Mangrove forests of India

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Mangrove forests of India are globally unique with the highest record of biodiversity, gifted with the mangrove genetic paradise at Bhitarkanika, and the globally threatened wildlife species in the Sundarbans. The Sundarbans of India and Bangladesh is the only largest mangrove forest in the world colonized by the Royal Bengal Tigers. Mangroves are dense and floristically diverse along the east coast of India and the Andaman and Nicobar Islands. They are largely distributed in the high energy tidal coast of two extreme conditions: (i) humid and wet in Sundarbans with rich biodiversity, and (ii) arid and dry in Gujarat with low biodiversity. Despite increasing pressures, the mangrove cover in India increases annually at the rate of 1.2%, as against the global mangrove cover that disappears at 0.66%. However, India has a large track of sparse mangrove stand. This article discusses the present status of mangrove forests, conservation and management strategies being followed successfully in India, and recommends the future directions for mangrove restoration, improvisation of sparse stands, participatory management, and quality publications on mangrove research.

Keywords: Bhitarkanika, mangrove forest ecosystems, management, Sundarbans.

MANGROVES are woody plants, forming the only tall tree forests in the world, ably located between land and sea in tropical and warm temperate coasts. Mangroves are specially adapted to harsh environment, where no other plant species can survive. This is a structurally simple forest system with the highest biomass production in the intertidal and estuarine areas, and its standing crop is greater than any other aquatic systems on the Earth. It is structurally and functionally unique to have well-developed aerial roots, viviparous germination, salt regulation, and nutrient retention. Mangroves are the only 'blue carbon' forests of the ocean, and are also known as 'Coastal woodland', 'Oceanic rainforest' and 'Tidal forest'[1,2]. It is a rare type of forest in the world with only 73 tree species, occupying 15.2 million hectares in 123 countries[3].

Mangrove forests are ecologically significant and economically important. They provide ecosystem services worth at least US$ 1.6 billion each year and support coastal livelihoods worldwide[4]. They serve as the nursery, feeding and breeding grounds for crabs, prawns, mollusks, finfish, birds, reptiles and mammals. A large amount of global fish catches (up to 80%) is dependent on mangroves, thereby ensuring the food security of coastal people[5]. The mangroves provide firewood, timber, cattle feed, honey, medicines and tourism development. They protect groundwater aquifers from seepage of seawater, thereby ensuring water security for coastal population. Mangrove forests remove coastal pollution particularly toxic heavy metals. They offer coastal protection against the fiery effects of natural calamities such as tsunami, storm surges, cyclone and floods[1,2,6]. The potential of mangroves in carbon capture and sequestration is remarkable in mitigating the impacts of global warming and climate change[7,8]. In India, mangrove forests can remove nine tonnes of CO_2 everyday which is approximately equivalent to 270 billion US dollars in the international market[2]. Long term survival of mangroves is at a great risk and it is possible that the ecosystem services offered by the mangroves may totally be lost in the world within the next 100 years[9]. With increasing destruction and degradation, it is critical to understand the mangrove forests of India for the present status and future actions required for effective conservation and management.

Mangroves in India: uniqueness

India has a mangrove forest cover of 4740 sq. km, occupying only 2.8% of global mangrove forest. Sundarbans has the largest mangrove cover, occupying 44% and Gujarat has the second largest cover with 23% of total cover in India[10]. The two areas alone occupy 67% of the mangrove cover, surprisingly in adverse condition of high energy tidal coast, experiencing two extreme situations. For instance, Sundarbans is in humid and wet condition with high biodiversity, whereas the mangrove forest of Gujarat is in arid and dry condition with low biodiversity.

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Interestingly the Andaman and Nicobar islands have the third largest mangrove forest in India, occupying 13% of the total cover, located in low energy tidal coast with rich biodiversity.

Sundarbans is internationally recognized as the world heritage site of UNESCO. The Gangetic Delta in which Sundarbans is situated is the largest wetland with the highest sedimentation in the world. Sundarbans in India and Bangladesh put together is the largest mangrove forest, and it is also the only mangroves colonized with the Royal Bengal Tigers, in the world. This is the dense mangrove forest, unique in extending 100 kilometers inland from the sea front, and the flora and fauna residing here have amazingly adjusted to the rigorous ever-fluctuating tidal environment. Sundarbans supports globally threatened species such as tigers, fishing cat, gangetic dolphin, estuarine crocodile, horse shoe crabs, water monitor lizard and river terrapins[1,2].

India is the third richest country for mangrove biodiversity in the world, after Indonesia and Australia[11]. Bhitarkanika in the Odisha state is considered as the 'mangrove genetic paradise' in the world, like the one in Baimaru of Papua New Guinea. Bhitarkanika is also associated with the largest population of birds and crocodiles especially albino crocodiles. Other natural treasures along the mangroves in India are: (i) world's largest nesting site for the Olive Ridley turtle in Gahirmatha coast of Odisha; (ii) seagrass meadows associated with the seacow (Dugong); (iii) coral reefs associated with most beautiful ornamental fishes; and, (iv) intertidal mudflats teeming with the migratory and residential birds, of about 2 million, belonging to 200 species[2]. Mangroves are worshipped in several places around the world; there is a temple for mangroves in Chidambaram of Tamil Nadu, where the mangrove species, *Excoecaria agallocha* has been worshipped for the last 17 centuries[1,2].

India has the highest record of biodiversity in mangrove forests of the world and no other countries have recorded so many species to be present in the ecosystem. So far, 4107 species including 23% of flora and 77% of faunal species have been recorded. Eight groups of organisms are dominant by exceeding 100 species and they are mangrove species (true mangroves + mangrove associates), marine algae (phytoplankton + seaweeds), fungi, crabs, mollusks, insects, other invertebrates and finfish[12] (Table 1).

Present status of mangroves

Mangroves are dense, healthy and floristically diverse along the east coast of India and Andaman and Nicobar Islands, compared to the west coast of India. The east coast has 59% of total mangrove cover, with 88% of mangrove species in India, whereas the west coast has 28% of cover, with 62% of mangrove species[13]. This can be attributed to the mighty rivers (e.g. Ganga, Brahmaputra, Mahanadhi, Krishna, Godavari and Cauvery) along the east coast that form deltas, rich in sedimentation, upstream water discharge, nutrient-rich alluvial soil, in addition to the smooth topography, which increases the intertidal areas for colonization of mangroves along the east coast. On the contrary, the west coast has narrow intertidal areas due to steep coast, and absence of deltas as a result of funnel-shaped estuaries. The Andaman and Nicobar Islands have 13% of the total mangrove cover, endowed with 75% of mangrove species, colonizing in low energy tidal coast with accumulation of peat and calcareous materials in coastal fringes, tidal estuaries, small rivers, neritic inlets and lagoons[14].

According to the Forest Survey of India, Dehradun, the mangrove coverage was 4046 sq. km in 1987 and was 4740 sq. km in 2015, based on remote sensing data (Table 2). In the past 28 years, the mangrove cover decreased in Andhra Pradesh and Andaman and Nicobar Islands at 0.95% and 0.36% per year respectively, whereas it increased in all other places by 58.6% in Maharashtra; 16.1% in Odisha; 159.3% in Gujarat; 2 folds in Tamil Nadu and Puduchery; 3 folds in Karnataka, Daman and Diu; 9 folds in Kerala and, 26 folds in Goa. There was a marginal increase of only 1.5% at 0.054% per year in the Sundarbans. Overall, the mangrove cover increased by 17.2% over 28 years at 0.61% per year in India.

Mangrove cover in India increased by 112 sq. km between 2013 and 2015 at 1.2% per year as against global

Table 1. Total number of floral and faunal species reported to exist in mangrove ecosystems of India

Groups		No. of species
Floral groups:	Mangroves	44
	Mangrove associate plants	86
	Seagrass vegetation	11
	Marine algae (phytoplankton + seaweeds)	557
	Bacteria	69
	Fungi	103
	Actinomycetes	23
	Lichens	32
	Total of floral species	925
Faunal groups:	Prawns and lobsters	55
	Crabs	145
	Insects	661
	Mollusks	337
	Other invertebrates	745
	Fish parasites	7
	Fin fish	554
	Amphibians	13
	Reptiles	84
	Birds	513
	Mammals	68
	Total faunal species	3182
	Total number of species	4107

Table 2. Change of mangrove cover in different maritime states and union territories of India between 1987 and 2015 according Forest Survey of India

State/UT	Mangrove cover (sq. km)		Change of cover between 1987 and 2015	
	1987	2015	Area (sq. km)	Percentage of increase, loss or fold of increase
Andhra Pradesh	495 (12.4%)	367 (7.7%)	–128	–25.9
Andaman and Nicobar	686 (17.2%)	617 (13%)	–69	–10.1
Gujarat	427 (10.7%)	1107 (23.4%)	+680	+159.3
Maharashtra	140 (3.5%)	222 (4.7%)	+82	+ 58.6
Odisha	199 (5.0%)	231 (4.9%)	+32	+16.1
West Bengal	2,076 (51.9%)	2106 (44.4%)	+30	+1.5
Goa	0	26 (0.5%)	+26	+ 26 fold
Kerala	0	9 (0.2%)	+9	+9 fold
Daman and Diu	0	3 (0.06%)	+3	+3 fold
Karnataka	0	3 (0.06%)	+3	+3 fold
Tamil Nadu	23 (0.58%)	47 (1.0%)	+24	+2 fold
Puducherry	0	2 (0.04%)	+2	+2 fold
Total	4046	4740	+694	17.2

Values in parentheses are percentage of total cover.

mangroves, which disappear at 0.66% (refs 3, 10). However, the open sparse mangrove cover is 40% in the country[10]. This deserves attention for its transformation into a dense mangrove cover. Further, India has two globally threatened species (*Heritiera fomes* and *Sonneratia griffithii*) of the total 11 species under IUCN Red List[15,16]. These two species are nearing local extinction due to low-seed viability and slow growth[15]. Sundarbans in India is named after the beautifully looking species, locally known as 'Sundari' (*H. fomes*), but these species here are disappearing fast[15]. Further, there are eight mangrove species recorded only in Andaman and Nicobar Islands, and they are *Lumnitzera littorea*, *Rhizophora* × *lamarckii*, *Rhizophora* × *mohanii*, *Sonneratia* × *urama*, *Sonneratia* × *gulngai*, *Sonneratia griffithii*, *S. lanceolata* and *S. ovata*[11].

Drivers and pressures on mangroves

Mangrove forests continue to be stressed by various factors like conversion for urbanization, aquaculture, agriculture, salt farming and other developmental activities such as tourism, mining, refineries, oil pipeline passages, port/harbour, dam and road constructions; changes in hydrological regimes; increasing salinity; coastal pollution; siltation; exploitation of fishery resources; cattle grazing; private ownership and ineffective institutional regimes. Specific stressors are: (i) agriculture and prawn seed collection in the Sundarbans, West Bengal, (ii) prawn farming and encroachment in Andhra Pradesh and Odisha, (iii) cattle feed in Tamil Nadu and Gujarat, (iv) industrial developments in Gujarat, (v) cyclone and floods along east coast, (vi) mangrove areas under private lands in Kerala, Maharashtra and Karnataka; and (iv) urbanization in Mumbai[14].

There is a growing threat of climate change especially sea level rise in low lying coastal areas of the country. Mangrove habitats of the east coast have a smooth slope, whereas the west coast except Kerala has a steep slope. Hence, the east coast of India and Kerala are vulnerable to sea level rise, than the west coast[12]. After the 2004 tsunami, the coastal soil salinity has increased which changes the floral species composition and affects the benthic organisms in the mangrove sediments particularly along the east coast[17].

Management of mangrove forests: success stories

Despite increasing pressures, mangrove forests are successfully managed in India by adopting three management strategies: (i) promotory; (ii) regulatory and (iii) participatory[12]. In the promotory approach, the Government of India implements the Management Action Plan (MAP) in 38 mangrove areas, identified all along the coast. In the regulatory approach, India is strong on the policy front with sufficient legal support for mangrove protection in the National Park, Wildlife Sanctuary, Reserved Forests, Protected Forests and Community Reserves; however, effective implementation of the legislations is often constrained by lack of financial and human resources, poor infrastructure and lack of political will[12]. Focus on participatory management involving all stakeholders especially from the industrial sectors is essential. In this regard, India has demonstrated the best practices of conservation and management of mangroves, and they are (i) Canal bank planting with 'Fish Bone' design for mangrove restoration; (ii) Maharashtra Mangrove Conservation Model; (iii) Kannur Mangrove Mission and (iv) Participatory mangrove management model.

Canal Bank planting with 'Fish Bone' design for mangrove restoration

Mangroves are largely degraded in Tamil Nadu and Andhra Pradesh. The reason for the degradation is attributed to high salinity of dry soil as a result of lack of regular tidal flushing due to low tidal amplitude[18]. To overcome this situation, the M. S. Swaminathan Research Foundation (Chennai) and the Forest Department demonstrated the 'Canal-Bank Planting' technique with 'fish bone' design, in Muthupet and Pichavaram in Tamil Nadu as well as East Godavari and Krishna districts of Andhra Pradesh[19,20]. In this technique, canals are formed so that the high saline soil gets regular tidal inundation, leaches out salts and becomes suitable for mangrove restoration. This effort was undertaken with the participation of local mangrove user communities resulting in increased forest cover by about 90% in the degraded areas of Pichavaram mangrove wetland, between 1986 and 2002 as proved by satellite data[21].

Maharashtra Mangrove Conservation Model[22]

The Government of Maharashtra initiated mangrove conservation, after the landmark order of the Bombay High Court on 6 October 2005. The high court order prohibited all constructions in mangrove areas as well as within 50 m radius from the mangrove boundary. It also directed that mangroves on government land be declared as 'protected areas' under the Indian Forest Act and transfer them to the forest department. As a result, 5469 ha of mangroves on government land were transferred to the Thane Forest Division by the revenue authorities. However, such efforts for the rest of the mangrove areas in Maharashtra are yet to be undertaken[22].

The Government of Maharashtra constituted 'Mangrove Cell' in January 2012, and then the 'Mumbai Mangrove Conservation Unit' in 2013 to protect mangroves in Mumbai and the adjoining areas, and elevated the status of mangrove forests on government land from 'protected forests' to 'reserved forests'. This led to notification of 15,088 hectares of mangroves on Government land as 'reserved forests' in seven districts of Maharashtra. The mangrove cell also achieved plantation in more than 200 ha of mangrove degraded areas in the Greater Mumbai region. In addition, the cell demarcated the areas under the control of Forest Department on the ground with boundary markings, based on satellite mapping at 1 : 50,000 scale. As a result of all these efforts, the mangrove cover increased phenomenally by 20% between 2013 and 2015 (ref. 22).

Further, the Mangrove Cell undertook the UNDP-GEF project on 'Mainstreaming of Coastal and Marine Biodiversity into Production sectors in Sindhudurg District' during the mid-2012. Under this project, the cell implemented a number of programmes such as deployment of artificial reefs; transplantation of corals; identification and protection of sea turtle nesting sites; release of the turtle hatchlings into the sea; survey of corals, coastal birds, sea snakes, otters, monitor lizards and marine mammals (dolphins and finless porpoises). The cell detected blue whales and Bryde's Whales for the first time, and safely released the two stranded blue whales to deep waters with the help of local people. The Cell has also promoted crab, oyster and seabass fish farming practices in the mangrove waters, as supplementary livelihood for the benefit of local people. In addition, the Mangrove Cell implemented GIZ project 'Sustainable Management of Coastal and Marine Protected Areas' in 2014 under 'International Climate Initiative Agreement' between Governments of India and Germany. This led to the notification of the 'Thane Flamingo Sanctuary', which spreads over an area of 1690 ha and supports 10 mangroves and 200 bird species[22].

The Mangrove Cell has successfully demonstrated a cross-sectoral approach towards marine and coastal conservation, in partnership with leading national institutions, agencies, NGOs and with a wide range of Government departments such as Fisheries, Agriculture, Tourism, Police, Revenue, Urban Development, etc. The government of Maharashtra has recently set up a registered body of 'Mangrove and Marine Biodiversity Conservation Foundation of Maharashtra', for promoting conservation and management[22].

Kannur Mangrove Mission

The 'Mission Mangrove Kannur' was taken up by the District Collector, Kannur (Kerala), along with the forest department in May 2014 to survey, notify and save mangroves of the district. The mission took 14 months to achieve its goal for the first time in Kerala. As a result, a comprehensive survey of mangroves was completed and 236 ha of mangroves was notified as 'Reserved Forest', for permanent conservation. In addition, the mission started the process of acquisition of 1,200 acres of mangroves from private owners[23].

Participatory mangrove management

In India, mangroves are managed prominently in the states of Tamil Nadu, Odisha, Andra Pradesh, West Bengal and Gujarat through community-based co-management[24]. With financial support from Indo-Canada Environmental Facility (ICEF), New Delhi, the M. S. Swaminathan Research Foundation achieved Joint Mangrove Management (JMM) for restoration and conservation of mangroves through the participation of local people along with the forest departments. The JMM project involved 5240 families from 28 villages along the east coast of India.

About 1475 ha of mangroves were restored by planting 6.8 million mangrove saplings. To empower local people, 194 self-help groups were organized to implement poverty alleviation programmes such as supplementary income-generating activities for firewood, fodder, fencing and house construction. A similar effort was undertaken by the Gujarat Ecology Commission with financial support of ICEF, New Delhi. This project has promoted community-based regeneration and management of the mangroves in about 5000 ha area along the Gulf of Kachchh and Gulf of Khambhat in five years from 2001 to 2006.

Mangroves for the future

India had a mangrove cover of 6000 sq. km during year the 1960s, and it has reduced by 21%, i.e. 4740 sq. km. However, since 1995, the mangrove cover has got stabilized close to 4500 sq. km with an increasing trend, despite increasing pressures. There was an increase of 112 sq. km mangrove cover between 2013 and 2015, significantly in Maharashtra, Odisha, Andhra Pradesh and, Andaman and Nicobar Islands[10]. It is necessary to achieve a target of 6000 sq. km by restoring the mangroves in potential areas within a period of 10 years. In this regard, the best proven practices of participatory management can be suitably replicated in other mangrove areas.

Mangrove planting efforts have largely been a failure, due to death of planted seedlings. In this regard, 'ecological restoration' is suggested in which right conditions are provided for the mangroves to grow back naturally. It is necessary to understand local ecological conditions and hydrological regimes to restore the hydrology and remove the barriers to natural regeneration. It is also necessary to select appropriate species for planting, and assessment of success and functionality (vegetation, succession, faunistic recruitment, environmental factors and process) in the restored areas. This approach is more effective to ensure the restored mangroves survive and function better[25]. Afforestation refers to the plantation in new areas, whereas restoration refers to the planting in damaged, degraded and destroyed areas. Of the restoration types, natural restoration and hydrological restoration are more preferable than artificial restoration by planting (Figure 1).

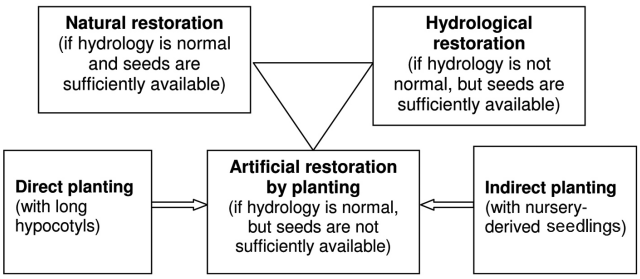

Figure 1. Methods of mangrove restoration and their requirements.

Mangrove species are highly vulnerable to developmental activities. In Bhitarkanika (Odisha), there is an island named 'Kalibhanji dia' situated adjacent to Dhamra Port, and this small island is endowed with most of the mangrove species of India. There are several such areas with rich plant diversity which should be identified along the country and managed as 'Mangrove Germplasm Preservation Centres'. A few species of mangroves are at a high risk of extinction. It is necessary to collect information about the extinct, rare and fast disappearing species of specific areas and understand biology and limiting factors of population reduction in those species. This will help in implementing the recovery of species in the specific areas. More studies are required to understand the interactions between animal and plant communities in the mangrove ecosystem, especially the interdependence between mangrove plant components and pollinators, as well as ants, crabs, gastropods and birds. Much more efforts are necessary to alleviate the stress factors for the loss of mangrove forests.

India is a global leader in mangrove research and management. Our country is ranked third position in mangrove research publications, next to China and USA. Twelve per cent of the total publications on mangroves during 2000–2010 were from India, as against USA and China with 17% and 14% respectively. Among the top 10

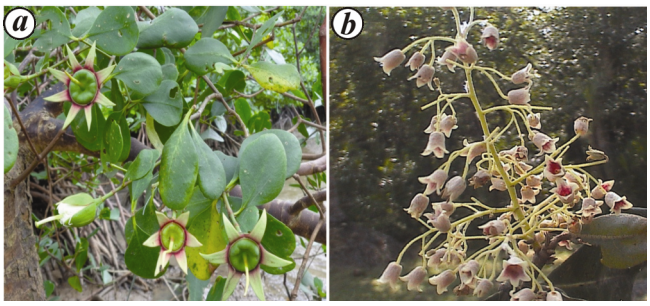

Figure 2. Globally threatened mangrove species of India: shoot branches with (***a***) flowers and fruits in *Sonneratia griffithii*; and (***b***) inflorescence of *Heritiera fomes*.

Figure 3. Mangrove restoration along the Vellar estuary, Tamil Nadu with (***a***) 15-year-old *Avicennia marina*; and (***b***) one-year-old *Rhizophora mucronata*.

highly cited mangrove research publications in the world, two are from India[26]. Our country has the potential to attain the top position, only if high quality publications are increasingly contributed in the years to come. In addition, the Annamalai University has offered training and capacity building for over 250 coastal managers of 28 countries on the management of mangrove ecosystems, with the support of UNU-INWEH and UNESCO since the year 2000.

India is a pioneer in bioprospecting the mangroves, which are a rich source of salt-resistant genes, novel chemicals and high value products such as (i) black tea beverage, (ii) mosquito repellents, (iii) lignins for controlling oral and cervical cancers, (iv) polysaccharides from preventing the Human Immunodeficiency Virus (HIV) that causes AIDS, (v) anti-diabetic extract, (vi) hair growth stimulant, and (vii) rapid synthesis of nanoparticles[27]. Further studies in this aspect will lead to development of patents, processes, and valuable products including medicines.

Mangrove restoration can be a novel counter-measure for global warming as it reduces considerable emission of carbon to atmosphere. It deserves the attention of policy makers in planning for its utilization in carbon market and trading as well REDD (Reducing Emissions from Deforestation and Forest Degradation). The future of mangroves in India requires restoration of ecosystem services of the mangroves with strong involvement of community participation to mitigate the impacts of climate change.

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