Manual on
Mangrove Restoration Techniques

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MSSRF
Science for Sustainable Development

M. S. Swaminathan Research Foundation and
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Introduction

Mangroves collectively refer to plant communities occurring in the inter-tidal areas along the coasts of tropical and sub-tropical countries between 25˚N and 25˚S with the ability to grow in saline water. They often form dense vegetation along the estuaries. Nearly 40% of the world's mangrove cover is in South East Asia and South Asia. Species diversity in these regions is higher compared to other areas of the planet where mangroves occur. Mangroves are taxonomically unrelated groups of trees and shrubs belonging to diverse genera and families possessing similar physiological characters and structural adaptations, enabling them to grow in saline anaerobic environments. They are extremely important coastal resources, supporting livelihoods to the coastal communities. Mangroves serve as a bioshield protecting the coastal areas such as habitations, agricultural lands, livestock and other livelihood assets from tidal water inundation. Mangrove wetlands act as a spawning and nursery ground and also a habitat for fishes, shellfishes, crustaceans and other invertebrates. Mangrove habitats also host a variety of larger faunal species like tigers, monkeys, jackals, fishing cats, otters and reptiles like saltwater crocodiles, alligators and snakes. Coastal mangroves perform regulatory ecosystem functions such as reducing coastal erosion, controlling floods, nutrient recycling and retarding runoff. Apart from these vital ecosystem services, mangroves are potential sites for ecotourism. The ecological importance of these ecosystems in maintaining marine life, their higher productivity and their role in supplying organic matter to the marine ecosystems have been reported across India and in other mangrove growing regions.

Despite their multiple benefits, mangroves are disappearing due to the utilization of mangrove growing regions for economic activities such as aquaculture, agriculture, human habitation and industries. Anthropogenic pressures and utilization of mangroves for fuel wood, timber for domestic needs, fodder and grazing have exacerbated the situation further. Natural geo-climatic events such as cyclones, shoreline erosion, storm surges coupled with strong waves, tsunamis and increasing in salinity levels due to rise in temperature, higher rates of evapotranspiration, siltation of creeks due to sediment deposition, changes in water quality, damming of rivers for irrigation upstream of mangrove growing regions have also affected the extent and health of mangrove ecosystem.

Global Extent of Mangroves

Global Mangrove Watch estimated planetary extent of mangroves in 2020 as 147,000 km^2 (Table 1). Within this, highest mangrove cover occurs in Southeast Asia, with Indonesia alone comprising a fifth of global total mangrove area. Together, Indonesia, Brazil, Australia, Mexico and Nigeria account for half of the world's mangroves. Loss in mangrovecover is reducing appreciably, due to concerted restoration and better conservation efforts along the deltas. The average mangrove loss over the last decade was just 66 km^2 (0.04%) of all mangroves per year (Spalding and Leal, 2022).

Table 1. Mangrove cover worldwide

S. No.	Region	Area (km^2)
1	North & Central America & the Caribbean	22,827
2	South America	20,378
3	West & Central Africa	21,715
4	East & Southern Africa	7,630
5	Middle East	285
6	South Asia	9,549
7	Southeast Asia	48,222
8	East Asia	228
9	Australia & New Zealand	10,467
10	Pacific Islands	6,058
	Total cover	**14,7359**

Mangrove wetlands in India

In India, mangroves occur over an area of about 4,975 km^2, of which West Bengal contributes 42.45%, followed by Gujarat (23.66%) and the Andaman and Nicobar Islands (12.39%). Major mangrove wetlands are situated along the East Coast of India due to extensive estuarine areas in this region. On the West Coast, the mangrove cover is high in Gujarat. On the eastern coast of India, tidal amplitude, quantum of freshwater flow and periodicity decrease from Sundarbans to Muthupet. This correlates with diversity and extent of mangrove wetlands from north to south. Mangrove cover in coastal states of India is listed in Table 2 [data from the

Indian State Forest Report (2021)]. The extent of mangrove cover increased from 4975 to 4,992 km^2 between 2019 and 2021. Within states, Odisha showed an increase of about 8 km^2 followed by Maharashtra (4 km^2), and Karnataka (3 km^2). Restoration activities and natural regeneration are the main factors contributing to the increase in mangrove cover.

Table 2. State-wise extent of mangroves in coastal states of India

S. No.	State	Area (km^2)
1	West Bengal	2,114
2	Gujarat	1,175
3	Andaman & Nicobar Islands	616
4	Andhra Pradesh	405
5	Maharashtra	324
6	Odisha	259
7	Tamil Nadu	45
8	Goa	27
9	Karnataka	13
10	Kerala	9
11	Daman & Diu	3
12	Puducherry	2
.	**Total cover**	**4,992**

Mangrove wetlands in Andhra Pradesh

Mangrove wetlands in Andhra Pradesh are predominately located along the estuaries of the Godavari (Kakinada and B R Ambedkar districts) and Krishna rivers (Krishna and Bapatla districts). Apart from these two major river estuaries, smaller extent of mangroves is found along the coast of Srikakulam, Visakhapatnam, West Godavari, Prakasam, Sri Potti Sriramulu Nellore and Tirupati districts (Fig. 1). The total wetland area in the Godavari and Krishna estuaries is 58,263 ha of which 33,263.32 ha is along the Godavari estuary and 24,999.47 ha along the Krishna estuary. This includes mangroves, water bodies, sandy shore areas, mud-flats and other coastal vegetation. The extent of mangroves as per the State of Forest Report Andhra Pradesh (2014) is about 31,888.74 ha while the recent India State of Forest Report (2021) estimate is 40,500 ha (Table 3).

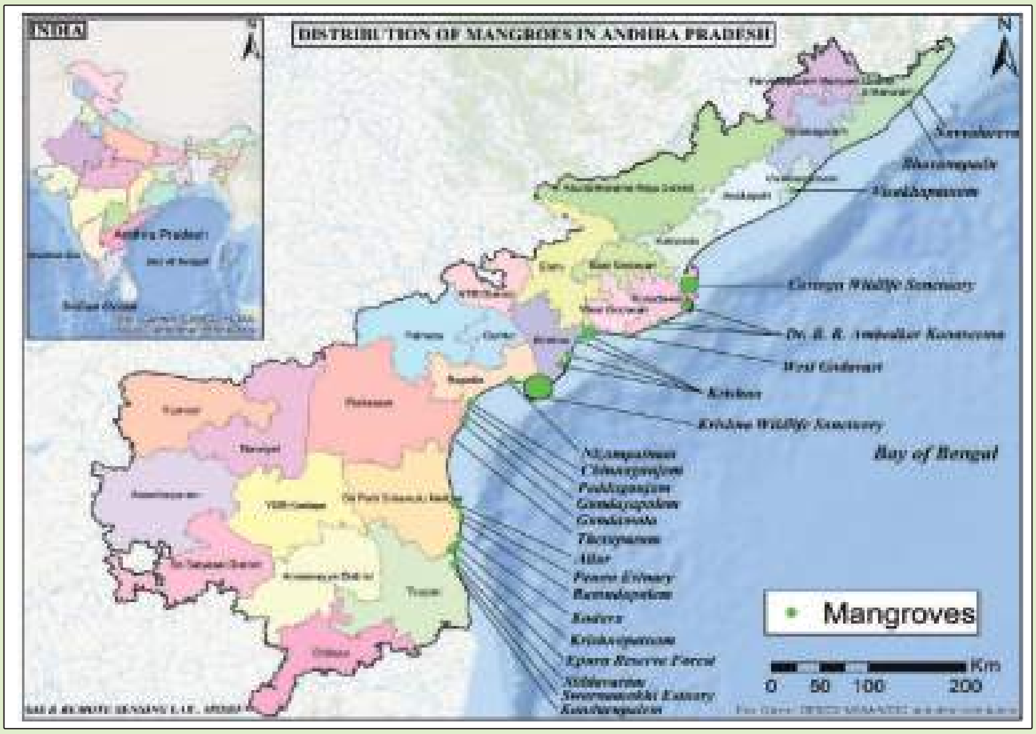


Fig. 1. Distribution of Mangroves along the Andhra Pradesh coast

The Godavari mangrove wetland is located in the Godavari estuary of Kakinada and B R Ambedkar Konaseema districts, Andhra Pradesh (coordinates 16^0 39' - 17^0 N and 82^0 14' - 82^0 23' E). The Godavari River originates near Nasik in Maharashtra and flows into the Bay of Bengal after traversing a distance of about 1,465 km. It is the second-largest river in India, with a total catchment area of about 314,685 km^2. Two-thirds of the catchment flows into the Bay of Bengal. The total area of the Godavari mangrove wetland is 316 km^2 as per the records of the state Forest Department, Government of Andhra Pradesh (Fig. 2).

Table 3. District-wise mangrove extent in Andhra Pradesh

S.No.	Districts	Area (km^2)
1	Kakinada (CWS) and B R Ambedkar Konaseema	187.81
2	Krishna (KWS)	137.76
3	Bapatla (KWS and Nizampatnam)	67.97
4	Prakasam	1.00
5	Nellore and Tirupati	10.24
Total cover		**404.78**

Climatic conditions in the Godavari delta are tropical humid, with warm summers (< 30°C). The monsoon season begins in June and extends till December, with an average rainfall of about 1,160 mm. In January, the weather is mainly dry and progressing gradually to a hot summer between March and May. The delta receives a copious supply of freshwater in the South-West monsoon and watersalinity during this period is low.

Coringa Wildlife Sanctuary and mangrove wetland in B R Ambedkar Konaseema District

The Coringa Wildlife Sanctuary in Kakinada district is about 235.7 km^2 in area and includes Corangi Reserve Forest (RF), Corangi RF extension and Bhairavapalem RF areas (Mittal, 1993). The mangroves in the Coringa sanctuary are connected through Kakinada Bay to the Bay of Bengal. Mangroves in the Coringa sanctuary receive tidal water through Tulyabhaga Canal (Matlapalem Canal), Corangi and Gaderu Rivers. Gaderu and Corangi are distributaries of the River Goutami-Godavari. In addition, a network of numerous small canals, also supply tidal water to these mangroves. The River Goutami-Godavari flows into the Bay of Bengal via two mouths, one near Bhairavapalem in the north and the other near Kottapalem in the south. Rathikalava, Masanitippa, Matlatippa, Balusutippa, Kothapalem and Kandikuppa RFsare situated on the southern side of the delta, located in B R Ambedkar Konaseema district (Ramasubramanian et al., 2006). Fishermen living in the adjoining villages depend on the mangrove wetlands for fishing and other domestic needs. *Avicennia marina* and *Excoecaria agallocha* are the dominant species in the wetland. *Sonneratia alba, Xylocarpus moluccensis, Scyphiphora hydrophyllacaea* and *Brownlowia tersa* also occur but in lesser numbers. The mangroves in Godavari wetlands are healthier than those in Krishna estuarine region due to nature of soil texture as well as higher freshwater flow. Mangroves of the Godavari wetland provided protection to the coastal community and their livelihood assets during the devastating tropical cyclone 07B in the year 1996 in which there were more than 1000 fatalities. Loss of life and livelihood assets was found to be minimized in regions of denser mangrove cover. It also reinforced knowledge among the local communities about the importance of mangroves in providing coastal protection.

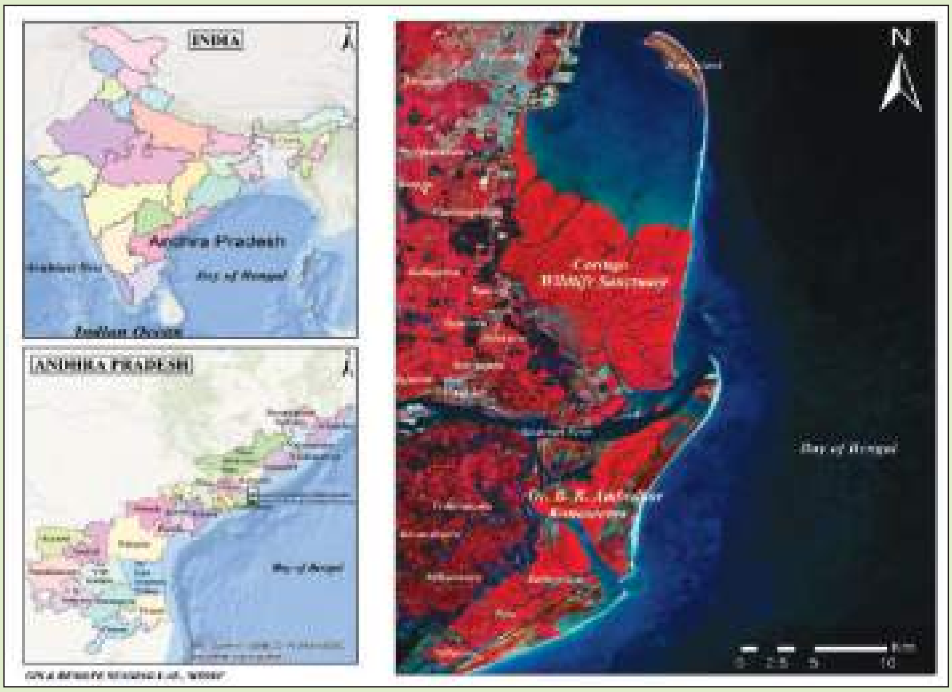


Fig. 2. Distribution of Mangroves in Godavari mangrove wetland

Krishna Mangrove Wetland

The Krishna mangrove wetland is located between coordinates 15° 42' and 15° 55' N and 80° 42' - 81° 01'E and spread across Krishna and Bapatla Districts of Andhra Pradesh. The extent of mangrove cover is about 250 km^2 (Fig. 3) that is spread across Sorlagondi, Sorlagondi Extn., Nachugunta, Yelichetladibba, Lankivanidibba, Molagunta, Kottapalem Bit-1, Kottapalem Bit-2 and Adavuladivi RFs. The Krishna wetland comprises dense and sparse mangrove regions, tidal mudflats, sand spits, sandy beaches and other water bodies. The River Krishna originates in the Western Ghats near Mahabaleshwar in Maharashtra and travels in the south-eastern direction for a distance of about 1,401 km before merging with the Bay of Bengal. The river divides into three major distributaries and also forms a network of creeks supplying tidal water into the mangroves. The river brings fresh water and sediments during the monsoon season that is a vital nutrient supply for the mangroves to thrive in the wetland. Mangrove resources are utilized by the local community for their domestic needs. The coastal community, particularly the fisher-folk and the Yanadi tribe depend on mangroves for their livelihood. *A.marina* and *E. agallocha* are the dominant species in the wetland. Other mangrove species such as *Ceriops tagal, Xylocarpus granatum* and *Aegialitis rotundifolia* are rare in the wetland. The climate is hot and humid, with the maximum temperature ranging between 23-33°C and the minimum temperature ranging between 19-23°C (Ramasubramanian and

Ravishankar, 2004; Nabi et al., 2012). The area receives nearly 65% of the rainfall during the South-west monsoon and the mean annual rainfall is about 1,100 mm. The soil in the wetland comprises of silty clay.

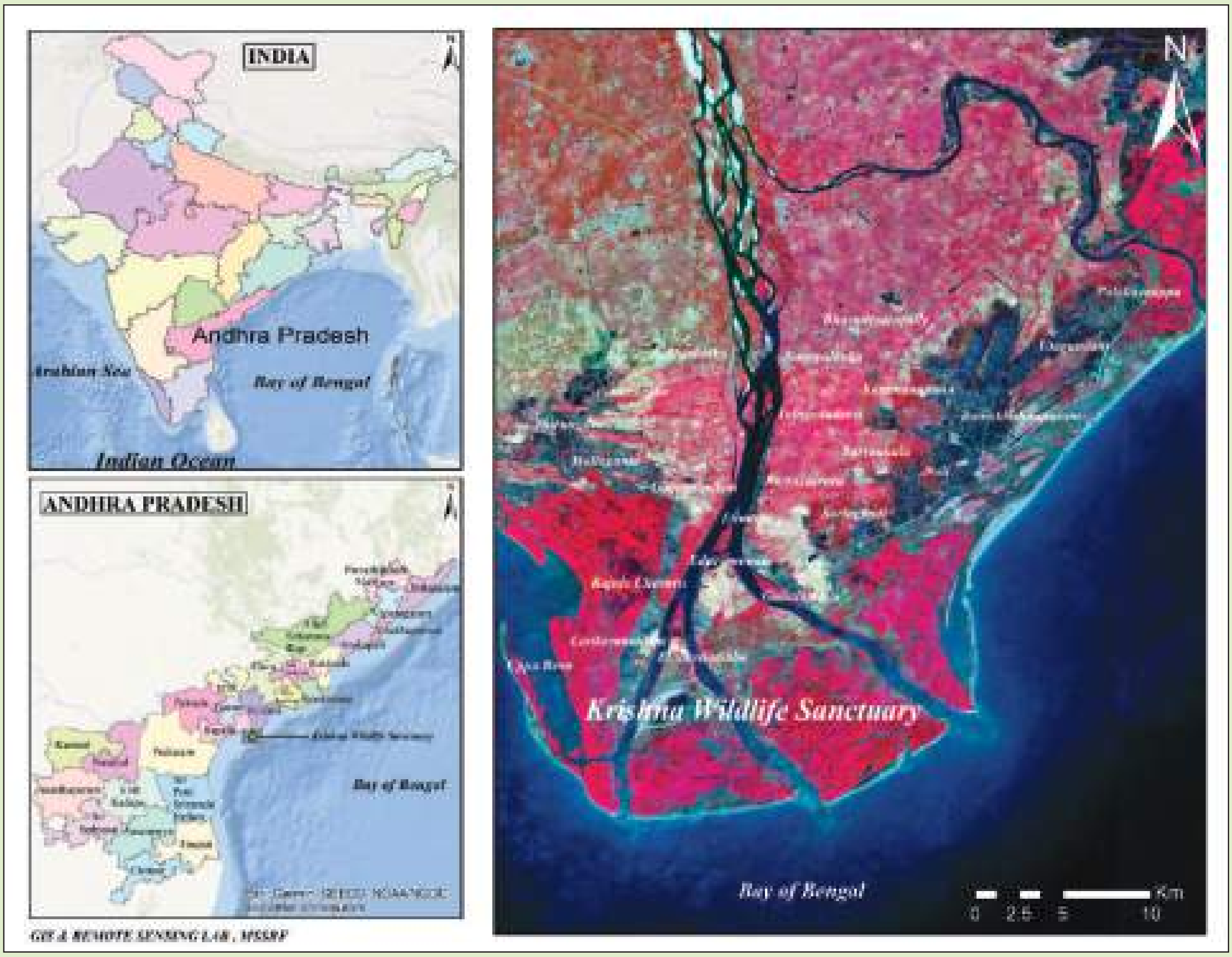


Fig. 3. Distribution of Mangroves in Krishna Wildlife sanctuary

Mangrove wetlands in Nellore and Tirupati districts

The total mangrove wetland area in Nellore district is 1,615.88 ha and is distributed between Krishnapatnam in Nellore district and in Kandaleru Creek in Tirupati district. In Nellore, mangroves are found near Krishnapatnam, along the Buckingham Canal (Muthukuru taluk); Govindapuram (Kota taluk); Kandaleru creek (Kavali rural taluk) and Ipuru (Chillakuru taluk). Kandaleru mangroves spread across an area of about 813.25 ha. Krishnapatnam is situated between 14^{0}15.153' N and 80^{0} 07.385' E. *A. marina, A. officinalis, Rhizophora mucronata, R. apiculata, Bruguiera gymnorrhiza, C. decandra* and *E. agallocha* occur in this area.

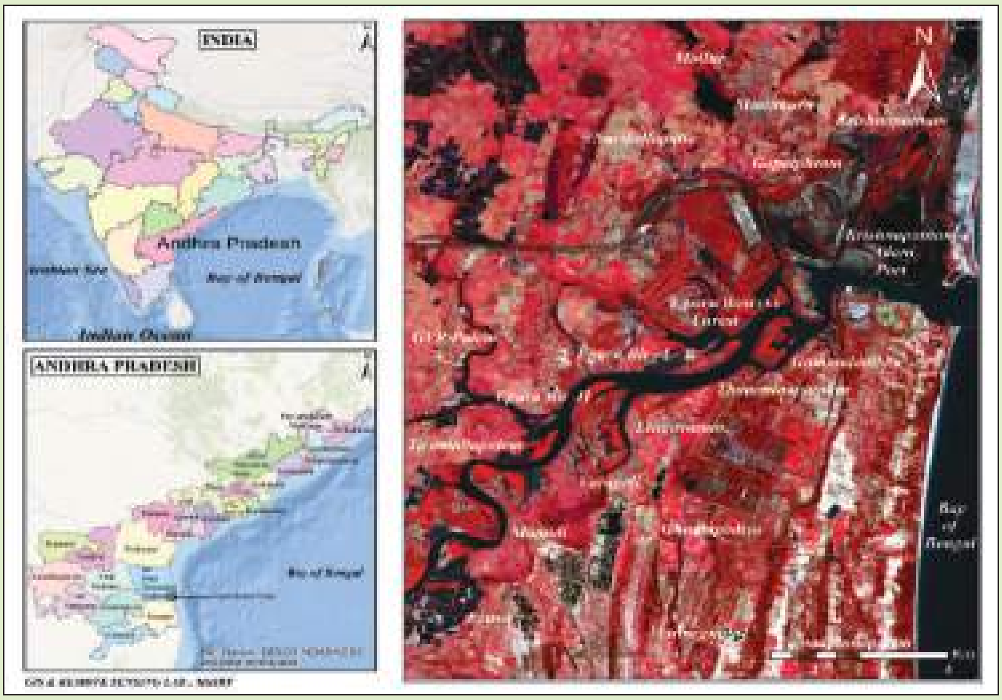


Fig. 4. Distribution of Mangroves in Nellore District

Restoration of Degraded Mangrove areas

Worldwide, mangrove habitat has declined from 225,000 km^2 in the 1970s to about 137,000 km^2 in 2014 (Friess et al., 2019). Restoration has been practised in several tropical countries to increase mangrove cover (Field, 1998; Ellison, 2000; Lewis et al., 2019). Restoration of degraded mangroves is a management strategy to compensate for the loss in the ecosystem goods and services and had added benefits including increase in mangrove resource base, providing employment opportunities to the local community, protecting the fragile tropical coastlines and enhancing faunal diversity including fishery productivity (Mclvor et al., 2012; Spalding et al., 2014; Sandilyan and Kathiresan, 2015).

In the Philippines, planting of mangroves was carried out as far back as the 1930s for timber and charcoal production (Walters, 2003). In Indonesia also, mangrove restoration was initiated in the 1930s for timber production (Ilman et al., 2011). *R. apiculata* was planted in 1978 in mangrove denuded regions affected by herbicide spray during the Vietnam war (Hong, 2001). Many international ecosystem restoration initiatives such as the "Convention on Biodiversity Aichi Target 15",'Global Mangro ve Alliance' and the World Wildlife Fund have been involved in ambitious programs to conserve and restore mangroves. Indonesia announced a target of about 6,000 km^{2}for mangrove conservation by 2024.

The number of mangrove restoration projects being implemented has nearly tripled in the last 20 years and most of these projects have been carried out in Southeast Asia and Brazil (Duarte et al., 2020). Several studies on mangrove restoration were carried out in Thailand, Malaysia, Indonesia, Philippines and Vietnam (Salmo, 2019; Hai et al., 2020; Nawari et al., 2021). In Vietnam, nearly 1,500 km^2 of degraded mangroves were successfully restored between 1978 and 1998 (Van et al., 2016), with an annual average of about 6,000 ha of restored area. Mangrove afforestation and restoration programs increased mangrove cover in the Arabian Gulf and Bangladesh (Uddin et al., 2022). Large scale mangrove restoration projects initiated in the United Arab Emirates (UAE) during the 1970s,resulted a two-fold increase in the mangrove cover (Almahasheer, 2018). In Myanmar, the government has implemented afforestation schemes targeting 1,000 ha of mangroves/year after Cyclone Nargis (2008) that damaged large mangrove areas in the Irrawaddy Delta (Lovelock et al., 2022). Mangrove restoration and management in the Philippines (Garcia et al., 2014), Thailand (Thompson, 2018), Vietnam (Hai et al., 2020), Malaysia (Gopalakrishnan et al., 2021), and Indonesia (Basyuni et al., 2022) has increased the mangrove cover in the respective countries. After the Indian Ocean tsunami in 2004, many large-scale mangrove restoration projects were implemented by the government, as well as national and international non-government organizations (NGOs), to enhance mangrove cover for coastal protection (Lovelock et al., 2022). Restoration of mangroves enhances carbon stock in the soil, creating a potential for carbon trade in the global market. The advantages in artificial regeneration of mangroves include the ability to control species composition and distribution, introduction of genetically superior stocks and reduce pest infestation (Kairo et al., 2001). Mangrove restoration is thus a tool for returning life into degraded mangrove ecosystems.

The Indian Sundarbans Biosphere Reserve conserve mangroves through i) better management practices to minimise degradation and ii) restoration of degraded mangroves and bringing mangroves in the accreted mudflats. Mangrove nurseries have been established in different regions of Sundarbans to provide good quality seedlings for planting. The species planted are mainly *X. granatum, S. apetala* and *Heritiera minor* as potted seedlings; and *R. apiculata, Bruguiera gymnorrhiza* and *Nypa fruticans* as propagules. Seeds of *Avicennia* spp., *E. agallocha* and *Ceriops* spp. are mainly dibbled in the trenches after they are filled with loose mud by tidal waters.

In 1987, the Andhra Pradesh Forest Department (APFD) initiated planting of mangroves in the Godavari wetland near Rammannapalem village over 0.5 ha in a pilot study. Initially, mangrove planting was carried out similar to other terrestrial forests/ agroforestry plantations. Later in 1989, a restoration method involving digging canals to facilitate tidal water flow was evolved. The canals were dug perpendicular to the river and the side canals were at right angles to the main canal. In 1997,in collaboration with MSSRF, the mangrove restoration technique was further refined. Fish bone-shaped canals were dug to facilitate tidal water flow from 1999 onwards. Similarly, in Tamil Nadu planting of mangroves was first attempted in 1987 in the Muthupet mangrove wetland. Different mangrove restoration methods were developed (Baruah, 2004) and among these, the fishbone design has been found to perform better. The restoration of mangroves gained much attention and importance after observing the role of mangroves in disaster risk reduction during the Indian Ocean tsunami in 2004.

Recently, the Government of India launched the MISHTI (Mangrove Initiative for Shoreline Habitats & Tangible Incomes) Programme after India joined the Mangrove Alliance for Climate change during the 27th Conference of Parties. Through this initiative, about 540 km^2 of sparse mangrove cover will be improved in nine coastal states and four union territories between 2023-28. This programme will create 22.8 million man-days of employment for the rural coastal community with an estimated sequestration of 4.5 million tons of carbon.

Causes for Mangrove Degradation

The Mangrove ecosystem in Andhra Pradesh shows degradation due to the following reasons.

Past management practices

The Godavari and Krishna mangrove forests were coupe felled by the forest department for revenue generation till 1972. Some of the coupe felled areas could not regenerate naturally due to changes in the topography and lack of tidal water inundation. This scenario was mostly observed in the Krishna mangrove wetland as compared to the Godavari wetland. These large degraded areas were restored successfully through the fishbone canal method.

Silting of canals supplying tidal water flow

Tidal inundation for at least 10-15 days in a month is important for the mangroves to grow. Siltation in natural creeks blocks tidal water flow on the landward side, increasing soil salinity and leading to mangrove forest denudation.

Formation of topographically elevated areas

Land has become relatively elevated at a few places along the river banks and creeks due to sediment deposition (levees) during floods in the monsoon period. These levees prevent tidal water flow from the creeks into the mangrove wetlands increasing soil salinity. As a consequence, only the fringe areas support mangroves and the mangroves in the interior areas are degraded or sparse.

Reduction in Freshwater flow

Fresh water is very important for the mangroves to grow luxuriantly and the optimal salinity for the mangroves to grow better is 20 parts per thousand (ppt). The Krishna River is highly utilized for irrigation in peninsular India. As a result, there has been a reduction in freshwater flow over a period of time leading to an increase in water and soil salinities. Similarly, in Eperu RF (Nellore District), mangroves are stunted due to reduced freshwater flow in addition to soil texture.

Natural Disasters

In 1977, mangroves in the Krishna estuarine region were severely damaged during the Diviseema cyclone. A storm surge of over 30 feet (near the lighthouse in Sorlagondi RF) had caused extensive sand casting over large areas in the mangrove wetland, resulting in the siltation of creeks that supply tidal water. The vertical elevation of the mangrove wetland due to sand casting also led to degradation/poor regeneration. Cyclone Nargis destroyed nearly 38,000 ha of natural and restored mangroves in the Irrawaddy Delta in Myanmar. Similarly, in the Muthupet mangrove wetland in the Cauvery delta, Tamil Nadu nearly 3 km^2 of mangroves (mostly restored) were destroyed due to Gaja cyclone (India State of Forest Report, 2019). In the Gulf of Carpentaria in northern Australia, about 7,400 ha of mangroves were degraded between 2015 and 2016 due to a combination of extreme temperatures, drought and lowered sea levels.

Anthropogenic causes

Increase in human population, coupled with activities related to economic growth, led to the use of mangrove wetlands for various purposes such as aquaculture, agriculture, construction of roads, ports, harbours and industries. But now due to better legal protection through stringent acts like the Coastal Regulation Zone, Wildlife (Protection) Act (1972), Indian Forest Act and other regulatory measures, conversion of mangrove wetlands for other land uses is illegal. During the late 1980s, the mangrove wetlands especially in the revenue areas, were converted to shrimp farms. Large areas in Krishna and Godavari wetlands located in revenue and private lands were converted for aquaculture.

Degraded area in Krishna mangrove wetland

Mangrove Nursery

In Andhra Pradesh, the matured seeds/propagules of the mangrove species, particularly *A. marina* and *A. officinalis* are available during the period of the north-east monsoon (October and November). These seeds are therefore not available during the planting season, that is, during the southwest monsoon period. On the West Coast, most of the seeds are available during the southwest monsoon. Direct dibbling (planting) of mangrove seeds during November leads to low survival rates because of very little rainfall leading to higher soil salinity. During summer, the soil salinity increases further and thus affects the survival of the newly planted saplings. Generally, the mangrove wetlands in Andhra Pradesh receive fresh water during the south-west monsoon, that significantly reduces soil salinity. To take advantage of this, the mangrove saplings are raised in the nursery and planted during the southwest monsoon period. The survival rate of nursery-raised seedlings in restoration areas is higher when compared to the direct dibbled seeds/propagules because nursery-raised saplings have a well-established root system as they are grown in the nursery for 8–9 months (from October to July). The root system of the planted saplings will be further established well before the onset of summer thus reducing the mortality. The local community, particularly women also get employment opportunities in establishing the nurseries.

Site selection for the mangrove nursery

The site for a mangrove nursery should be in the inter-tidal area, preferably close to a natural creek to receive tidal water or to draw water for raising mangrove saplings. The area should be fenced to prevent grazing by cattle. The site should be accessible either by road or via creek to ensure easy transportation of saplings from the nursery to the restoration site. A water pumping facility should be established for irrigating the saplings as needed. Generally, during February-April, due to reduced tidal amplitude irrigation needs to be facilitated using motor pumps.

Selection of mangrove species for the nursery

A. marina and *A. officinalis* are the most common species available in Andhra Pradesh and also the most preferred mangrove species for raising in nurseries. These species are highly suitable for planting in degraded sites. The matured seeds are available in plenty between October –November. Apart from these species, *E. agallocha* and *Aegiceras corniculatum* are also suitable for planting in degraded areas. In the newly formed mudflats that receive tidal water inundation twice a day, *Rhizophora* spp., *S. apetala* and *A. alba* are highly suitable for planting. Nursery-raised mangrove saplings of these species can be planted to obtain maximum survival rates. Generally, the recommended mangrove zonation pattern should be followed for species selection for planting.

Preparation of sunken beds

The inter-tidal areas close to the high tide line are ideal sites for preparing the nursery as the seedlings will not be submerged over a prolonged period. Submergence of seedlings for a few days will lead to rotting. Sunken beds with dimensions 10 x 1 x 0.25 m (LBD) can be prepared as shown in Fig. 5. Irrigation canals need to be dug to water the saplings. The nursery bags with the sprouted saplings should be placed in the beds, which can then be watered by flooding/pumping. The nursery site and the number of beds may be prepared according to the number of seedlings required.

IntertidalNursery Bed preparation

Nursery bag filling and Soil used for bag filling

Bio-degradable polybags of 5" x 8" are used to raise the mangrove saplings in the nursery. Initially, the soft mud-filled bags should be kept in the shade to harden. Soft clayey mud available in the creeks can be collected during low tide. Debris and hard materials should be removed. The soft mud is made into a paste and used to fill the bio-degradable polybags. Generally, the alluvial soil deposited in the creek is rich in organic matter.

Planting of seeds

The seeds of *A. marina* and *A. officinalis* are soaked in water overnight to remove the seed coats. The sprouted seeds will be then planted in the bags kept outside the beds. *E. agallocha* seeds / young plants can be planted directly in the bags. The polybags are then transferred to the nursery beds after germination. During the initial period, seedlings would be watered twice using rose water cans to obtain maximum germination as water stagnation for an extended period will lead to rotting of seeds.

Maintenance of saplings in the nursery

The saplings need to be maintained in the nursery for at least six months before planting. Casuality replacement, grading, pest control and irrigation are the major activities during the maintenance period.

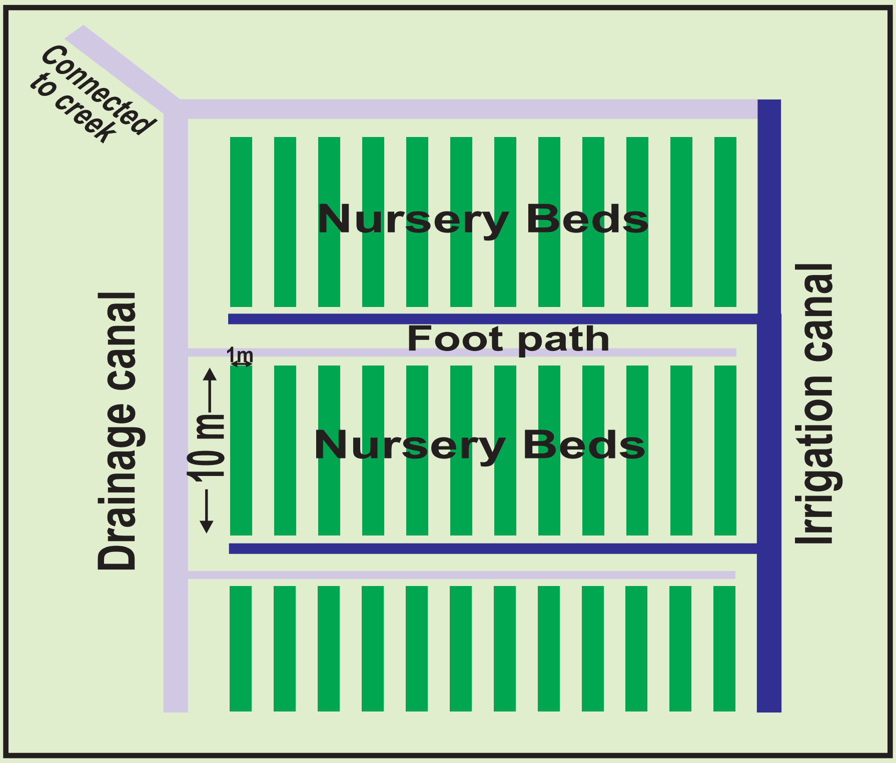


Fig. 5. Intertidal mangrove nursery layout

Intertidal Mangrove Nursery in Coringa Wildlife Sanctuary

Restoration of Mangrove Wetlands

Identification of degraded mangrove areas for restoration

The degraded mangrove areas will be identified through participatory methods such as Participatory Rural Appraisal (PRA) and focus group discussions with the villagers. Since most of the coastal communities living near the mangroves are to be involved in mangrove restoration, it will be easier to identify suitable locations for planting mangroves. Remote sensing images (Fig. 6) especially those obtained using Google Earth will help in the identification and demarcation of the degraded areas precisely. However, this needs to be verified through ground truthing. Site suitability and ownership need to be ascertained prior to initiation of restoration work. Mangrove species will be selected based on the species zonation, soil texture, tidal inundation cycles and physicochemical parameters such as water and soil salinity and pH.

Fig. 6. Godavari Mangrove wetland (1986 Landsat 5 TM) showing degraded areas

Geomorphology and hydrology in mangrove restoration

Based on the contour and hydrological studies (tidal amplitude), the depth and dimensions of the canals will be finalized. In Godavari and in Krishna wetlands, areas lying close to the bunds of creeks/rivers are elevated (levee) in few places compared to areas inside. These levees were formed due to the deposition of sediments during floods and prevent tidal water flow during most of the year except in high flood season (Fig. 7). Similarly, in few areas tidal water stagnates for a prolonged period during monsoon season due to elevated areas in the periphery (Fig. 8). The salinity of the soil increases due to evaporation of water during summer. As a result, in these regions, the seedlings do not regenerate naturally and even those seedlings that establish show mortality due to hypersaline conditions of the soil. Hence, digging fish bone-shaped canals (Fig. 9) is a viable option to reduce the soil salinity by regulating tidal water flow for the mangroves to grow.

The tidal amplitude ranges between 0.6 and 1.5 m in the Godavari and Krishna mangrove wetlands. Generally, during summer, the tidal amplitude is less and during the monsoon season it is higher. Based on tidal amplitude and topography, the layout for fish-bone-shaped canals will be prepared. Generally, 40-50 cm deep canals are preferred to get proper tidal water flushing.

Water stagnation in the degraded area

Halophytes and sparse mangroves in slightly elevated areas

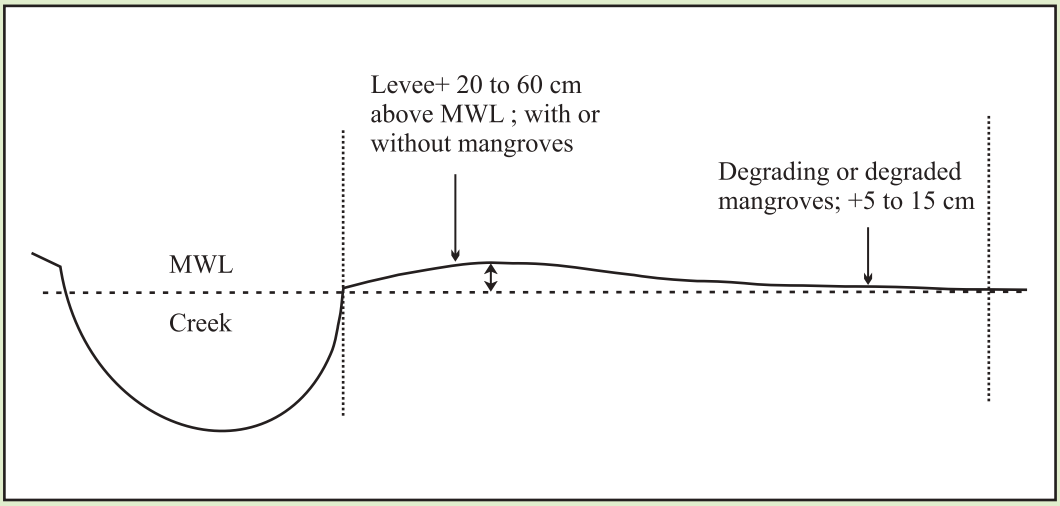


Fig. 7. The degraded elevated area in Godavari mangrove wetland

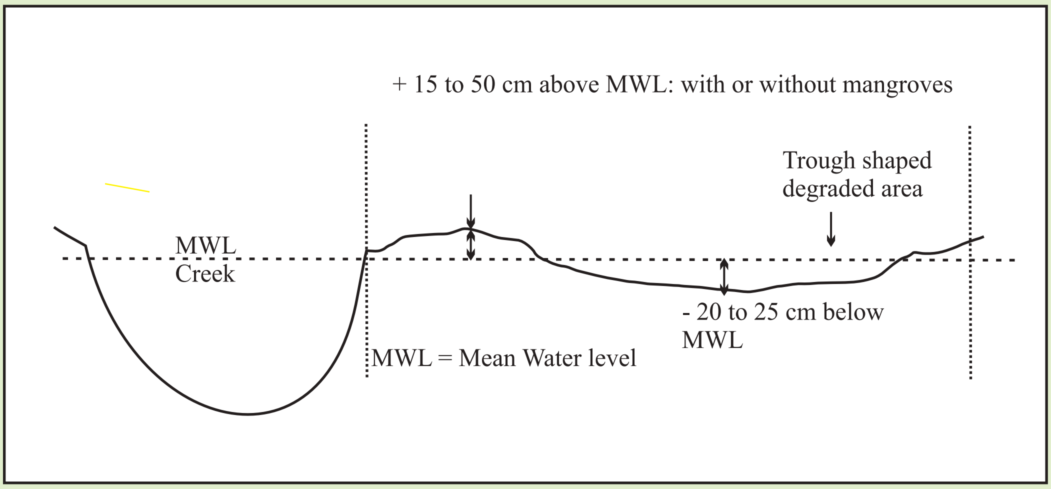


Fig. 8. The degraded area in Krishna mangrove wetland

Dimensions of canals

The depth of the canals near the river/creek should be deeper due to levees found near the natural creeks. The depth of the main canal will vary between from 0.45-0.60 m and the side canals between 0.4-0.6 m as per the topography. The top width of the main canal is usually between 2-3 m and the corresponding bottom width is 0.4-1.25 m. Dimensions of the side canals are as follows: 2 m top width, 0.4 m bottom width and 0.45-0.6 m depth. The distance between the two side canals can vary between 6-8 m. Earlier, distance between the side canals was 12.5 m that was then reduced to 6–8 m to obtain a denser canopy cover (Fig. 10).

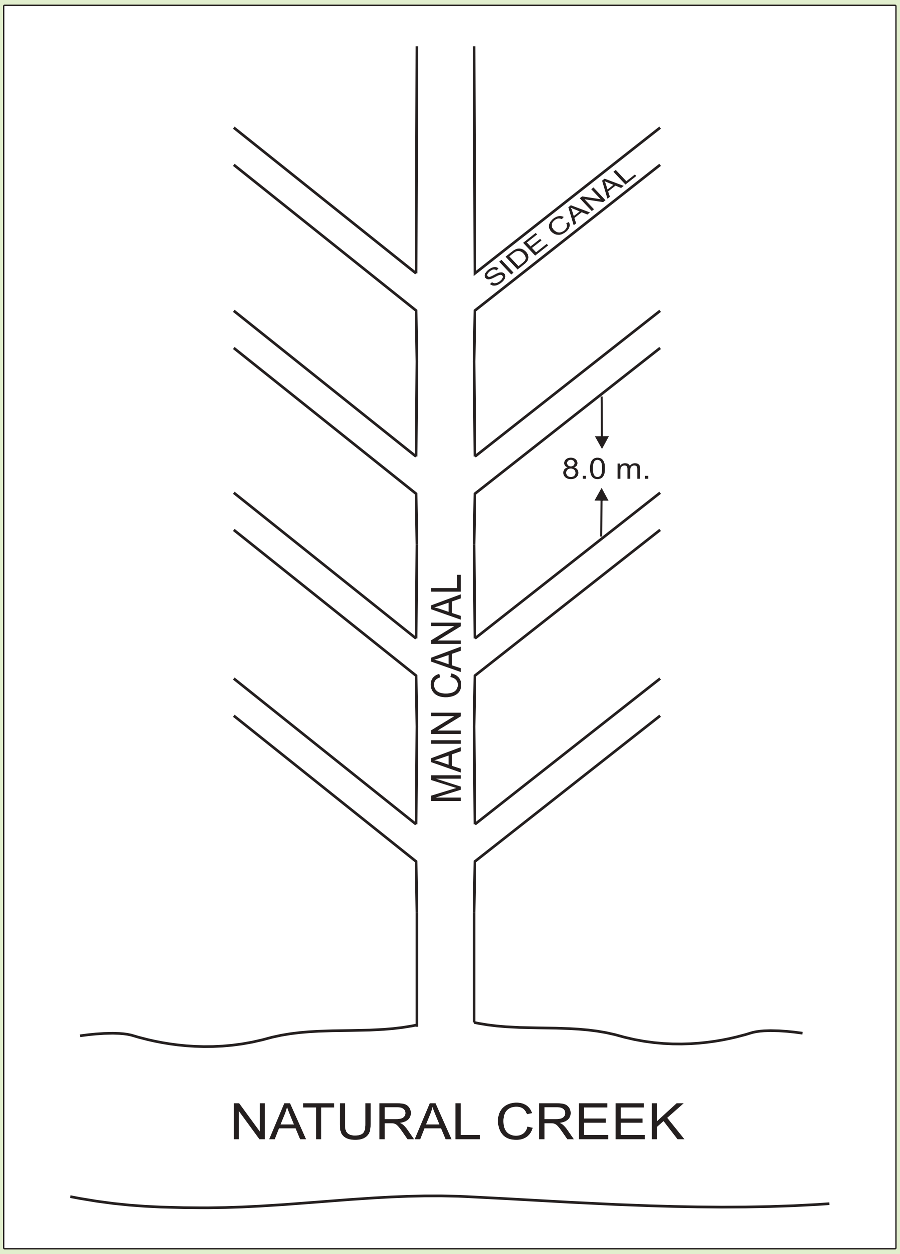


Fig. 9. Fish-bone shape canals

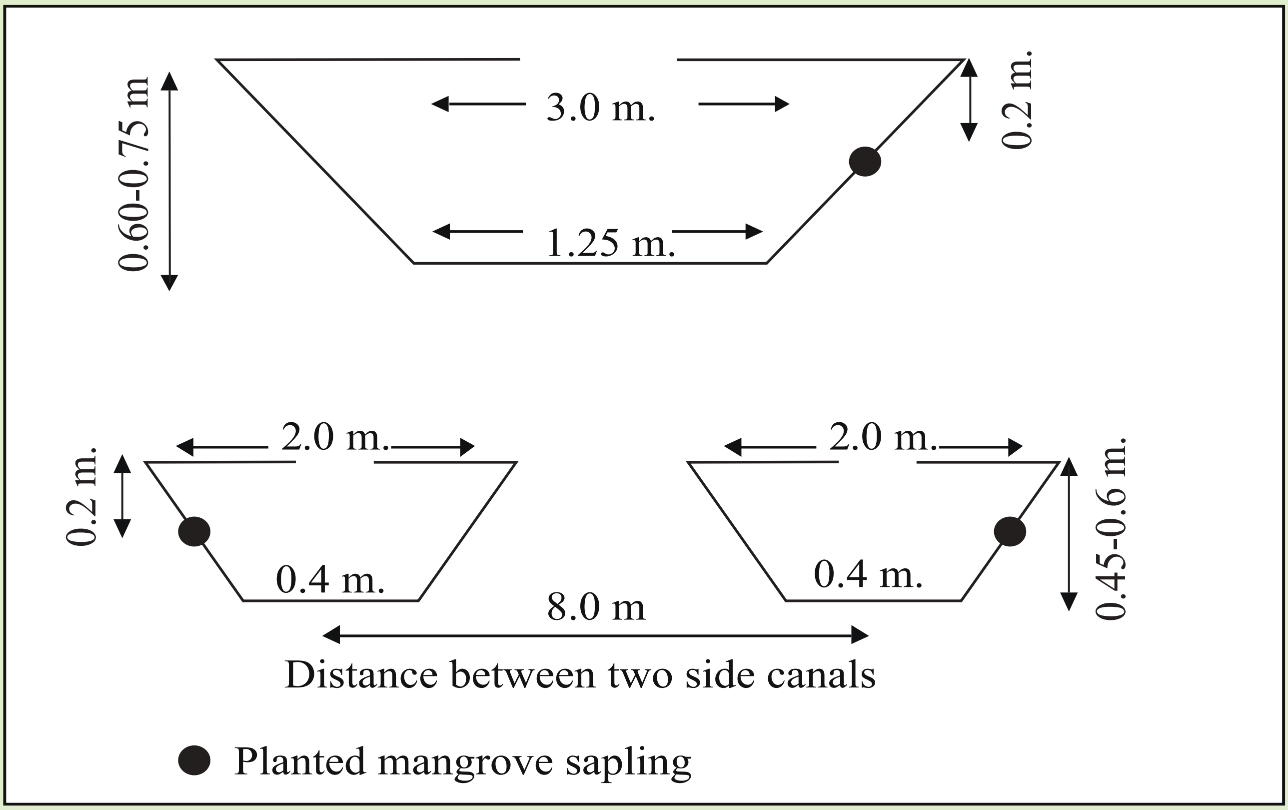


Fig. 10. Dimensions of the canals

Digging of canals for tidal water flushing

Fish Bone canals for planting of mangroves

Selection of species and planting

Mangrove species namely *A. marina, A. officinalis* and *E. agallocha* are highly suitable for planting in the degraded areas in Andhra Pradesh. Generally, the soil salinity of the degraded area will be high (140 ppt) during summer. The tidal water flow through the canals dug for mangrove restoration will gradually reduce the salinity levels of the soil. The young mangrove saplings will survive better in lower salinities. Hence, the planting will be done during the Northeast monsoon (October and November). Rainwater reduces both soil and water salinities during the monsoon and is therefore the ideal time for planting saplings. Generally, mangrove seeds will germinate better in lower salinities (5 ppt).

In addition, other species like *A. corniculatum, B. gymnorrhiza, R. apiculata, R. mucronata* and *X. moluccensis* can also be planted to ensure higher species diversity. Six–eight-month old mangrove saplings raised in the nursery show better survival in the restoration sites. The mangrove saplings will be planted along the slopes (20cm from the top) of the canals with 1-2m spacing between the saplings.

Transport of mangrove saplings

Mangrove saplings in the restoration site

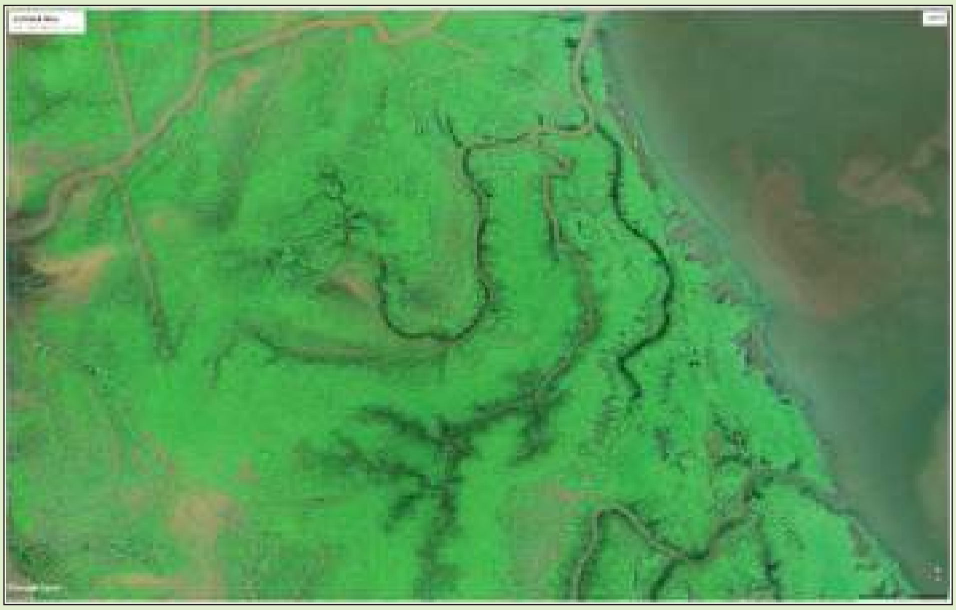
De-silting of canals and casualty replacement

The soil excavated along the canals will silt the canals during the monsoon season. These silted canals should be de-silted before the onset of summer as in summer tidal amplitude is reduced. Tidal flushing during summer will keep the soil salinity in check. Hence, desilting should be carried out before the onset of the summer season. Generally, canals are more silted up in the first and second years. Once the area is covered with *Suaeda* and mangroves species the rate of silting reduces. Hence, desilting in the first 2-3 years is crucial to establish successful planting.

Monitoring survival rates of saplings is very important, at least during the initial two years. Generally, mortality rates are high during the first year. Desilting of canals and casualty replacement in the initial years are very important for the success of the mangrove planting drives. Nursery-raised mangrove saplings/direct planting of seeds can be done for casualty replacement. Once the trees start fruiting (generally after 3-4 years), large number of seeds fall below, leading to natural regeneration, sometimes forming dense mangrove cover. Some of the restored sites in Krishna and Godavari regions are very dense.


Desilting of canals for facilitating tidal water flow


Restored area near Gadimoga in the Coringa Wildlife sanctuary - Left (Google Earth 2003 image) and Right (Google Earth 2022 image)



Restored area in Sorlagondi RF in Krishna Wildlife sanctuary (Google Earth 2023 image)

Community involvement in mangrove restoration

Participatory mangrove conservation and management is very important to get better results. The APFD and MSSRF involve the local community as the main stakeholders in mangrove restoration and management. The APFD has formed Eco-Development committees in the villages adjoining the mangrove wetlands and implemented mangrove restoration activities through these village-level institutions. This approach will help to sustain mangrove conservation and management activities and also encourage ownership of the communities on mangrove wetlands. Mangrove restoration will also provide employment opportunities.

Impact of Mangrove Restoration in Andhra Pradesh

The land use/land cover study showed that the extent of mangroves in the Godavari wetland has increased from 178 km^2 in 1990 to 226 km^2 in 2020 of which restoration contributed to significant mangrove cover (MSSRF, 2022). In Coringa Wildlife Sanctuary (Godavari delta), the mangrove extent between 1988 and 2000 showed an increase from 107.2 to 114.2 km^2 (Sudhakar Reddy and Arijit Roy, 2008). Similarly, in the Krishna mangrove wetland, the mangrove extent in 1972 was merely 82.76 km^2, dropped to 80.47 km^2 in 1981, and 69.52 km^2 in 1990. However, in 2000 mangrove cover was 101.98 km^2, 138.36 km^2 in 2009 and 158.16 km^2 in 2014. Overall, an increase of 88.64 km^2 of mangrove area was observed from 1990 to 2014 that is due to both mangrove restoration and natural regeneration (Rama Chandra Prasad et al., 2017). The mangrove cover in Krishna and Godavari mangrove wetlands have increased significantly due to better mangrove conservation and management (Figs. 11 &12)

The experience in mangrove restoration in Andhra Pradesh demonstrated that the success of mangrove restoration depends on the following factors: Restoration sites identified should not be elevated much. Generally, elevated areas have very low tidal water flow, are overgrown with *Prosopis* and other terrestrial vegetation. These are very difficult terrains to restore and should be avoided.

Clayey soils are highly suitable for mangrove restoration as the saplings grow better due to retention of soil moisture and also the canals will be more stable in clay soils than the sandy soils. In Coringa Wildlife Sanctuary, the soil is clayey and the land is also not elevated. Hence, most of the restored mangrove areas in the Coringa Wildlife Sanctuary are highly successful. The mangrove areas restored in 1994 near the tourism complex now looks like a natural forest with a lot of species established in a natural succession. The canopy is also very dense.

Dense Mangrove cover in the Restored area during 1994 near Tourism complex in Coringa Wildlife sanctuary

Restored Mangrove area in Kona RF in Machilipatnam

Mangrove restoration in the intertidal areas

Planting of mangrove propagules/ seedlings is also being carried out in the intertidal mudflats where there are no mangroves. Generally, these mudflats will be found in the lagoons as well as shallow coastal areas. Nursery-raised saplings/propagules of *Rhizophora* spp. can be planted in these areas. Since, the newly accreted mudflats receive constant tidal water flushing and the sediments are rich in nutrients, the saplings planted will grow vigorously.

Planting of mangrove saplings in the intertidal areas

Dense Mangrove cover in the restored area in Sorlagondi RF

However, regarding mangroves in the southern Godavari delta (B R Ambedkar Konaseema district) most of the degraded areas are elevated (Rathikaluva RF) due to the deposition of more sediment. The alluvial soil deposits with a mix of drift sand, loamy soil to silt clays are very compact and support mostly *Prosopis* due to lack of tidal water flushing. Krishna wetland also has similar areas along the Krishna River in Nachugunta, Lankavanidibba and Yelichetladibba RFs. Since, Krishna wetlands had large degraded areas with lesser elevation, both the restoration and natural regeneration contributed much to the increase in the mangrove extent. The formation of new mud-flats on the western side of the Lankavanidibba RF (sheltered coast due to less wave energy) has contributed to natural establishment of mangroves over a large area. These mangroves are very dense as the soil is rich in organic matter and also receives tidal water flow twice a day.

These restored sites will improve the fish stock in the mangrove and offshore waters. The local fishers and Yanadi tribal community harvest fishes, crabs and shrimps in the restored areas. The availability of crabs in the restored area is high due to the availability of tidal water and detritus food for them to feed on. Though, *A. marina* is the most suitable species for planting, other species also can be planted in small numbers to obtain higher species diversity. Other species like *E. agallocha* and *A. corniculatum* brought through tidal action will slowly colonise naturally.

Mangrove restoration provides more employment opportunities to the local community. A large number of men and women have been trained in mangrove restoration techniques and will help in expanding mangrove restoration work under the MISHTI programme.

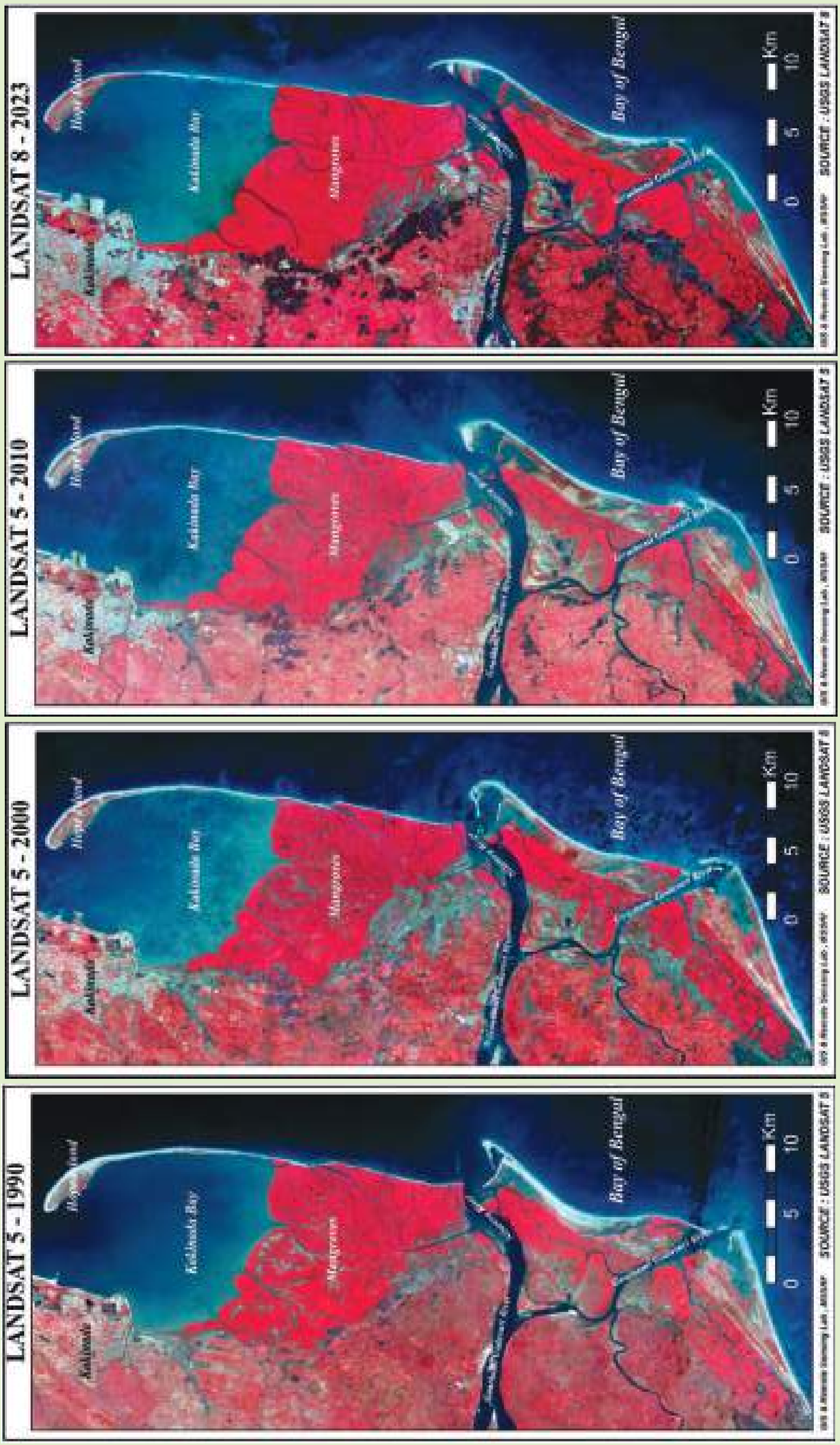


Fig. 11. FCC satellite images of Godavari Mangrove wetland between 1990 and 2023

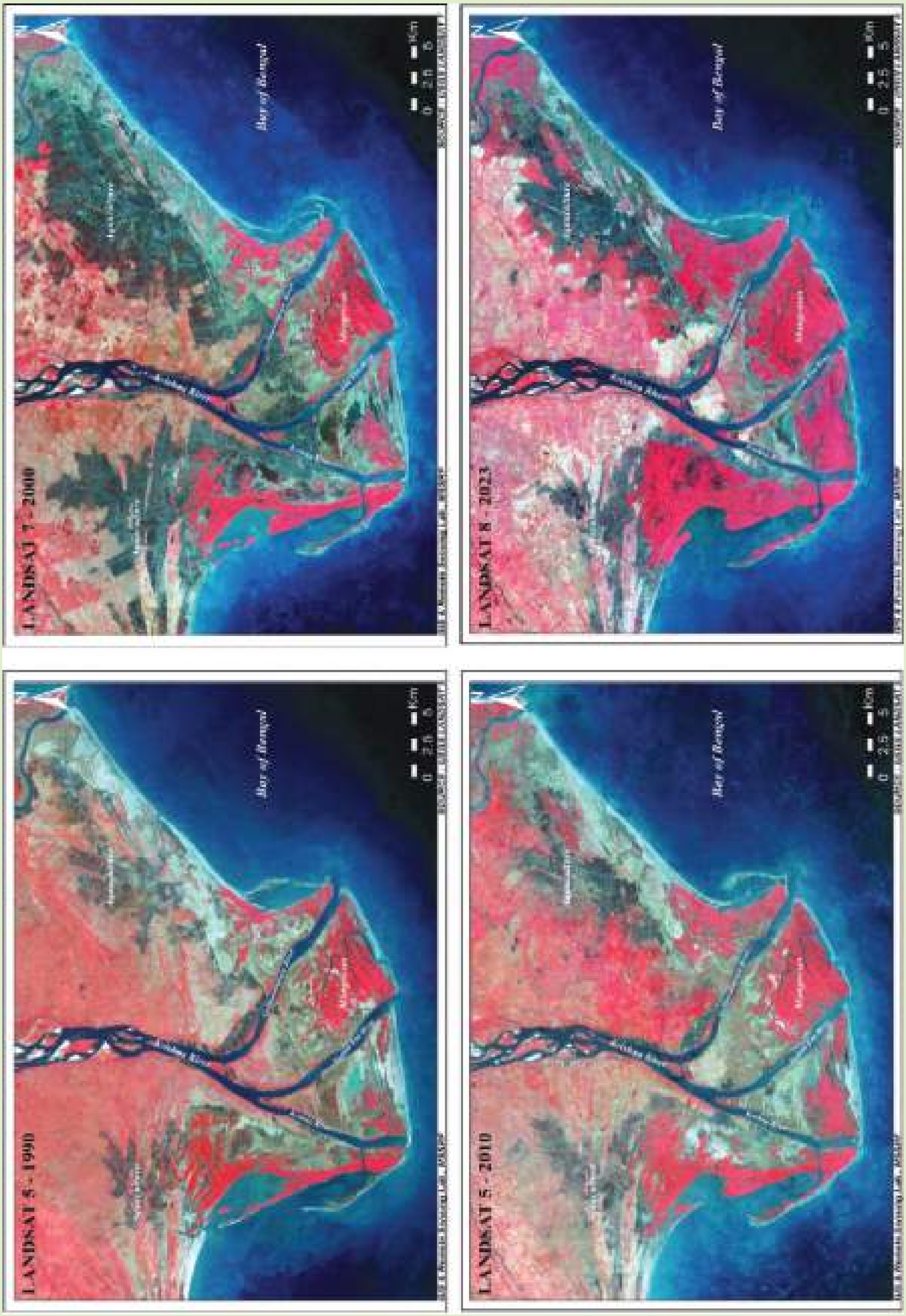


Fig. 12. FCC satellite images of Krishna mangrove wetland between 1990 and 2023

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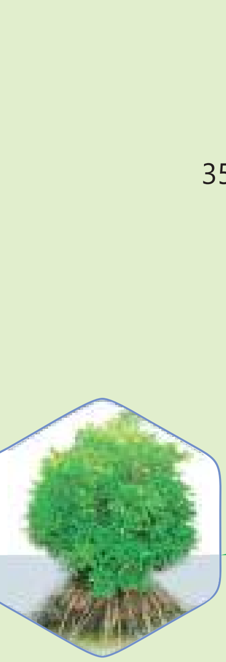

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