aurantia)* showed significantly improved shoot length , root length, number of leaves and collar diameter than single or dual beneficial microbes inoculated propagules. The dual beneficial microbes *(Azospirillum brasilense + Frateuria aurantia)* inoculated propagules showed significantly improved collar diameter than other dual beneficial microbes inoculated propagules. The number of leaves was also increased significantly

($p < 0.05$) in the dual beneficial microbes inoculated propagules than single beneficial microbes inoculated propagules of *B.sexangula* .

EFFECT OF BENEFICIAL MICROBES IN MANGROVES

Mangrove ecosystem got very much importance for marine fauna and protection of coastal regions from natural disorders. However due to anthropogenic pressures and increased land use for human habitation the mangrove areas are being depleted (Ravishankar and Ramasubramanian, 2004). Degradation of mangroves results in a decline of coastal fisheries in many tropical and subtropical countries (Bashan and Holguin, 2002). To restore the mangrove areas with suitable mangrove plants it is necessary to maintain microbial communities in the mangrove ecosystem that helps to conserve the essential nutrients for mangroves. Microbial communities involved in primary production, decomposition, nutrient recycling and nutrient transformation within the mangrove forest ecosystems (Kathiresan, 2010). In turn mangrove roots fuelling the microbial communities by oxidizing the soils (Sherman *et al.*, 1998). Therefore it was understood that the mangrove propagules to be inoculated with beneficial microbes as a pre requisite for successful establishment in mangrove degraded areas. Earlier research regarding microbial diversity in Indian mangroves especially for nitrogen fixers (*Azotobacter* and *Azospirillum*) and phosphate solubilizers (Kathiresan and Bingham, 2001; Kathiresan and Masilamani, 2005). However, the inoculation of beneficial microbes in to the propagules of the endangered and threatened mangrove *B.sexangula* and *B.cylindrica* was attempted in this study and revealed that the inoculation of beneficial microbes significantly improved the growth and biomass in the propagules of *B.sexangula* and *B.cylindrica*. In this present study the nitrogen fixers, P solubilizers and K mobilizer were isolated and executed for improvement of planted propagules of *B.sexangula* and *B.cylindrica*. Nitrogen fixing beneficial microbes was isolated in previous studies by (Sengupta and Chauduri, 1990; 1991) from the rhizosphere and roots of various mangrove species. Similarly, Phoaphate solubilising microbes were isolated from the rhizosphere of mangroves (Vazquez *et al.*, 2000). These earlier studies confirmed the presence of beneficial microbes in the rhizosphere of *B.sexangula* and *B.cylindrica* was also found in this present study. However the K mobilizing bacteria Frateuria aurantia isolated from the roots of *B. sexangula* is a new finding for this study. These microbes are very important for mangroves as they are capable to increase the uptake of N, P and K from insoluble forms to soluble ones. The inoculated beneficial microbes mobilized the available nutrients to the seedlings of *B. sexangula* and *B.cylindrica* under nursery conditions and helped to increase the uptake of nutrients such as N, P and K (Chen et al., 2008). It was in accord with Toledo *et al.,* (1995) stated that the total N concentration in N fixer inoculated black mangrove seedlings was significantly increased in uninoculated controls. The number of leaves was showed significantly increased in the beneficial microbes' inoculated seedlings of *B.sexangula* and *B. cylindrica*. Rojas *et al.*, (2001) found similar results in black mangrove seedlings. Multiple inoculations promote seedlings growth of *B. sexangula* and *B.cylindrica* rather than single or dual inoculation of beneficial microbes as found in this study. Combined inoculation always promotes the plant growth and biomass in multiple ways of nutrient uptake (Muthukumar *et al.*, 2001). In soil also, the multiple inoculations of beneficial microbes showed increased nutrients due to interaction of beneficial microbes in soil (Rajendran and Devaraj, 2004). It was further confirmed by Karthikeyan and Sivapriya (2018) in the *B. sexangula* seedlings inoculated with the beneficial microbes. It was understood from this study that the beneficial microbes enhanced the growth and nutrient uptake and thereby improved the biomass in *B. sexangula* and *B. cylindrica* propagules. Normally the chemical fertilizers such as Di ammonium phosphate and urea are used for mangroves in nursery (Ravishankar and Ramasubramanian, 2004). This study is providing an alternate technique for successful establishment of mangroves in nursery without chemical fertilizer application. It will be helpful to restore the mangroves with native beneficial microbes in degraded mangrove areas.

8

MANGROVES OF ANDAMAN AND NICOBAR IN THE POST TSUNAMI

8 MANGROVES OF ANDAMAN AND NICOBAR ISLANDS: POST TSUNAMI RECOVERY

INTRODUCTION

Compared to the east and west coasts of mainland India, mangroves of ANI is free from anthropogenic impacts and in terms of diversity, density and growth mangroves of ANI are best in the country (Ragavan *et al.,* 2019). However, sea level rise (Lovelock *et al.* 2015) and increasing natural events (like cylones, earthquake and Tsunamis; Harris *et al.* 2018, Sippo *et al.* 2018) are remains the potential threat for mangroves of ANI. For instance the 2004 earthquake and subsequent *tsunami* drastically affected the mangroves of ANI (Saxena *et al.* 2013). Considering this fact in this text status of mangroves of the ANI is discussed with references to climate change and impact of Tsunami and research gap in mangroves of ANI are highlighted to streamline the future efforts.

CURRENT STATUS

Mangrove cover in ANI is 617 km^2 (FSI 2017) and consists of 38 true mangrove species belonging to 13 families and 19 genera, (Table 1, Ragavan *et al.* 2019). Recent critical review on mangrove floristics (Goutham Bharati *et al.* 2014) and extensive floristic surveys (e.g. Ragavan *et al.* 2019 and Nehru and Balasubramanium 2018) led to an understanding of extended distribution of few extant mangrove species and the discovery of new entities from ANI. Significant findings of these studies are four new records for India (*Sonneratia lanceolata, S. ovata, S.×urama*, and *S.×gulngai*), two new distribution records for the Andaman and Nicobar Islands (*Excoecaria indica* and *Rhizophora×annamalayana*), extended distribution of Rhizophora stylosa, Scyphiphora hydrophyllacea from Nicobar Islands and rediscovery of three species (*Sonneratia griffithii, Brownlowia tersa* and *Acanthus volubilis*) after a lapse of 90 years. In addition, a critical analysis of Rhizophora species has revealed the occurrence of a hybrid between *R. mucronata* and *R. stylosa (R. × mohanii)* and two new entities (*Rhizophora stylosa var. andamanica* (an advanced stage of hybridization between *R. mucronata* and *R. stylosa*) and *R. mucronata* var. alokii). A hybrid between *Acrostichum aureum* and *Acrostichum speciosum* has also been identified. Furthermore, incorrect reports on occurrences of species (*Avicennia alba, Aegialitis rotundifolia, Aglaia cuculata, Bruguiera sexangula, Ceriopa decandra, Kandelia candel* and *Sonneratia apetala*) in the ANI have also been noted. Forest structure of mangroves of ANI has also been studied elaborately in recent times (Ragavan *et al.* 2015; Kiruba-sankar *et al.* 2017). High canopy height (6.2-16.3 m), high basal area (30.8–59.6 m^2 ha^{-1}), and low stem density (487–2383 trees/ha) reported from ANI is the indicative of existence of complex stand in ANI. Furthermore, the highest complexity index (Ic =196.84–507.48) of mangroves of ANI shows the high structural development and low disturbances. Tropical climate with high rainfall, suitable environmental settings and close proximity with Southeast Asian countries would be attributed to high species richness and luxuriant growth of mangroves in the ANI.

IMPACT OF TSUNAMI

Despite the less anthropogenic disturbances, catastrophic event i.e. the earthquake of 9.1 on the Richter scale, which struck ANI on December 26, 2004 and the subsequent tsunami have brought about devastating human tragedy and considerable loss to the ecological resources, including mangroves in these islands (Saxena *et al.* 2013; Fig. 1). This event affects the mangroves of ANI in two ways (1) physical destruction caused by *Tsunami* waves, which is immediate and (2) subsidence and up-liftment caused permanent submergences (in Southern part) and reduced flooding by tidal water (in Northern Part) respectively, which is gradual. Thus, there is uncertainty between the immediate assessments and recent post-tsunami analysis. For instance, Saxena *et al.* (2013) reported the gradual decrease in mangroves of the ANI and assessed the loss of 43 sq km (19 sq km in Andaman Islands and 23 sq km in Nicobar Islands) of mangrove in ANI from 2003 to 2007, in contrast with FSI's rapid assessment (FSI 2007). Recently, Nehru and Balasubramanium (2018) reported loss of 97% mangrove cover in contrast with the earlier estimations that ranged between 60 and 70 % mangrove cover loss (Bahuguna *et al.* 2008). These results indicate the prevalence of degradation caused by 2004 catastrophic event. The submergence in South Andaman and Nicobar group of Islands also leads to the seawater inundations in settlement with agricultural land, reserve forest, plantation, sandy beaches, mudflats and degraded mangroves. Regular inundation by tidal water makes these areas conducive for colonisation of mangroves. Particularly in Great Nicobar Islands most inundated forests, plantation and agriculture lands are now colonized by Sonneratia spp, whereas in south Andaman most of the inundated areas supports the colonization of Acrostichum spp, Avicennia spp, Sonneratia spp and Rhizophora spp. Mangroves are naturally have high resilience potential so it is imperative to assess the natural succession in the inundated areas and efforts should be taken to assist the natural regeneration if the area supports the natural colonization of mangroves. In contrast, the uplifted areas of North Andaman Islands support the colonization terrestrial plant species and gradually affect the mangrove cover.

IMPACT OF CLIMATE CHANGE

Sea level rise and increasing extreme events are climate change induced threat for mangroves of ANI. Many organisms, including mangrove trees, have the ability to cope with short-term oscillations and long-term fluctuations of climatic conditions, but the consequences of global climate change, such as increased extreme events, and will have unprecedented effects on biota and threaten the resilience and recovery potential of ecosystems (Harris *et al.* 2018, Sippo *et al.* 2018). Mangroves have the potential to cope sea level rise by their ability to build surface elevation and upscale dispersal and establishment towards the natural corridors (mudflats, saltmarsh, saltpans etc.,) in the landward side. Mangroves build vertically by trapping sediments and increasing root biomass, which is varied between the mangrove habitats based on environmental settings, species composition and fresh water supply. So mangrove areas were the rate of vertical accretion is in pace with sea level are less vulnerable. Recently, Lovelock *et al.* (2015) reported that 69% of Indo-West pacific mangroves, including ANI, are not building surface elevations at rates that equaled or exceeded sea-level rise. Further, change in land use pattern of natural corridors of mangroves by human activities alter the habitat characteristics and renders these natural corridors unsuitable for natural migration of mangroves to cope the climate change consequences. So the Islands like ANI, where vertical accretion not in pace with sea level rise and availability natural corridors are scarce, need to be paid special attention to ensure their sustainability.

CONCLUSION

Keeping global warming below 1.5°C is a global agenda to avoid dangerous climate change consequences 6 and increasing soil carbon stocks and protecting carbon-rich soils are crucial for achieving the Paris climate. Mangroves are considered as potential carbon sinks and proposed as a low-cost effective option for mitigating greenhouse gas (GHG) emissions and climate change. Thus, mangrove conservation needs to be prioritized globally. However, still mangroves experience an annual loss of 0.2–0.7% between 2000 and 2012 and remain the most threatened ecosystem of the world (Hamilton & Casey 2016). Land conversion for agriculture and aquaculture activities and other coastal developmental activities remains a potential threat for mangroves. Furthermore, climate change-induced extreme weather events, disease and pest impacts (Kathiresan 2002, Osorio *et al.* 2016) and seaquake-induced tsunamis have also threatened mangrove ecosystems (Roy and Krishnan 2005, Sippo *et al.* 2018). India, on a regional basis, is often referred to as a good example of conservation and restoration of mangrove ecosystems (Bhatt and Kathiresan 2012). However, except floristics and ecology with minimal attention to management related issues, mangroves of ANI, as well as Indian mangroves, remain underexplored in various other aspects. Mangroves are highly dynamic and are site specific rather than global generalization. Further, they have witnessed drastic changes in the past and experiencing ongoing climate consequences. So additional information, such as the connectivity of mangroves and adjacent coastal, marine and terrestrial ecosystems, recent changes in the distribution, species composition and/or health status, the distribution of threats to biodiversity or service-provisioning and possible impact of climate change, is needed to consider in policy-making. Realizing the failure of conventional conservation measures many nations shifted to “Ecosystem Based Management (EBM)”. The lack of sufficient data is still a major impeding factor for success of mangrove conservation. But, EBM requires more precise information of various components of a given ecosystem to be managed. To transform current conservation measures into effective EBM-based measures, a multi-disciplinary approach will be needed. National legislations need to form multi- and interdisciplinary teams to critically revisit the available information and make efforts to fill knowledge gaps for better policy-making. On the whole, in-depth site-specific understanding of dynamics and functions, strict legislative measures and long-term monitoring are pivotal to ensure the sustainability of mangroves of ANI as well as in India.

Fig 8.1. 1 Impact of Tsunami in (A) owing to dying North Andaman and (B) Inundation Nicobar Islands

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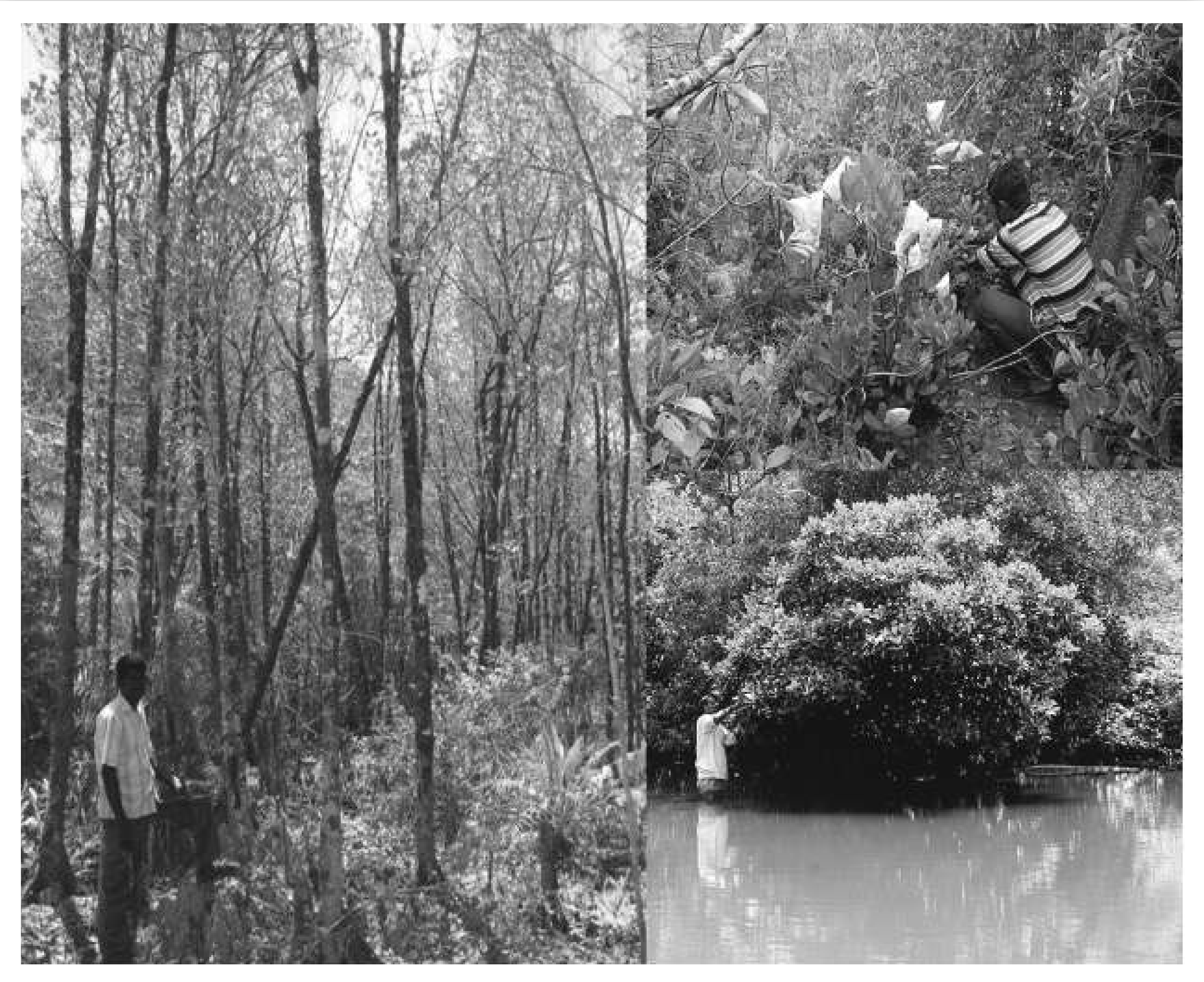
ECOSYSTEM SERVICES AND CARBON STORAGE IN MANGROVES



9 ECOSYSTEM SERVICES AND CARBON STORAGE

Mangroves offer several substantiate benefits, about one billion people's protein supplementation is met from marine fish resources. The nutrition dynamics of the marine food web in tropics is implicated by the detritus food chain of mangroves. It is estimated that 35 million people are directly engaged in fishing and aquaculture. The following are some of the very important services of mangroves:

- Life support systems
- Substrate and habitat for flora and fauna
- Habitat support for Avifauna
- Spawning and breeding habitat for fishes
- Flood Control
- Reduction of sediments
- Recharging of Aquifers
- Recreational and Ecotourism benefits
- Repository for Scientific Research

Bioprospecting of Indian Mangroves is traceable to 18th Century early British Colonial rule (Pearson 1914). With decrease in supply – demand ratio of tannin rich plants such as Terminalia chebula, T.bellerica, Anogeissus and Zizhiphus the erstwhile tannery industries were constrained. There was a steep increase for leather articles that were deployed by warfare for several purposes. It is during this period that usage of mangrove barks found place in good quality tannin extraction. In fact it was this process that resulted in large tracts of mangroves being cleared by colonial rulers. As green barks were necessary for tannin extraction plenty of resources comprising Bruguiera, Rhizhophora, Sonneration and Ceriops were lost in masses. After bark extraction the wood was used as firewood. It was calculated that about three tons of green bark was extracted in every one acre of mangroves. Approximately, it required 15 tonnes of green felling for provision 1 tonne of fresh bark (Pearson, 1914). Estimates reveal that the economic operations of the mangroves was hardly Indian British Rupees Rs.36/- per acre. It appears both the World Wars cost plenty of mangrove resources. Unfortunately, the regeneration was not in the tune or harmony with the felling carried out.

ECOSYSTEM SERVICES OF MANGROVES

Recently valuing ecosystem functions upholds the necessity and services of mangrove conservation. The global estimated economic value of mangrove forests ranges from US$9900 – US $ 35921 per hectare (Constanza et al., 1997, Sathirathai and Barbier 2001). In the North Malabar region of Kerala the Ecosystem services of Mangroves with about twenty three vital components is valued at Rs.4.5-5.0 Lakhs/hectare (Khaleel and Jaleel, 2009). In Bhitankanika

Conservation Area (BCA) of Orissa empirical studies on the storm protection services is rated as the prime one by the local inhabitants of many villages inhabiting mangroves (Badola and Hussain, 2005).

Despite constant research efforts on biology, productivity and ecosystem dynamics to understand mangroves and making the public and governments to conserve destruction in some form seems to be universal in this global ecosystem (Rollet 1981, Saengner *et al.,*1983, Field *et al.,* 1998; Semesi *et al.,* 1998). The ecosystem services of mangroves are continued to be neglected and conversion of landscape continues (Swallow 1994). This is very true in the case of privately owned mangrove wetlands in the Kerala and Karnataka regions in our country. Conservation of these may very difficult in future unless and until participatory management has some economic benefit to the private owners. The economics of direct products from mangroves proves to be important in decision for their management. For mangrove conservation and exploitation to go simultaneously economic analysis that focus on multi-use aspects are needed (Ruitenbeek 1994).

The ecosystem services of mangroves are estimated to worth not less than 1.6 billion $ per year (Costanza *et al.*,1997).The livelihood of people who living in and near to mangroves are mostly depends on fishing and harvest of mangrove forest products (Christensen, 1982 Kunstadter *et al.,* 1986, Diop 1993 Spadling *et al.,* 1997, Ronnback *et al.*, 2007).

In India mangrove largely consumed for fuel, fodder, construction, fibre, tannin, and diverse traditional medicinal purposes. Mangroves support a wide range of microbes, plants, fishes, water birds, etc. It was reported that Indian mangroves supports 3985 species of flora and fauna. They also provide protection to the coastal zones against natural disasters like cyclone, flood, Tsunami etc. Mangrove forests are also known for its carbon storage and sequestration which is significant in mitigating the impacts of global warming (Kathiresan *et al.,* 2013, Kathiresan *et al.,* 2014).

In future, appropriate values for ecosystem services once derived may be inserted in the decision making process (Constanza *et al.,* 1997 b). This would lead to better management and conservation practices. In future, it appears the conservation and management procedures for mangroves in protected areas and private ownership could be very different. But it is imminent that conservation of mangroves in our country would be highly localized and specialized that cannot be achieved without participation of people.

CARBON STORAGE

Compared to the rich and colourful coral reef and rainforests visual pleasantries Mangroves are considered foul nascent, muddy and hostile landscapes (Dittmer *et al.,* 2006). The *Tsunami* of 2005 brought in a global realisation on their natural barrier ability and capacity in implicating commercial fishing patterns (Mumby *et al.,* 2004). Technically mangroves link the carbon cycles of the land with the ocean system (Dittmer *et al.,* 2001).

Tidal transport along with the Riverine flow provision the most important sources of terrigenous organic matter to the ocean. About 50% of net primary production in mangroves is exported as organic matter to the ocean (Roberson *et al.,* 1992., Ditmarr and Lara 2001). Which is almost 2 orders of magniture higher than the global average terrestrial ecosystems (Spitzy and Leenheer 1991).

The importance of ocean margins and intertidal systems for organic carbon burial in sediments is well recognized (Hedges *et al.,* 1997 ; Jennerjahn and Itteekot, 2002) as well as their contribution to dissolved organic matter (DOM) inventories of the oceans interior (Bauer and Druffel, 1998). Since mangroves play a major role for the DOM exchange between continents and oceans, their rapid decline over the recent decades (Valeila *et al.,* 2001) may already have reduced the flux of terrigenous DOM to the earth. The potential consequences of this observation on global element cycles and climate place an enormous responsibility on society to the preserve these environments (Dittmar *et al.,* 2006).

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POLICY AND LEGAL INSTRUMENTS

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THREATS

Both biotic and abiotic pressures are mounting on coastal wetlands are perils cumulating with years. One of the transformations observed in the recent past is severe fragmentation leading to change in hydrological patterns, particularly in vegetations thriving in private ownership. Owing to high valued real estate in the Kerala region mangrove wetland are being transformed in to less productive real estates. In the wetlands Ernakulam district of Kerala most private properties with large mangrove vegetations are land filled leading to soil compacting. Consequently rare species such as *Bruguiera gymnorrhizha* simply thrive but fail to reproduce. Local people in the region perceive and merely value true for firewood and the invaluable ecosystem values are simply neglected. To transform these perception lots of extension works need to be carried out among private mangrove vegetation owners. It appears that special support studies would require managing mangroves in an urban set up like Ernakulam, Kerala.

The following have been perceived and quantified as biotic and abiotic threats:

- Siltation and weed infestation
- Waste water discharge from local bodies
- Surface runoff
- Impact of Industrial effluents and
- Water level fluctuation and transformation of landscape
- Habitat destruction
- Removal of trees for firewood
- Encroachment
- Dredging and Landfilling
- Hydrological intervention and disruption of aquifers
- Deterioration of water quality
- Ill-effects of fertilizers and insecticide used in agricultural fields

LEGAL FRAME WORK

Till date there is no distinct provision or a specific legal instrument as a policy to handle mangrove conservation in India. However, there are legislations enacted with relevance to wetland conservation. This includes Indian Forest Act 1927, Wildlife Act 1972, Air Act (Prevention and Control of Pollution) 1974, Water Cess Act 1977, Forest Conservation Act 1980 and Environment Protection Act 1986. The provision Coastal Regulation Zone Notification 1991 under the provision of EPA 1986 restricts setting and expansion of industries. In recent times the Biodiversity act 2002 and the Biodiversity rules 2004 also offer protection and safeguarding the floral and faunal biodiversity. The National Environmental Policy (NEP) approved by the cabinet (19May, 2006) considerably recognizes the numerous ecological services rendered by different types of wetlands. It offers a six fold action plan highlighting the following aspects:

- Setting up a legally enforceable regulatory mechanism
- Formulate conservation with participation of local communities and stakeholders
- Formulate and implement ecotourism strategies
- Evaluate environmental services and comprehend cost-benefit analysis
- Integrate wetland conservation through traditional techniques

Among the states the Kerala has pioneered to have a legal frame work to conserve through "The Kerala conservation of Paddy land and Wetland act, 2008". The said Act 28 of 2008 is currently enacted in the state. A Local Level Monitoring Committee (LLMC) constituting the local governing body, Village officer and farmer representative act to the enactment. This enactment could be suitable adapted in other states of India.

INVENTORISATION

Survey and inventory of wetlands should encompass mapping through revenue records, survey and assessment and document land use pattern using GIS techniques. The data should overlay drainage pattern, vegetation cover, siltation levels, wetland encroachments and usage pattern at primary, secondary and tertiary levels. In Kerala the Biodiversity Board, Salim Ali Centre for Ornithology and Natural History (SACON) and ENVIS, MoEF, Government of India has jointly invertorised the wetlands in Kerala (www.keralawetland.org). A similar approach need to be adapted by other states also so that networking of these resources would give a complete inventory of wetlands in the country.

INSTITUTIONAL MECHANISMS

Wetland conservation and management is a highly specialized technical and scientific field wherein multi inter-disciplinary approach is a prerequisite. This involves various components such as water management, fisheries, hydrology, nutrient cycling, socio-economy, community participation and biodiversity conservation. The states that have already initiated wetland conservation are Chilika Development Authority (CDA), Orissa, Loktak Development Authority (LDA), Manipur, Shore Area Development Authority (SADA), Andhra Pradesh, Lake Development Authority (LDA), Karnataka and Lake Conservation Authority (LCA), Madhya Pradesh. The authorities are mostly concerned freshwater ecosystems. Such authorities in future need to be extended for conservation of mangroves also.

CONSERVATION AND MANAGEMENT

The conservation and management of wetlands need to be built upon comprehensive strategies. This should include legal framework, policy support to inventorization, institutional mechanisms, capacity building and active participation of communities. Reconnaissance floristic surveys fairly reflect regeneration and population status. A recent study in Orissa reveals that taxa such as Cynometra ramiflora, Rhizophora mucronata and Sonneratia apetala had lesser number of juveniles compared to other species in Bhitarkanika (Upadhyay and Mishra, 2008). Mangroves being a dynamic and very efficient ecosystem, periodical monitoring using Long Term Ecological Monitoring Plots

(LTEMP) could be vital rather critical. Establishment of such assets would give the status of various aspects such as floristic diversity, population status, general health, salinity, hydrology and geological changes.

From a geological perspective, mangroves come and go at considerable speed with the current distribution of forests a legacy of the Holocene, having undergone almost chronic disturbance as a result of fluctuations in sea-level. The ultimate disturbance, climate change, may lead to a maximum global loss of 10-15% of mangrove forest, but must be considered of secondary importance compared with current average annual rates of 1-2% deforestation. A large reservoir of below-ground nutrients, rapid rates of nutrient flux and microbial decomposition, complex and highly efficient biotic controls, self design and redundancy of keystone species all contribute to mangrove resilience to various types of disturbance (Alongi 2008).

BIBLIOGRAPHY

Adame FM, Lovelock CE (2011) Carbon and nutrient exchange of mangrove forests with the coastal ocean. Hydrobiologia 663:23–50.

Alexander MP (1969) Differential staining of aborted and non aborted pollen. Stain Technology 44:117-122.

Allen JA and Duke NC (2006) Bruguiera gymnorhiza (Large Leafed Mangrove), ver.2.I. In:Elevitch, CR(ed). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai'I <http://www.traditionaltree.org>.

Alongi DM (2008) Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. Estuarine, Coastal and Shelf Science 76 1-13.

Alongi DM (2018) Mangrove Forest. In Blue Carbon (ed. Alongi, D.M.), Springer, Switzerland, pp.23-36.

Anupama C and Sivadasan M (2004) Mangroves of Kerala,India. TheRheedea 14: 09 – 46.

Aronson J Ovalle C Aguilera L and Leon P (1994) Phenology of 'immigrant' savanna tree (Acacia caven, Leguminosae) in the Mediterranean climate zone of Chile. Jour. of Arid Environ. 27:55-70.

Badola R and Hussain SA (2005) Valuing Ecosystem Functions: An empirical study on the storm protection function of Bhitarkanika Mangrove Ecosystem, India. Environmental Conservation 32(1): 85-92.

Bahuguna A, Nayak S, Roy D (2008) Impact of the Tsunami and earthquake of 26th December 2004 on the vital coastal ecosystems of the Andaman and Nicobar Islands assessed using RESOURCESAT AWiFS data. Int J Appl Earth Obs Geoinf 10: 229–237.

Bashan Y, Holguin G (2002) Plant growth promoting bacteria: a potential tool for arid mangrove reforestation. Trees 16: 159-166

BashaSC (1992).Mangrovesof Kerala–A fastdisappearingAsset.Ind.For.,118:175-190.

Batis AI and Vazquez-Yanes (1996) Potentially valuable native trees for restoration and reforestation: a database. In Dieters MJ, Matheson AC, Nikles DG, Harwood CE and Walker SM (eds.). Tree Improvement for Sustainable Tropical Forestry Proc. QFRI-IUFRO Conf., Caloundra, Queensland, Australia 27 October – 1 November 1996. pp 422-423.

Bhatt JR, Kathiresan K (2012) Valuation, carbon sequestration potential and restoration of man-grove ecosystems in India. In: Sharing lessons on mangrove restoration proceedings and a call for action from an MFF regional colloquium, Mamallapuram, 30–31 Aug 2012, pp 19–38.

Borchert R (1983) Phenology and control of flowering in tropical trees. Biotropica 15:81-89

Ceron-Souza I , Rivera ocasia E, Medina, Jimenez J A, Mcmillan W O and Bermingham E (2010) Hybridization and introgression in new world red mangroves, Rhizophora (Rhizophoraceae), American Journal of Botany 97(6), 945-957.

Chand Basha S (1992) Mangroves of Kerala – A Fast Disappearing Asset. Indian Forester 118: 175-190.

Changtragoon S (2001) Forest Genetic resources of Thailand: Status and Conservation. In :Forest Genetic Resources: Status, Threats and Conservation Strategies. Eds: Umashaanker R, Ganeshiah KN and Bawa KS. Oxford and IBH, India. Pp 141-151

Chen Z, Ma S Liu L (2008) Studies on phosphorus solubilizing activity of a strain of phosphobacteria isolated from chestnut type soil in China. Bio resource Tech 99: 6702-6707

Chen XY (2000) Effects of plant density and age on the mating system of Kandelia candel Druce (Rhizophoraceae) a viviparous mangrove species. Hydrobiologia 43 (2): 189-193.

Chidambaram K (2004) Status of Mangrove in Tamil Nadu. In Proc. (Eds: Basha, CS and Ouseph,KP) Mangroves Conservation and Management Training workshop, Kerala Forest Department Kannur, 25-27 June, 2004, Pp: 28-31.

Clarke P J (1993) Dispersal of grey mangrove (Avicennia marina) propagules in southeastern Australia, Aquatic Botany 45: 195-204.

Clarke P J and Myerscough PJ (1991) Floral biology and reproductive phenology of Avicennia marina in South Eastern Australia. Australian Journal of Botany 39:283-293

Clough BF Andrews TJ and Cowan IR (1982) Physiological process in Mangrove systems in Australia: Structure, Function and Management (Ed. Clough BF) 194-210, Australian National University Press, Canberra.

Congdon RA and Herbohn JL (1993) Ecosystem dynamics of disturbed and undisturbed sites in North Queensland wet tropical rain forest. I. Floristic composition, climate and soil chemistry. Journal of Tropical Ecology 9: 349-363.

Constanza R Cumberland J Daly H Goodland R and Norgaard R (1997). An introduction to Ecological Economics. Florida USA. International Society to Ecological Economics.

Constanza R d'Arge, de Groot, FarberS Grasso M Hannon B Limburg K Naeem S Oneill RV Paruelo J Raskin RG Sutton P and van Den Belt (1997b). The value of world's ecosystem services and natural capital. Nature 387: 253-260.

Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ et al (2014) Changes in the global value of ecosystem services. Glob Environ Chang 26:152–158.

Coupland GT Paling EI and McGuinness KA (2005) Vegetative and Reproductive phenologies of four mangrove species from northan Australia. Australian Journal of Botany 53: 109-117.

Coupland GT Paling EI and McGuinness KA (2006) Floral abortion and Pollination in four species of tropical mangroves from Northern Australia. Aquatic Botany 84: 151-157.

Cruden RW (1977) Pollen-ovule ratios: a conservative indicator of breeding systems in flowering plants. Evolution 31: 32-46.

Dafni A (1992). Pollination Ecology A Practical Approach. Oxford University Press, Oxford, Newyork. Pp165-196.

Die Bie S Ketner P Paase M and Geerling C (1998). Woody plant phenology in the West Africa Savanna. Jour. of Biogeo.25:883-900.

Dominguez C A , Eguiarte L E, Nunez Farfan J and Dirzo R (1998) Flower morphometry of Rhizophora mangle (Rhizophoraceae): Geographical variation in Mexican populations, American Journal of Botany 85(5), 637-643.

Drexler JZ (2001) Maximum longevities of Rhizophora apiculata and R.mucronata propagules. Pacific Science 55(1):17-22.

Duke NC (1990a) Morphological variation in the mangrove genus Avicennia in Australasia: Systematic and Ecological considerations. Aust. Jour. of Bot.3: 221- 239.

Duke NC (1990b) Phenological trends with latitude in mangrove genus Avicennia marina. Journal of Ecology 78:113-133.

Duke NC (1990c) Phenological trends with latitude in mangrove genus Avicennia marina. Jour. of Ecol. 78:113-133.

Duke NC (1992) Mangrove floristics and Biogeography. In A.Robertson and D.Alongi (Eds), Tropical Mangrove Ecosystem, 63-100, American Geographical Union, Washington, DC.

Duke NC Bunt JS and Williams WT (1984) Observations on floral and vegetative phenologies of Northeastern Australian Mangroves: Aust. Jour. of Bot. 32: 87-99.

FAO (1999) State of the World's Forests. Food and Agricultural organization of the United Nations, Rome , Italy.

Field CB Osborn JG Hoffman LL Polsenberg J Ackerly DD Berry JA Bjorkman O Held AA Matson PA Mooney HA Vitousek PM (1998) Mangrove biodiversity and ecosystem function. Global Ecology and Biogeography Letters 7 (1):3-14.

Forest Survey of India (1991). The State of Forest Report 1991

FSI (2007) India state of forest report 2007. Forest Survey of India, Ministry of Environment & Forests, Government of India publication, Dehradun (India)

FSI (2017) India state of forest report. Forest survey of India, Dehradun, pp 55–61.

Ganeshiah KN Umashaanker R and Bawa KS (2001) Conservation of forest genetic resources of a region: Combining species-centered and ecosystem-based approaches. In : Forest Genetic Resources: Status, Threats and Conservation Strategies. Eds: Umashaanker R, Ganeshiah KN and Bawa KS. Oxford and IBH, India. pp 273-281.

Ge J Cai B and Lin P (2003) Mating system and Outcrossing rates of Four Bruguiera gymnorrhizha populations of Mangrove, China. Nature and Science 1(1): 43-48.

Giri C, Ochieng E, Tieszin LL, Zhu Z, Singh A, Loveland T, Masek J, Duke NC (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20: 154–159.

Gitiru WR Wang QF Wang Y and Guo YH (2002) Pollination ecology, breeding system and conservation of Caldesia grandis (Alismataceae) an endangered marsh plant in China. Bot. Bull. Acad. Sin 43: 231-240.

Goutham-Bharathi MP, Dam Roy S, Krishnan P, Kaliyamoorthy M, Immanuel T (2014) Species diversity and distribution of mangroves in Andaman and Nicobar Islands, India. Botanica Marina 57 (6):421–432.

Hamilton SE, Casey D (2016) Creation of a high spatio-temporal resolution global database of 1071 continuous mangrove forest covers for the 21st century (CGMFC-21). Glob Ecol Biogeogr 25 (6):729–738.

Harris RMB, Beaumont LJ, Vance TR., Tozer CR, et al. 2018. Biological responses to the press and pulse of climate trends and extreme events. Nature Climate Change 8: 579–587.

Hubbel SP and Foster RB (1992) Short-term dynamics of a neo-tropical forest: why ecological research matters to tropical conservation and management: Oikos 63: 48-61.

Islam S Md, Lian C, Geng Q, Kameyama N and Hogetsu T (2008) Chloroplast microsatellite markers for the mangrove tree species Bruguiera gymnorrhiza, Kandelia candel and Rhizophora stylosa, and cross- amplification in other mangrove species. Conservation Genetics 9: 989-993.

ITTO/RCFM (2000). Technical guidelines for the establishment and management of ex situ conservation stand of tropical timber species. International Timber Trade Organization, Yokahama, Japan and Regional Centre for Forest Management, Kaula Lumpur, Malaysia.

Jana S and Deshmukh S (1994) Mangroves: Morphology, Anatomy and Reproduction. In Conservation of Mangrove forest genetic resources – A Training Manual. (Eds. Desmukh SV and Balaji V) M. S. Swaminathan Research Foundation and International Tropical Timber Organization.Pp 65-70.

Jonathan K H and Solomon Raju A J (2009) Insect pollination and self-planting seed dispersal strategy in the true viviparous mangrove tree species Ceriops tagal (Perr.) C.B. Robinson (Rhizophoraceae). Journal of Threatened Taxa 1(3): 133-140.

Karthikeyan A, Sivapriya NB (2018). Responses of Bruguiera sexangula (Lour) Poir.propagules to beneficial microbes in the nursery. J Forest Res: 29 :1093-1098

Kathiresan K, Bingham BL (2001) Biology of mangroves and mangrove eco systems. Adv Mar Biol 40: 81-251.

Kathiresan K (2002) Why are mangroves degrading? Current Science 83:1246–1249.

Kathiresan K, Masilamani SM (2005) Evaluation of beneficial bacteria from mangrove soil. Botanica Marina 49: 86-88

Kathiresan K (2010). Importance of mangrove forests of India. J Coast Env 1: 11-25

Khaleel KM and Jaleel CA (2009) Environmental challenges to the mangrove wetlands of North Malabar (Kerala), India: Their sustainable development and influence on local people. Knowledge and Management of Acquatic Ecosystems 392:1-8.

Kiruba-Sankar R, Krishnan P, Dam-Roy S, Raymond Jani Angel J, Lohith Kumar K, Goutham-Bharathi MP, Ragavan P, Kaliamoorthy M, Muruganandam R, Rajakumari S, Purvaja R, Ramesh R (2018) Structural complexity and tree species composition of mangrove forests of the Andaman Islands, India. J Coast Conserv 22:217–234.

Krishnamoorthy M Nagarajan B Pandiarajan C and P Sophia (2009). An Initiative to Conserve Bruguiera Sexangula (Lour.) Poir. A Critically Endangered Taxon. In Conservation and Management of Mangroves in India. Zoological Survey of India Pp 485-490 (In Press)

Lakshmi M Rajalakshmi S Parani M Anuratha C and Parida A (1997) Molecular phylogeny of mangroves I. Use of molecular markers in assessing the intraspecific genetic variability in the mangrove species, Acanthus ilicifolius Linn. (Acanthaceae). Theor. Appl. Genet 94:1121-1127.

Lakshmi M Parani M Parida A (2001) Genetic diversity in Indian mangrove family Rhizhophoraceae. In : Forest Genetic Resources: Status, Threats and Conservation Strategies. Eds: Umashaanker R, Ganeshiah KN and Bawa KS. Oxford and IBH, India. pp 31-47.

Loveless MD and Hamrick JL (1984) Ecological determinants of genetic structure in plant populations. Ann. Rev. Ecol. Syst. 15:65-95.

Lovelock CE, Cahoon DR, Friess DA, Guntenspergen GR, et al (2015) The vulnerability of Indo-Pacific mangrove forests to sea-level rise. Nature 526: 559–563.

Malik M, Fenshret R, Mentz O (2015) Economic valuation of mangroves for comparison with commercial aquaculture in South Sulwasi. Indonesia. Forests 6: 30:3028-3044

Mall LP Billore SK and Amrithpale D (1982) Certain ecological observations on mangroves of the Andaman Islands. Tropical Ecology 23(2):225-233.

Mall LP, Singh VP, Garge A and Pathak SM (1987) Ecological studies on mangrove forests of Ritchie's archipelago in relation to Substrata. Tropical Ecology 28:182-192.

Martin FW (1959). Staining and observing pollen tubes in the style by means of fluorescence. StainTechnology., 34:125-128.

Mohanan, C. N. 1999. Mangroves. In: Thampi, K.B. Nayar, N. M. & C.S. Nair (Eds), The Natural Resources of Kerala, WWF India, Thiruvananthapuram. 149-158.

Moza KM and Bhatnagar AK (2007) Plant reproductive biology studies crucial for conservation. Current Science, 92(9):1207.

Muthukumar T, Udaiyan K, Rajeshkannan V (2001) Response of Neem (Azadirachta indica A. Juss) to indigenous arbuscular mycorrhizal fungi, phosphate solubilizing and symbiotic nitrogen fixing bacteria under tropical nursery conditions. Biol Fertil Soils 34: 417-426

Nagarajan B Nicodemus A Mandal AK Verma RK and Mahadevan N.P. 1998. Phenology and controlled pollination studies in tamarind. Silvae Genetica 47(5-6): 237-241.

Nagarajan B Nicodemus A Sivakumar V Mandal AK Kumarvelu G Jayaraj RSC Narmatha Bai V and Kamalakannan R (2006) Phenology and controlled pollination studies in Casuarina equisetifolia Forst. Silvae Genetica 55(4-5):149-155.

Nagarajan B Pandiarajan C and Krishnamoorthy M (2008). Managing True Mangroves: Are Bird Pollinated Taxa the Most Vulnerable to Climate Change? In Proc. Forest Adaptation 2008: Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A Review of Science, Policies and Practices, Ume, Sweden 25 – 28 August, 2008. Organized by IUFRO, Austria, FAO of UN, Rome and SLU, Sweden. Pp 178.

Nagarajan B Pandiarajan C Krishnamoorthy M and Sophia P (2008). Reproductive Fitness and Success in Mangroves: Implication on Conservation. Sengupta, M. and Dalwani, R. (Editors). Proceedings of Taal 2007: The 12th World Lake Conference, Jaipur. India, 28th October – 2nd November, 2007.pp 29-33.

Nagarajan B, Krishnamoorthy M and Pandiarajan C (2008). Fruit dormancy in Ceriops decandra: An adaptation to overcome climate adversary? In Proc. Forest Adaptation 2008: Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A Review of Science, Policies and Practices Umea, Sweden 25 – 28 August, 2008 Organized by IUFRO, Austria, FAO of UN, Rome and SLU, Sweden. , Pp 177.

Nagarajan B Krishnamoorthy M Pandiarajan C Manimekalan A (2009) Can sweetness be difficult to handle when in excess? Current Science 96(11):1433

Nagarajan B Pandiarajan C Krishnamoorthy M and Sophia P (2013). Comprehending floral diversity and Ecological Adaptations in Mangroves. In Mangroves in India: Biodiversity, Protection and Environmental Services Pp. 125-133.

Nehru P, Balasubramanian P (2018) Mangrove species diversity and composition in the successional habitats of Nicobar Islands, India: A post-tsunami and subsidence scenario. Forest Ecology and Management, 427:70–77.

Noske R A (1993) Bruguiera hainesii: another bird pollinated mangrove? Biotropica 25 (4): 481-483.

Old-field S Lusty C and Machine A (1998). The World List of Threatened Trees. World Conservation Press, WCMC, Cambridge, UK.

Osorio JA, Wingfield MJ, Roux J (2016) A review of factors associated with decline and death of mangroves, with particular reference to fungal pathogens. South African Journal of Botany 103: 295–301.

Owens JN (1993) Biological constraints to seed production in tropical forest trees. In (Eds: Drydale RM John ST and Yap AC) Proc. International symposium on Genetic conservation and production of tropical forest Tree Seeds, 14-16 June 1993. Chiang Mai, Thailand. Pp 40-51.

Pandiarajan C Nagarajan B Krishnamoorthy M and Sophia P (2009). A Comparative account on Phenology, Floral Adapatations and Reproductive Success in the Genus Ceriops. Conservation and Management of Mangroves in India (2009). Zoological Survey of India Pp 205 – 211

Pandit S and Choudhury B C (2001) Factors affecting pollinator visitation and reproductive success in Sonneratio caseolaris and Aegiceras corniculatum in a mangrove forest in India, Journal of Tropical Ecology 17: 431-447.

Parani M Lakshmi M Élango S Nivedita R Anuratha CS and Parida A (1997) Molecular phylogeny of Mangroves II. Intra and Inter specific variation in Avicennia revealed by RAPD and RFLP markers. Genome 40:487-495.

Parani M Lakshmi M Senthil kumar P Nivedita R and Parida A (1998) Molecular phylogeny of mangroves VI: Analysis of genome relationship using RAPD and RFLP markers. Theor. Appl. Genet.97: 617-625.

Parida A Anuratha CS Lakshmi M Parani M and Kurten J (1995) Application of molecular markers in assessing genetic diversity in Indian mangroves. In Use of induced mutations and molecular techniques in crop improvement (FAO/IAEA, Vienna, Austria, 1995). Pp 595-600.

RadfordAE DickinsonWC MasseyJR and Bell CR (1974) Vascular Plant Systematics. Harper and Row Publishers, New York, USA pp 595-600.

Ragavan P, Mohan PM, Saxena A, Jayaraj RSC, Ravichandran K, Saxena M (2019) Mangrove floristics of the Andaman and Nicobar Islands-Critical review and current scenario. Marine Biodiversity 48(3): 1291-1311.

Ragavan P, Saxena A, Jayaraj RSC, Mohan PM, Ravichandran K et al (2016) A review of the mangrove floristics of India. Taiwania 61(3):224–242

Ragavan P, Saxena A, Mohan PM, Ravichandran K, Jayaraj RSC, Saravanan S (2015) Diversity, distribution and vegetative structure of mangroves of the Andaman and Nicobar Islands, India. Journal of Coastal Conservation 19:417–443.

Rajendran K, Devaraj P (2004) Biomass and nutrient distribution and their returns of Casuarina equisetifolia inoculated with bio fertilizers in farm land Biomass Bio energy 26: 235-249

Rajendran N and Sanjeevi B (2004) Flowering plants and Ferns in Mangrove Ecosystems of India. ENVIS Publication Series: 1/2004. Parangipettai.

Raju SAJ Jonathan KH and Vijayalakshmi A (2005) Pollination biology of Ceriops decandra (Griff.)Ding Hou (Rhizophoraceae) an important true viviparous mangrove tree species. Current Science 91 (9):1235-1238.

Ramachandran S, Sundaramoorthy S, Krishnamoorthy R, Devasenapathy J and Thanikachalam M (1998) Application of remote sensing and GIS to coastal wetland ecology of Tamil Nadu and Andaman and Nicobar group of Islands with special reference to Mangroves. Current Science 75 (3): 236-244.

Ramachandran, K.K., Mohanan, C. N., Balasubramonian, G., Kurien, J. & J. Thomas 1986.The Mangrove Ecosystem of Kerala: Its mapping, inverntory and some environmental aspects.(Unpublished Interim Report 1985-86).CESS, Trivandrum.

Rao (1994) Mangroves: Morphology, Anatomy and Reproduction. In Conservation of Mangrove forest genetic resources – A Training Manual. (Eds. Desmukh SV and Balaji V) M. S. Swaminathan Research Foundation and International Tropical Timber Organization. Pp

Rao AN Molour S and Walker S (1999) Mangroves of India: Report Summary, Biodiversity conservation prioritization project (BCPP) India, Endangered Species Project, Conservation Assessment and Management plans. Zoos' print : News of Nature Networks in India and elsewhere: published by Zoo Outreach Organization , Coimbatore, India XIV(2):10-32.

Rao R and Koskela J (2001) Action plans and research needs to conserve forest genetic resources in Asia. In : Forest Genetic Resources: Status, Threats and Conservation Strategies. Eds: Umashaanker R, Ganeshiah KN and Bawa KS. Oxford and IBH, India. pp 283-301.

Ravishankar T, Ramasubramanian R (2004) Manual on mangrove nursery techniques. M.S. Swaminathan Research foundation. Chennai. India 48p

Rojas A, Holguin G,Glick BR,Bashan Y (2001) Synergism between Phyllobacterium sp (N fixer) and Bacillus licheniformis (P – solubilizer) both from a semi arid mangrove rhizosphere. FEMS Microbiol Ecol 35:181-187

Rollet B (1981) Bibliography in Mangrove Research, 1600-1975. Paris, France UNESCO.

Roy SD and Krishan P (2005). Mangroves stands of Andamans vis-à-vis tsunami. Current Science 89(11): 1800-1804

Ruitenbeek HJ (1994) Modelling economy-ecology linkages in mangroves: Economic ecidence for promoting conservation in Bintuni Bay, Indonesia. Ecoological Economics 10(3):233-247

Saengner P Hegerl EJ and Davie JDS (1983) Global Status of Mangrove Ecosystems . Gland, Switzerland IUCN commission on Ecology Papers (3). The World Conservation Union.

Sathirathai S and Barbier EB (2001) Valuing mangrove conservation in Southern Thailand. Contemporary Economic Policy 19 (2):109-122

Saxena A, Ragavan P, Saxena M (2013) Impact of Extreme Events on Salt-Tolerant Forest Species of Andaman and Nicobar Islands (India)." In Crop Improvement Under Adverse Conditions, pp. 35-63. Springer New York, 2013.

Semesi AK (1998) Mangrove management and utilisation in Eastern Africa. Ambio 27(8):620-626.

Sengupta V, Chaudhari S (1990) Halotolerant Rhizobium strains from mangrove swamps of the Ganges River Delta. Indian J. Microbiol 30: 483-484

Sengupta V, Chaudhari S (1991) Ecology of heterotrophic dinitrogen fixation in the rhizosphere of mangrove plant community at the Ganges river estuary in India Oecologia 87: 560-564

Sherman RE, FaheynTJ, Howarth RW (1998) Soil plant interactions in a neotropical mangrove forest: iron,phosphorus and sulfur dynamics. Oecologia 15:553-563

Singh VP Mall LP Garge A and Pathak SM (1985) Some ecological aspects of mangrove forest of Andaman Islands. J. Bomb. Nat. Hist. Soc. 83:525-537.

Singh VP, Garge A, Pathak SM and Mall LP (1987a) Pattern and process in mangrove forests of the Andaman Islands.Vegetatio 71:185-188.

Singh VP, Mall LP, George A and Pathak SM (1987b) A new record of some mangrove species from Andaman Islands and their distribution. The Indian Forester 113:214-217.

Sippo JZ, Maher DT, Tait DR, Holloway C, Santos IR (2016) Are mangroves drivers or buffers of coastal acidification? Insights from alkalinity and dissolved inorganic carbon export estimates across a latitudinal transect. Global Biogeochemical Cycle, 30 (5): 753-766.

Solomon Raju A J Jonathan KH and Vijayalakshmi A (2005) Pollination biology of Ceriops decandra (Griff.)Ding Hou (Rhizophoraceae) an important true viviparous mangrove tree species. Current Science 91 (9):1235-1238.

Sophia P NagarajanB Krishnamoorthy M and C. Pandiarajan (2009) Phenology and Reproduction in Bruguiera Cylindrica (L.) In Conservation and Management of Mangroves in India. Zoological Survey of India Pp 255-260. (In Press)

Spalding MD Blasco F and Field CD (1997) World Mangrove atlas. The International Society for Mangrove Ecosystem, Okinawa, Japan.

Sun M Wong KC Lee Joe SY (1998) Reproductive biology and Population Genetic Structure of Kandelia candel (Rhizophoraceae), a viviparous mangrove species. American Journal of Botany 85 (11): 1631-1637.

Suvarnaju P, Jonathan K H and Solomon Raju A J, 2012 (TESFS), A study on floral biology and pollination in Excoecaria agallocha L. (Euphorbiaceae) pp 257-260

TatedaY (2002). Sequestration of CO2 from planted mangroves. Central Research Institute of Electric Power industry News, Tokyo, Japan.

Toledo G, Bashan Y, Soeldner A (1995) Cyanobacteria and black mangroces in Northwestern Mexico: colorization and diurnal and second nitrogen fixation on aerial roots Can J Microbiol 41: 999-1011

Tomlinson PB Primack RB and Bunt JS (1979) Preliminary Observations on Floral Biology in Mangrove Rhizophoraceae. Biotropica 11(40): 256-277.

Tomlinson PB (1986) Botany of Mangroves, Cambridge University, Cambridge, United Kingdom.

Umashaanker R, Ganeshiah KN and Bawa KS (2001).Forest Genetic Resources: Status, Threats and Conservation Strategies. Oxford and IBH, India. Pp 317.

UNEP (1992). United Nations Environmental Program. Convention on Biological Diversity. UNEP/BIO./Conf/L.

Upadhyay VP and Mishra PK (2008) Population status of mangrove species in estuarine regions of Orissa coast, India. Tropical Ecology 49(2): 183-188.

Valiela I Brown JL and YorkJK (2001) Mangrove Forests: One of the World's threatened major tropical environments. Bioscience 57(10): 807-815.

Vazquez P, Holguin G, Puente ME, Cortes LA, Bashan Y (2000) Phosphates solubilizing microorganisms associated with the rhizosphere of mangroves in a semiarid coastal region. Biol Fertil Soils 30: 460-468

Ved DK Prathima CL Morton N and Shankar D (2001) Conservation of India's medicinal plant diversity through novel approach of establishing a network of in situ gene banks. In: Forest Genetic Resources: Status, Threats and Conservation Strategies. Eds: Umashaanker R, Ganeshiah KN and Bawa KS. Oxford and IBH, India. pp 183-195.

Wiens D Calvin CL Wilson CA Davern CI Frank D and Seavey SR (1987). Reproductive success, spontaneous embryo abortion and genetic load in flowering plants. Oecologia., 71: 501-509.

Hyposaline zone species *Sonneratia, Nypa* and *Bruguiera sexangula*
in Jackson's Creek, Little Andamans

Family structure emergence in *Ceriops tagal* (South Andamans)

Nypa fruticans

Fruit of *Pandanus*

Protandry in Kandelia kandel

A bat Roost within *Rhizhophora* vegetation

Regeneration in *Ceriops tagal*

Habit of *Bruguiera parviflora*

Dried up *Rhizophora* rejuvenating and regeneration in South Andamans

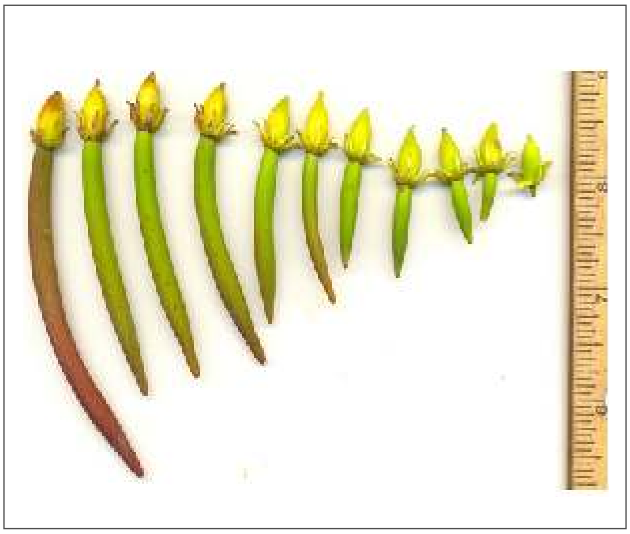
Bee Pollination

Bird Pollination

Controlled Pollination

Bruguiera cylindrica inflorescence in full bloom

Non-social bee Allodape pollinating *B. cylindrica*



Different growing stages of propagules in *B. cylindrica*

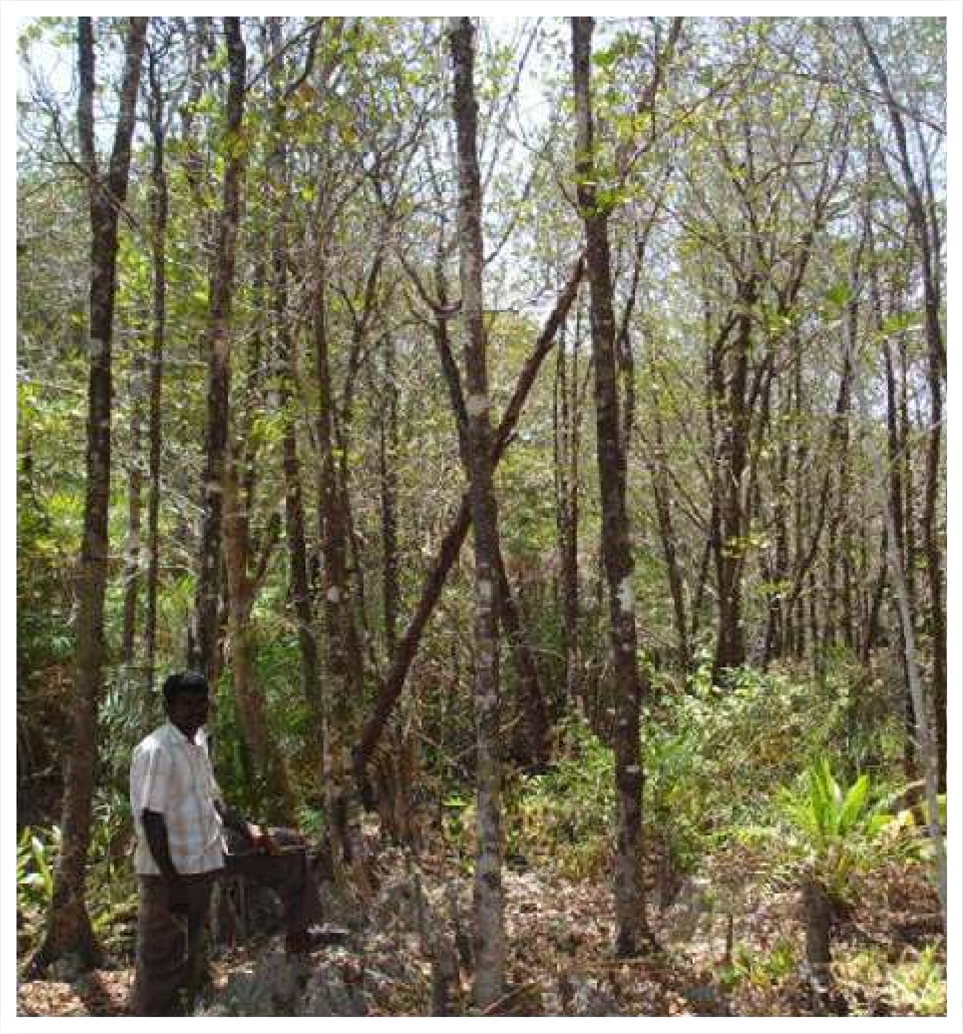
A stunted habit of *B.cylindrica* showing scanty reproduction in hypersaline patch.

A *B. cylindrica* flower in its protandrous phase

Early aborted stage of propagules in *B. cylindrica*

Reviving *Rhizhophora* vegetation in Long Islands

Rhizhophora mucronata growing in a hypersaline coral patch in
Rameshwaram, Tamil Nadu



A mangrove vegetation of *Ceriops tagal* slowly replaced by deciduous elements.

Breeding system data recording in *Ceriops tagal*

Tagging anthesis in *B. sexangula*

Fully grown *B. cylindrica* patch in Pichavaram

A fully anthesised *B. cylindrica* flower

Annual measurement and regeneration in
Pichavaram with preponderance of halophytes (Suaeda)

Cross section of ovary showing
Cellularisation of embryo

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