



(REVIEW ARTICLE)



Review on mangrove restoration: Re-greening the sea coast

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GSC Biological and Pharmaceutical Sciences, 2023, 22(03), 130–143

Publication history: Received on 03 February 2023; revised on 13 March 2023; accepted on 16 March 2023

Article DOI: <https://doi.org/10.30574/gscbps.2023.22.3.0112>

Abstract

Mangroves are important coastal resources that can provide exceptional ecosystem benefits. Several of its ecosystem functions, including sediment buildup, carbon sequestration, and storm surge protection, are being recognized as practical tools for climate change adaptation and mitigation. Its unique capacity to endure extreme environmental circumstances makes them; in particular, the only viable option for ecosystem-based adaptation in exposed coastal locations. Mangroves are among the most severely damaged tropical ecosystems, and they are continuing to disappear as a result of increased human activity. Especially in the Asia-Pacific region, where they exist in the form of complex socio-ecological systems, mangroves remain heavily threatened due to numerous anthropogenic activities. Mangroves are under grave danger; hence it is imperative that prompt steps be taken to methodically conserve and restore their ecosystems. The Asia-Pacific region is the location of nearly half of the existing mangroves, scattered over some of the poorest and post-conflict states. Dependence on traditional sources of income and the recent trend of coastal development have had a negative impact on the region's mangrove sustainability. Lacks of supportive policies and mangrove conversion to non-forest uses has been further fueled by insufficient institutional intervention. Nevertheless, in recent years, participatory, multi stake holder-based approaches for mangrove conservation and/or restoration have gained immense popularity in the region of Asia Pacific. Participatory management which exemplifies an ameliorative approach can also support sustainable development, community empowerment, and social inclusion. Despite its asserted superiority, a number of new sustainability challenges need to be carefully examined and reconciled due to conflicting results of earlier experiences.

Keywords: Mangrove; Coastal wetland; Conservation; Restoration; Ecology; Environment

1. Introduction

Mangroves are a group of salt-tolerant trees and shrubs that grow in intertidal zones and estuaries along tropical and subtropical coastlines. They are characterized by their unique ability to adapt to the harsh and fluctuating conditions of these environments, such as the high salt concentration, tidal inundation, and low oxygen levels in the soil. Mangroves play an important role in maintaining the health and productivity of coastal ecosystems. They provide a range of ecosystem services, such as stabilizing shorelines, protecting coastal areas from storm surges and erosion, and serving as important nursery habitats for many species of fish and other aquatic organisms. Mangroves are also important carbon sinks, as they store large amounts of carbon in their biomass and soil. However, mangroves are under threat from human activities such as coastal development, logging, aquaculture, and climate change, which can lead to their degradation and loss.

One of the most specialized ecological groups of halophytic plants, mangroves serve as a transitional area between the ocean and the land. They are made up of taxonomically varied shrubs and trees that are found throughout tropical and subtropical environments in habitats like shorelines, estuaries, tidal creeks, backwaters, lagoons, marshes, mudflats,

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and even upstream locations where the water is still salty. Mangrove forests are distinctive functional ecosystems that are very important for society, industry, and biology. As they provide significant ecosystem supplies and services to human society as well as coastal and marine systems, they are among the world's most productive ecosystems [1, 2].

Mangroves are salt-tolerant plants that can survive in intertidal areas of tropical and subtropical climates. The mangrove forests have been shown to sustain more than 70 direct human activities and are extremely important coastal resources, which are vital to our socio-economic development [3]. The ecological service of mangroves lies in protecting the coast from solar UV-B radiation, 'green house' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion and contribute significantly to the global carbon cycle.

In Andhra Pradesh mangrove forests account for only 582 sq km, representing only about 0.9% of the State's total forest area. Mangrove forest biomass may reach 700 t ha and estimate the total global mangrove biomass to be approximately 8.7 Gigatons dry weight (*i.e.* 4.0 Gigatons of carbon) [4]. As these naturally resilient, mangrove forests are disappearing at an alarming rate, with little public notice, there is a need to restore and manage these mangrove ecosystems. Creeks and estuaries are important coastal features as they play a crucial role in materials transport, groundwater re-charge, nutrient cycling, controlling floods and sediment filtration, thus helping balance the ecological processes. The intertidal regions of the creeks generally have a rich growth of mangroves along with mudflats that play a significant role in the nutrient enrichment of the creeks. The presence of mangroves in the creeks is important in the transport of organic matter and nutrients, thus providing breeding grounds for various marine organisms, including fishes.

These habitats interact with a wide array of aquatic or terrestrial flora and fauna, enabling their growth and establishment. Considering their value for the environment and coastal communities, mangrove conservation should become a priority and efforts must be invested to find new and successful methods for conserving mangrove ecosystems [5].

Advanced research with respect to earlier and current reports on diversity, distribution, growth sustaining attributes of mangroves may aid in the process of formulating proper afforestation strategies along diverse shoreline environments. They constitute the major structures in the mangrove community whereby forming the pure stand. To this, they have specialized morphological adaptations to survive in the mangrove environment and are believed to have a specialized mechanism for salt exclusion [6]. Heat, drought, and salinity are the main abiotic stresses to which plants generally respond, involving signal reception and transduction followed by genetical and physiological feedback. Commonly, plants are capable of adapting themselves to certain stress. But few species tend to survive in habitats with a high level of abiotic stress. Among the various abiotic stresses, salinity constitutes more than 7 % of the world's land area, approximately 930 million hectares [7].

One of the main abiotic factors that affect mangrove productivity and distribution in tropical and subtropical intertidal areas is salt. This occurs mainly due to the deposition of excessive Na⁺ ions which causes an osmotic imbalance in the living organisms [8]. Mangroves are unable to withstand freshwater because of the rise in salt content, which becomes a vital part of their biology. Numerous salt-induced tests were carried out in plants at various salt concentrations to compare the difference in salinity percentage to control conditions. Particularly, plants grown in a natural saline ecosystem have a tendency to control their salt tolerance more than other types of plants [9].

Mangroves grow where the land meets the sea in tropical and subtropical regions. They can withstand conditions such as high salinity, extreme tides, strong winds, high temperatures, muddy soil, and extreme tides. Due to these circumstances, mangroves had evolved viviparous propagules and roots for gas exchange. Mangroves create a special environment that serves as a habitat for invertebrates that are epibenthic, infaunal, and meiofaunal. Additionally, it provides habitat for a variety of other species, including fish, phytoplankton, and zooplankton. Mangrove ecosystem may draw bacterial, fungal, macroalgal, and invertebrate communities, trunks, leaves, and branches that host the aerial roots. Numerous crab species, insect species, reptile and amphibian species, birds, and mammals all thrive in the habitat and add to its distinctive features [10].

Heavy metals like Cu, Zn, Cr, Ni, Pb, Hg, Cd, Co and Mn were recorded from water and soil samples of mangrove ecosystem of Mahi and Dadar river estuaries [11]. Species of mangroves and their distribution in nations bordering the Indian Ocean. There have been reports of 55 species across the various nations bordering the Indian Ocean. India exhibits 809 different species of halophytes, bacteria, fungi, actinomycetes, lichens, seagrasses, and other microorganisms [12].

Due to numerous anthropogenic pressures, India lost significant amounts of its mangrove cover in the late 1980s. As a result, ongoing climate change has emerged as a potential threat to the remaining Indian mangroves and other coastal ecosystems [13].

Along tropical, subtropical, and some temperate coasts, intertidal mangrove forests can be found, frequently coexisting with dense populations of people. As a result, they offer crucial ecosystem services to hundreds of millions of people [14], including fish, timber, fuelwood, coastal protection, pollution control, and cultural values. In recent years, mangroves' ability to store carbon has been vigorously promoted [15], and they are now firmly on the international agenda for climate mitigation and adaptation. Mangroves are also seriously threatened throughout a significant portion of their range due to their location in an area with rising human population densities and competing coastal management priorities.

Large-scale mangrove deforestation has been facilitated by nearby drivers like aquaculture, agriculture, and urban development [16, 17]. Mangroves are further harmed by resource overexploitation and pollution [18]. At larger scales, mangroves are impacted by long-term processes like relative sea-level rise (rSLR) and sea-level fluctuations linked to climate oscillations [19, 20], which have significant effects on the vulnerability of the coastal populations that depend on mangrove resources. Strong understanding of the mangroves' actual condition is necessary for effective management. A picture of the condition of mangrove forests around the world has been provided by a number of studies. Global Status of Mangrove Ecosystems [21], one of the earliest reports, was released by the IUCN Working Group on Mangrove Ecosystems.

2. Definition of the Problem

The Millennium Ecosystem Assessment⁴'s central thesis is that there is a direct correlation between environmental and human conditions. Tallis *et al* [22] has been designated as the International Year for Biodiversity by the United Nations (UN), and India is one of the world's biodiversity hotspots.

The most endangered coastal habitats are mangrove forests, especially in developing nations. Ecology, geology, sociology, economics, and engineering are all combined in the rapidly growing field of restoration. This essay examines ecosystem restoration as a potential tool to counteract the detrimental effects of biodiversity loss. It also examines the options available to restore biodiversity and bring degraded ecosystems back to function in a way that benefits local communities with financially viable solutions.

3. Methodology

A qualitative research approach was used in this instance. According to Silverman 2006 [23], this study falls under the category of an instrumental case study, in which a case is primarily examined to shed light on a problem or correct a generalization. It is used to examine whether the intervention met its intended objectives and to fully comprehend the context in which it takes place as well as the various stakeholder viewpoints.

3.1. Data collection

Primary data comprise remote sensing data and data collected from field measurements on various parameters. Satellite data along with ground truth observations provided information on spatial features. Field data on water quality parameters were collected using standard methodologies.

3.2. Data analysis

As an analytical technique, an explanation building system was chosen. Due to multiple sources of evidence, triangulation was used in analysis. Primary analysis of data [24] collected by other researchers was an important segment of this research. Secondary data used include documents, brochures, and publications by other researchers. During my analysis, the focus was put on connection between existing findings and my findings.

4. Mangrove Restoration

4.1. Reasons for Mangrove degradation in the past and present

According to ecological research done by MSSRF between 1993 and 1995, degradation is primarily due to unscientific management techniques used in the past. Estimates predicted that 65% degradation of Pichavaram mangrove was due

to coupe-felling, illustrated in Figure 1. According to Knowler et al. (2009) [25], brackish water shrimp production in India increased from 3868 tons in 1980 to 30, 805 tons in 2005, making it the fourth largest shrimp producer in the world. Shrimp farms were not the primary cause of the degradation of the mangroves in India, but the toxicants that leak from shrimp farms pose a serious threat to the environment. Cattle grazing have been identified as the second significant issue. Cattle damage the propagules during the monsoon season, making natural regeneration impossible [3].

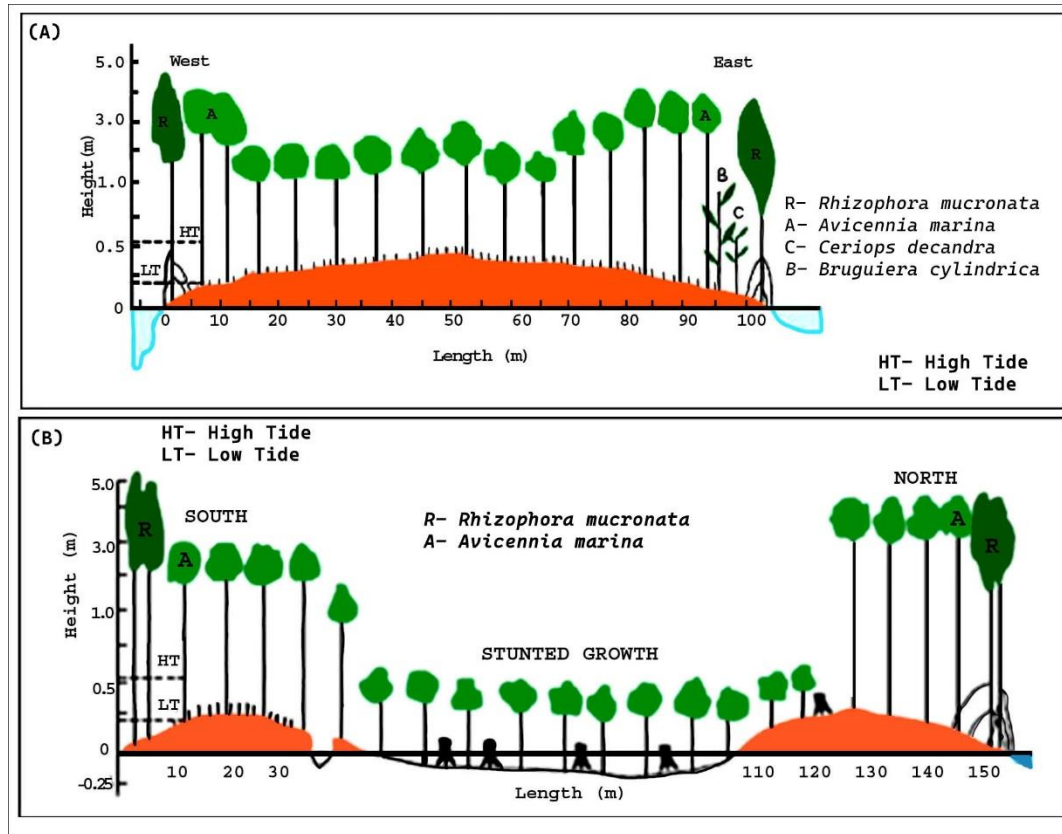


Figure 1 Microtopography of (A) healthy and (B) degraded mangrove areas Source: MSSRF, 2003[26]

4.2. Methods and considerations applied in restoration of the Mangroves

Mangrove restoration can be divided into three types:

- Identification and Protection of Vulnerable Mangrove Sites
- Restoration of Degraded Areas
- Community-Based Mangrove Conservation and Restoration
- Mangrove Plantation

4.2.1. Identification and Protection of Vulnerable Mangrove Sites

Mangrove areas that are vulnerable to sea level rise must be identified and protected. Small islands, a lack of rivers, micro-tidal zones, a scarcity of freshwater, high salinity, groundwater extraction, coastal development, underground mining, carbonate settings, tectonic movements, and steep topography can all be used to identify these areas.

Local indicators of mangrove areas less vulnerable to sea level rise include the presence of macro-tidal environments rich in sediment and the availability of freshwater to offset rising salinity. Based on their potential to move inland in response to sea level rise, mangrove species can be recognized. The mangrove habitats have a lot of mature trees that produce a lot of seeds and propagules, along with a lot of oysters and other epibiont communities.

Mangroves typically produce a lot of seeds and seedlings, but there are serious concerns about how well they disperse, survive, and establish. As a result, it's important to evaluate natural regeneration for its limitations and put corrective measures in place to make it easier for mangrove propagules to spread and establish.

In many places, particularly in the states of Kerala, Karnataka, Andhra Pradesh, and Maharashtra, mangrove lands are privately owned. Acute land scarcity brought on by a high rate of population growth prompted widespread reclamation of mangrove wetlands, which resulted in a sizable loss of mangroves. The management of the mangroves under private ownership requires the development of appropriate mechanisms.

4.2.2. Restoration of Degraded Areas

According to Hiraishi and Harada (2003), Kathiresan and Rajendran (2005), Danielsen et al. (2005), and Saudamini Das (2004) [26-32], mangroves improve fisheries, forestry output, and coastal protection from natural disasters. Mangrove ecosystems are, however, dwindling in many locations along India's coastline. High salinity resulting from improper tidal and freshwater fluxing, as well as the transformation of mangroves into shrimp ponds, are the main causes of mangrove shrinkage. Mangrove restoration, then, is the practice of replanting mangroves where they once were in order to increase the area covered by mangroves. Additionally, this promotes the preservation and improvement of biological diversity, the recovery of endemic and threatened species, and the development of fisheries without destroying mangroves. By building creeks and altering the hydrology to flush the degraded areas, restoration of degraded areas is practiced.

4.2.3. Community-Based Mangrove Conservation and Restoration

The 2004 tsunami in the Indian Ocean was a wake-up call that spurred many actions emphasizing disaster risk reduction. Many NGOs and other local institutions began conducting mangrove restoration activities as a result of increased motivation (IUCN 2007) [33]. These initiatives range from modestly sized projects with local funding to island-wide initiatives supported by funding from outside donor organizations. These restoration efforts' primary goals can be summed up as follows.

Education and Awareness raising

The most frequent emphasis has been on increasing awareness. The commonalities of mangrove conservation education programs are presented in **Table.1**

Table 1 Common characteristics of educational programs on mangrove conservation [34]

Tools used	Elements covered	Groups targeted
-Print-leaflets, booklets. -Electronic documentaries, films, Photos. -Activities-dramas, role plays. -Deliveries-lectures, talks, discussion.	-Ecology of Mangroves. -Distribution. -Diversity. -Uses/ benefits. -Threats and issues. -Conservation measures.	-School children. -Teachers. -CBO/ NGO workers. -Community members. -Youth groups. -Dependent groups - fishery, tourism etc.

Educational Workshops for Stakeholders

Supportive environmentalists who organize a variety of educational workshops for the local communities and NGO members to share knowledge on mangrove ecology and conservation have strengthened many of the island's coastal areas. The majority of these programs concentrate on all crucial elements of mangrove conservation.

Capacity Building

Many approaches have been taken to address society's capacity-building with the goal of enhancing public participation. These activities have been designed and carried out so that they provide more than just instruction but also some practical experience. For instance, while some projects give the community access to resources, others equip visitors with the knowledge and abilities they need to take constructive action.

Community Centers

These facilities act as "one-stop shops for information" and include demonstration areas and advocacy campaigns. Some offer tool kits that cover mangrove conservation through sustainable mangrove use, restoration, and alternative livelihoods.

Mangrove Museums

Some regions have established museums to instruct visitors by displaying specific preserved specimens and fragments of mangrove plants.

Community Participation in Active Conservation

Many different stakeholder groups, including fishermen families, farmers and people who live close to mangrove areas, women groups and handicraft experts, teachers and schoolchildren, students, members of the local authority, and government agencies, have been involved in some communities' community-led mangrove nurseries and tree planting programs. Some initiatives offer services to business owners like tour bus drivers. The local authorities, including the priests of the temples and churches, the fishery and farmer societies, provide these programs with their utmost support and cooperation.

Mangrove Exhibition Gardens

Mangrove exhibition gardens with both common and endangered species have been developed in some areas. Six of the 36 mangrove species found in one such garden is seriously threatened. One noteworthy aspect is that visitors can observe not only mangrove trees but also related environmental factors and local wildlife.

Stewardship/Income Generation

Because they don't provide the community with enough of an immediate financial benefit, many conservation programs fall short of their goals. In this context, some mangrove conservation programs have been created to provide the community with real benefits, such as alternative job training and microloans for underprivileged women living close to this country's mangrove forests. Community members are required to raise seedlings and small mangrove plants that are given to them by mangrove conservation projects in their gardens and other places.

Challenges

It is not always simple to restore the degraded mangrove sites' species diversity, ecological coherence, and natural balance with the aid of the community [35].

The successful planning, execution, and maintenance of community mangrove restoration projects may be hampered by a variety of issues. Again, these difficulties might differ based on the project's location, nature, and goals, as well as the surrounding communities. **Table.2**

Table 2 General challenges faced by mangrove restoration projects [34]

Element	Challenges
Social	<ul style="list-style-type: none"> -The participants' insufficient interest and commitment. -Insufficient financial rewards for conservation efforts. -Limited potential for stakeholders to generate income. -Uncertainty brought on by ownership issues. -The community's support is insufficient.
Technical	<ul style="list-style-type: none"> -A lack of ability, technical know-how, and restoration-related skills. -Engage both participants and organizers. -A lack of understanding of scientific and ecological issues that are "site-specific" -Weak monitoring, follow-up, and research efforts.
Economic	<ul style="list-style-type: none"> -Lack of adequate and ongoing local or international funding for the project's sustainability; inadequate assistance in managing financial resources.
Political	<ul style="list-style-type: none"> -The inability to combine restoration initiatives with local management strategies. -Weak assistance from local and governmental authorities in developing and carrying out projects. -A rigid approach to law enforcement. -Poor agency-to-agency coordination.

Summarizes the problems that mangrove restoration projects typically encounter. The above table shows the typical difficulties encountered by ongoing mangrove restoration projects in relation to four obvious aspects. The extent to which these problems impact a specific project, however, is arbitrary and may depend on a number of other multiple causal factors. However, the issues listed in the table offer a wide-ranging perspective, and many projects actually run into at least some of them while in operation.

If frequent evaluation and correcting processes are in place, these problems may be dealt with favorably or at the very least, the degree to which they impact projects may be diminished. For instance, more donors, particularly from the international community, could be drawn to provide funding in the future if the projects' objectives could be met and real results could be demonstrated with appropriate publicity.

4.2.4. Mangrove Plantation

Mangroves provide a wide range of ecological, economic and social services as a prominent wetland in the ecotone between land and sea. They consist of peculiar plants, animals, and microbes that make up a unique ecosystem. A sizable coastal population relies on this ecosystem for their traditional means of subsistence. However, the indiscriminate destruction and reclamation of this important ecosystem indeed, its filling up goes on unabatedly. According to Khaleel (2009) [35], India lost close to 38% of its wetlands during the 1990s. Mangroves, which make up less than 0.4% of the world's forests, are declining at a rate of 1% annually, with 0.66% of that loss occurring in India [36-38]. According to Miththapala (2008) [39], the rate of reclamation and degradation can reach as high as 2-8% annually in some places.

Techniques Followed in Mangrove Plantation

The first step in the mangrove plantation activity is to identify a suitable intertidal stretch area. When choosing an intertidal belt for planting, a number of biophysical factors are taken into account, including the gradient of the intertidal belt, the type of soil, the number of days of tidal flushing, the presence or absence of natural mangroves nearby, and the availability of an adequate intertidal extent. The number of days of tidal flushing, which is influenced by the gradient of the intertidal area, is one important factor that receives special attention; intertidal stretches with gentle gradient receiving good tidal flushing for >15 days in a month are chosen for plantation.

Method of Plantation

The selection of the method or methods can be used requires thorough knowledge of the site. Based on the site conditions and potential for a higher survival percentage, the three methods listed below are typically used in India and Pakistan to raise mangrove plantations, either separately or in combination.

- Transplantation of nursery-raised sapling.
 - Raised bed method.
 - Direct propagule dibbling.
 - Fish bone model
-
- Transplantation of Nursery-Raised Saplings (Polybag Method).

The nursery method is regarded as the most dependable and effective method for mangrove plantations, with a high rate of success. Another significant benefit of setting up a mangrove nursery is that it extends the planting season and provides a ready supply of saplings that can be planted at the right time of the year. Since nursery raised saplings have a strong root system and are maintained under simulated conditions for a longer period of time, transplanting them shows a higher survival rate than other methods. Additionally, there is very little evidence of crabs eating seeds and seedlings in nurseries. This method takes longer than other plantation methods and is more expensive and labor intensive. Nursery development takes place in parallel-placed beds of 1000 or fewer polythene bags [40].

The development of nurseries in an extensive manner outdoors in outdoor conditions along minor creek banks where they are fed by tidal flows is the norm rather than the uncommon indoor nursery practices. Fewer plants survive in this extensive nursery preparation method because of uncontrollable factors like natural tidal watering and water logging. When saplings reach a certain height, transplantation of nursery raised saplings is carried out. After an anticipated 10% mortality of planted saplings, different densities and gaps are followed to produce a final sapling density of 5,000-10,000/ha.

- Raised Bed Method

Since it is thought to produce better results while battling strong tidal currents, this method is preferred for the majority of plantation endeavors. With this technique, earthen mounts are raised to a height of 10-15 cm, and propagules in the range of 15-20 are displayed on the raised bed's surface.

In general, there are more than 400 raised beds per hectare, but by using different spacing, that number could increase to 1500 beds. To slow down the speed of ebb and flow tidal currents, mounts in each row are alternately raised. Raised earthen mounts counter the effects of the tide in coastal areas with moderate tidal currents.

- Direct Propagule Dibbling

Direct propagule dibbling requires less time and money. This technique is frequently used to restore potential mudflats and is frequently added to other plantation techniques to increase survival rates. This approach is straightforward, so even unskilled laborers can use it. Mangrove propagules are dipped in mudflats at predetermined intervals in this method. Propagules are dibbled so that almost two thirds of them are above the sediment's surface and the remaining one third is buried beneath it. Depending on the type of mangrove forest that will be developed, a different distance is maintained between each dibbled propagule. Propagules are soaked in freshwater for nearly 24 hours to speed up germination and generally a spacing of 1 m² is preferred.

- Fish bone type of canal system

The Pichavaram mangrove wetlands served as the development and demonstration site for this technique's restoration beginning in late 1995. This method, also known as the "fish bone canal" or "trench method" (**Fig.2**), entails digging trenches in the extremely salty soil to enable soil flushing and the successful emergence of mangroves.

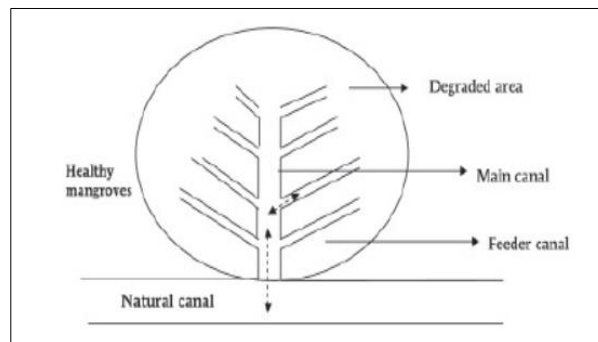


Figure 2 Fish bone type of canal system [26]

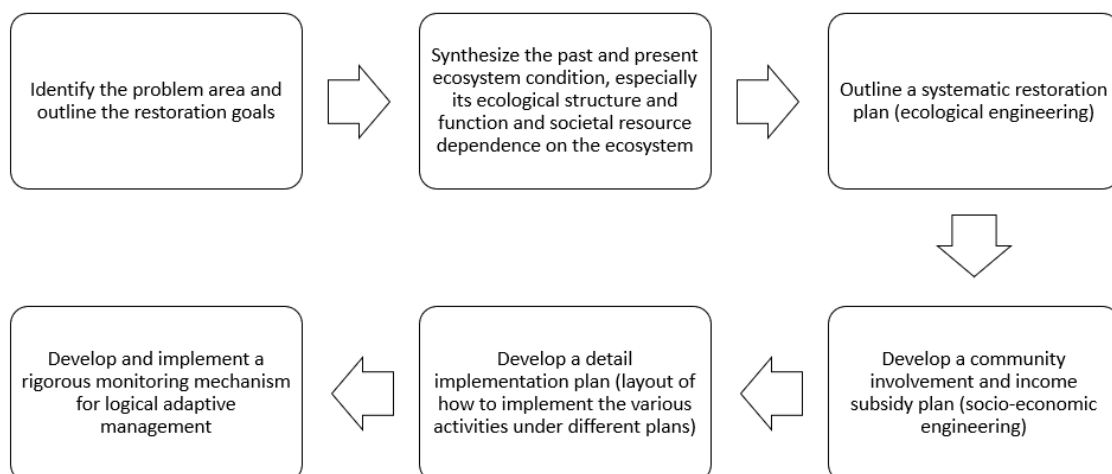


Figure 3 Practical guidelines for mangrove restoration [44]

MSSRF [43] created a thorough manual on how to restore mangroves. The technical aspects of mangrove restoration are covered, and they go into great detail about what needs to be done and how.

4.3. Community participation in Mangrove restoration.

“People will not restore or conserve mangrove if they do not understand why mangroves are important or if they do not have any benefits from that act.”

Without a doubt, one of the most important aspects of restoration is involving the local community [45]. Making people aware of the value of mangroves, connecting them to their way of life, and creating clear benefits from mangrove conservation and restoration are essential to achieving community participation. First, education is used to accomplish this, and then incentives are made.

Success depends on three things: political backing, a solid economic foundation, and well-organized society. Less emphasis is placed on biodiversity and more on community. Successful ecological restoration, according to Biswas et al. (2009) [44], should increase ecosystem functions, human wellbeing, and biodiversity conservation. It's crucial to hit all four goals and not just one.

Table 3 Achievements, challenges and recommendations in mangrove restoration

Achievements	Benefits to the environment, society, and economy are listed in the analysis.	
Challenges	Obtaining long-term funding. Stakeholder consultation. Creation of a database listing all mistakes and victories. Inter-institutional coordination.	
Recommendations	Funding agencies	Support initiatives with a clear plan that take into account both social and environmental factors. Support projects that have a monitoring plan and a long-term sustainability goal.
	Government /Institutions	Cooperation with NGOs in restoration and monitoring. Sustainable management and conservation of existing natural mangrove forests. Investment in research and scientific monitoring.
	NGOs	Promote community awareness and education. Determine potential issues and solutions for the future. Establish specific objectives. Prior to restoration, do not undervalue the impact of environmental factors.

It is recognized that the restoration of mangroves has the potential to increase biodiversity, restore ecosystem services, and act as a catalyst for local community growth. The GIS-based Information System is helpful in determining the condition of the mangrove ecosystem and could act as a baseline database for the decision-makers to track down mangrove areas, create appropriate management plans for afforestation, and also keep track of biodiversity. Mangroves are also known to be important carbon sinks.

Due to the high reliance of local communities on the resources and services provided by the mangrove ecosystem, ecosystem restoration in this context is not a luxury but a necessity. These advantages won't necessarily be apparent right away, but they will.

4.4. Issues in Mangrove Plantation

Currently improving extensive mangrove plantation by both government agencies and industrial houses due to its largest extent of mudflats suitable for mangrove plantation. Nevertheless, the region's attempts to plant mangroves are hampered by a number of unresolved problems. Poor survival is the main issue that many plantation activities encounter. Plantation activities are frequently carried out in technically unsuitable location, which leads to a high mortality rate for planted mangroves.

Site Selection, the most crucial factor that determines the extent of plantation success and necessitates scientific input, is frequently disregarded, which has a negative impact on plantation survival. Costly failures are also brought on by a lack of technical proficiency and a failure to comprehend the guiding scientific principles of plantation. Using a workforce that is well-versed in site-specific conditions and is trained and skilled.

It is crucial to improve the technical capabilities of the various organizations involved in mangrove plantation. This could be achieved through (a) education campaigns; (b) scientific research and the development of technical plantation packages in collaboration with expert consultants, implementing organizations, and community organizations; and (c) training courses on the ecological and financial importance of mangroves as well as other facets of regeneration and restoration.

The local community and various other agencies will be involved in awareness campaigns and site visits to other projects, allowing for the exchange of ideas and learning of new methods. Legal obstacles like the lack of suitable plantation sites on revenue land frequently place restrictions on coastal businesses and corporate entities that are required to plant mangroves.

- Establishing a forum of coastal industries with the goal of regenerating and restoring mangroves.
- Developing strategies to make forest land in the coastal belt accessible to aspiring industries for plantation.
- Planning workshops and gatherings with business organizations and industries to encourage them to participate in mangrove regeneration.
- Exposure trips for influential industry personnel.
- Networking and connections with NGOs and community groups to lobby against businesses that violate environmental protection laws.

It is frequently asserted that the primary cause of the overall shrinkage of mangroves is the impact of industries on mangroves through direct reclamation and chronic degradation. There aren't many studies that actually demonstrate this impact, though. In fact, the earlier project, which was funded by the India-Canada Environment Facility (ICEF) and implemented in various regions, has had very little success in engaging industries in mangrove restoration efforts. Land availability has been identified as one of the major obstacles to industries participating in mangrove plantations. It is necessary for businesses and government organizations to create a system that will allow them to restore and conserve mangroves without encountering bureaucratic obstacles.

A. marina is the only candidate species and makes up the majority of the mangrove plantations. Few coastal industries and the forest department made sporadic attempts at multispecies plantations using *Rhizophora mucronata* and *Ceriops tagal*, with very little success. Multispecies plantation efforts are significantly hampered by the zone's inherent aridity and hypersaline coastal waters. Because of its high adaptation to the current coastal milieu, ease of plantation due to tried-and-true techniques, hardiness, and abundance of seed, *A. marina* is the only candidate species for majority of plantation activities.

Macro level environmental factors like climate, rainfall, freshwater runoff, and sediment supply are not as favorable in many coastal regions to support high species diversity and luxurious growth of mangroves as in the Sundarbans or Bhitarkanika of Odisha. However, by adjusting minute environmental elements like soil quality and tidal flow, mangroves can be grown in the vast mudflats' mid-tidal regions. Mangrove seedling survival and growth are generally poor in plantations, and seedlings are frequently exposed to the elements or uprooted by strong tidal currents. Except in a few places, of coast's hard rocky formation just below the surface prevents the establishment of saplings.

Most of the mangrove plantation efforts by coastal industries are not in participatory mode. Coastal communities are involved only as laborers without any other stakes. The post-plantation care, which is essential to raise the planted mangrove into a full-fledged ecosystem, is taken care by the community in participatory mode. By negating community participation, many of the plantation activities tend to fail. Mangrove plantation, in general faces the menace of grazing by livestock, mostly owned by nearby coastal villages. Grazing and browsing by cattle largely could be controlled in participatory mode as villagers take an active interest to prevent their livestock from grazing in the raised plantation and that does not happen in single institutional plantation activities.

In some cases, the formation of village samithis, community clubs and the creation of grass plots close to villages were attempted in an effort to increase sustainability and lessen the degree of reliance on mangrove resources for the communities. The ICEF funded community-based mangrove plantation project serves as the best illustration. This effort included planting mangroves as well as promoting grassland to increase alternative sources of fodder and lessen reliance on mangrove resources. To ensure an equal distribution of gross production in line with each household's cattle

holding, a strong benefit sharing mechanism was developed. Even though the annual grass yield from these plots only provided a small portion of the needed fodder, it amply illustrated how a different source of fodder could be grown to wean the villagers off of relying solely on post-plantation upkeep has become a significant problem in mangrove coastal plantations.

It is understood that the best way to enable raised plantations to become a useful ecological entity is through participatory plantation methods with local community involvement. The development of sufficient funds for villager post-plantation activities is a crucial requirement for post-plantation maintenance. To ensure that products and services derived from mangrove forests meet the current fodder and ecological needs while securing their continued availability and contribution to long-term development, all plantation activities must be guided by an integrated sustainable mangrove management plan that involves various sectors and players. Administrative, legal, technical, economic, social, and environmental aspects of mangrove conservation and use are all included in sustainable mangrove management.

In comparison to other species whose tolerance limit is frequently limited, *A. marina* as a candidate species yields a higher success rate in plantation endeavors. *A. marina* has good success rates due to its easy availability of seeds, rapid germination in highly saline water, tolerance to prolonged drought conditions, and higher growth rates. In order to improve tidal flushing, species like *R. mucronata* and *C. tagal* that are less tolerant of water/soil salinity are planted close to the waterfront. *R. mucronata* are planted close to the waterfront in such plantations of multiple species, followed by *C. tagal* and *A. marina* to mimic their natural zonation. *R. mucronata* and *C. tagal* are both extremely sensitive to changes in salinity. They require significantly less sediment and water salinity, which is frequently present, for germination and sustained growth.

5. Summary

The establishment, upkeep, and strengthening of the "coastal belt of mangroves," which will aid in the process of re-greening the coast, have received a great deal of attention, according to a brief summary of the activities included in this chapter on community-driven restoration programs. However, it is crucial for an umbrella organization like a government institution to participate in various stages of such endeavors as an impartial observer, facilitator, coordinator, steward, and custodian in order to successfully advance the NGOs' mangrove restoration efforts.

From the two case studies, it was discovered that ongoing community involvement and benefit sharing, such as providing the community with livelihood support, play a significant role in the success of any initiative, whether it is local or island-wide.

For successful restoration, it is advised, as in many other nations, that a thorough assessment of the threats to and the root causes of mangrove vegetation destruction be made. Mangroves are found in particular environmental conditions, so having access to scientific information about their ecology, environmental factors like hydrology, and technical know-how is important for planning. Similar to this, it is crucial to encourage positive community involvement with some concrete "benefits" for them as well. Additionally, ongoing support from the government and funding from donors are crucial for survival.

The only method currently used for mangrove conservation is plantation. Instead of going for outright plantation, it is advised that other restoration techniques, such as biophysical amendments to increase tidal flow to the stunted mangroves, be tried in future plantation activities. This restoration effort will produce better results, especially in scrubby/stunted stands facing inadequate tidal flushing. For instance, desilting of natural canals will increase the number of tidal days and tidal flushing rates in naturally stunted stands, making the ecosystem healthier, viable, and more functional. These physical modifications to natural mangrove formations may be carried out in areas where tidal flushing is severely impeded.

Due to factors both natural and artificial, this could be accomplished more affordably and with better results than direct plantation. In order to transform stunted formations into denser ones, a thorough and detailed surveillance and classification of sites requiring various restoration approaches, such as desilting, canal widening, clearing obstruction at canal mouth, and even building new canals, could be more effective [46].

It is generally accepted that stopping mangrove deforestation is economically and ecologically more advantageous than restoration through plantation. Due to more aggressive conservation and restoration efforts, such as plantation, deforestation has been largely stopped and mangrove cover has seen an overall improvement. Mangrove restoration requires a multifaceted approach to be sustainable over the long term, including careful management planning, capacity building at the community level, and awareness among all stakeholders and managers. There are numerous

opportunities to streamline various states in India's current restoration efforts, which would greatly improve the restoration's results. A few examples of scientific input and intervention in plantation efforts include careful restoration method selection in accordance with the site's biophysical condition, scientifically sound site selection, and rigorous training of field staff.

An integrated approach can overcome many legal and technical obstacles that prevent proper site selection. Inadequate participation of mangrove stakeholders like coastal fishing communities, coastal industries, and cattle tenders is another significant flaw that was observed. Promoting such public participation in mangrove plantations will guarantee the raised resource's long-term viability and the establishment of a fully ecological entity. The absence of restoration-specific technical development and research that would make the plantation efforts stronger and more technically sound is also glaring. In spite of these weaknesses, a general positive methodology toward mangroves is unfurling lately among partners and strategy producers, which should be changed into significant projects [47].

Mangrove restoration is a crucial activity in preserving the coastal ecosystems and ensuring the livelihoods of coastal communities worldwide. Mangrove forests play a significant role in protecting the coastline from erosion and storm surges, serving as a habitat for marine organisms and supporting the livelihoods of coastal communities. However, human activities such as deforestation, pollution, and climate change have significantly impacted the mangrove ecosystem, leading to a decline in their populations.

Efforts to restore mangroves have increased over the years, with governments and non-governmental organizations implementing various restoration techniques, including natural regeneration, artificial planting, and the promotion of sustainable land use practices. While these techniques have proven successful in restoring degraded mangrove ecosystems, the effectiveness of the restoration largely depends on several factors such as the site conditions, the type of restoration method employed, and the involvement of local communities.

Mangrove restoration not only benefits the environment but also provides socio-economic benefits to the coastal communities. The restoration of mangrove ecosystems creates employment opportunities, supports sustainable fisheries, and provides coastal protection against natural disasters. Additionally, mangrove forests are a valuable source of carbon storage, helping to mitigate climate change.

However, the success of mangrove restoration also depends on addressing the underlying drivers of mangrove loss, such as unsustainable fishing practices, coastal development, and pollution. The active participation of local communities in mangrove restoration and management is essential in ensuring the sustainability of mangrove ecosystems.

6. Conclusion

In conclusion, mangrove restoration is a critical activity that helps preserve the coastal ecosystems and ensure the livelihoods of coastal communities. While restoration techniques have proven successful in restoring degraded mangrove ecosystems, the effectiveness of the restoration depends on several factors. Therefore, it is essential to address the underlying drivers of mangrove loss and involve local communities in mangrove restoration and management to ensure the sustainability of mangrove ecosystems.

Compliance with ethical standards

Acknowledgments

The authors acknowledge and are grateful for the support from the Department of Marine Biology, Vikrama Simhapuri University, Nellore.

Disclosure of conflict of interest

All the authors declare that there is no conflict of interest.

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