Exploring the Role of Mangroves in Mitigating Food System Emissions: Bridging Global Experiences and Local Action

Garima Taneja and Marie-Charlotte Buisson

Author affiliations

Garima Taneja[1], Marie-Charlotte Buisson[2],

[1] International Water Management Institute, New Delhi, India

[2] International Water Management Institute, Colombo, Sri Lanka

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The CGIAR Initiative on Low-Emission Food Systems, also known as Mitigate+, focuses on reducing GHGE from food systems in target countries by 1.1 gigatons per year (6.5 percent) by 2030, thus mitigating the predicted impact of climate change on sustainable development and social equity. The approach is consistent with the Paris Agreement, which aims to foster low-emission development without negatively impacting food production. An estimated 8 million people will benefit from these reduced emissions and associated benefits over the Initiative's 10-year lifespan. Learn more about Mitigate+ here: https://www.cgiar.org/initiative/32-mitigate-plus-research-for-low-emission-food-systems/

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Contents

Summary **3**

1. INTRODUCTION **4**

2. MANGROVE: A GLOBAL OVERVIEW OF COVERAGE, HISTORICAL TRENDS AND DEFORESTATION DRIVERS **6**

2.1. Historical status and current trends 6

2.2. Drivers of mangrove loss 8

2.2.1. Anthropogenic drivers 9

2.2.2. Biophysical Drivers 9

2.3. Changes in drivers of mangrove loss 9

2.4. Country-Specific Drivers of Mangrove Loss 10

2.5. Drivers of mangrove gains 12

3. MANGROVE AFFORESTATION PROGRAMS **12**

3.1. Expected impacts of mangrove afforestation programs on mitigation and adaptation to climate change 12

3.2. Review of mangrove afforestation programs 13

3.2.1. Inception of mangrove programs (1970-80s) 13

3.2.2. Community based mangrove management (1990s-2000s) 14

3.2.3. Restoration programs: Coastal protection, community-based natural resource management and multistakeholder partnerships (2000s – 2010s) 14

3.2.4. Evolution of global mangrove conservation: Nationally Determined Contributions and the Global Mangrove Alliance (post 2010- present) 16

3.3. Challenges in mangrove conservation programs 19

4. MANGROVES IN VIETNAM **20**

4.1. Coverage, historical trends and deforestation drivers 20

4.2. Mangrove afforestation programs 20

5. DISCUSSION AND CONCLUSION **22**

REFERENCES **25**

Summary

Mangrove forests are one of the most impactful carbon-trapping ecosystems, they are effective at locking away vast amounts of "blue carbon" and the IPCC (IPCC, 2022) report encourages the protection of coastal vegetative ecosystems as part of integrated coastal resource management. Mangrove also strengthens resilience to climate change by reducing the impacts of sea level rise, saltwater intrusion, cyclones, and floods. Mangrove forests in Vietnam are currently under threat from expansion of shrimp aquaculture. However, their role in the food systems of coastal and island communities is often ignored. For instance, they provide woods for cooking, its fruits (from the keora trees) are collected and sold especially by women, and it also hosts a rich ecosystem including aquatic foods and acts as breeding and nursery ground for economically and nutritionally important fish species. Mangrove afforestation programs can, in that sense, be considered as Low Emission Food Systems technologies, including in MITIGATE+ target countries like Vietnam.

This report reviews the literature on mangrove afforestation programs globally to identify the enablers and drivers of scaling. Specifically, the programs are characterized to identify the technologies and innovations in place, and the governance models and institutional drivers are assessed. Thus, the report is divided into four sections. The first section presents a global overview of mangrove plantations, their historical and present status, the drivers of mangrove deforestation globally and at country level. The second section reviews mangrove afforestation programs, the inception of these programs, their objectives and the governance and institutional models followed. The third section focuses on mangroves in Vietnam, it features some of the successful examples implemented in the country and analyses the supporting government policies. The last section is the conclusion which draws lessons on the factors required for successful mangrove restoration programs.

1. INTRODUCTION

Mangroves, one of the largest coastal habitats, are the most productive and biologically significant ecosystems. They provide protection to hundreds of millions of people, support biodiversity, detoxify pollutants following off the land and provide nursery areas for fisheries, increasing the supply of food and providing livelihoods (Stuchtey et al., 2020, Giri et al., 2011, Valiela et al., 2001, Wang, 2019). Coastal communities have long relied on the provisioning services of mangroves for extraction of construction materials, fueling food, and capturing food sources such as shellfish and finfish (Ellison et al., 2020).

Over time, there has been considerable attention on mangroves, as they form a natural infrastructure that provides coastal protection in tropical regions against the coastal hazards (Blankespoor et al., 2017). Recognizing the importance of mangroves in carbon sequestration, the IPCC has consistently highlighted their significance as critical ecosystems for both climate change mitigation and adaptation strategies. However, concerns have been raised regarding the vulnerability of mangroves to the detrimental effects of rising temperatures, ocean acidification, sea-level rise, altered precipitation patterns, and extreme weather events (IPCC, 2014, 2019).

Globally, mangrove forests occur in 105 countries; they enhance fisheries, sustaining 4.1 million small-scale fishers, protect coasts by providing flood prevention worth USD 65 billion per year, and mitigate climate change by storing 8.5 gigatons of carbon (Leal and Spalding, 2022, Hagger et al., 2022). Despite their ecological significance, mangroves are declining globally and exposed to various drivers of deforestation and degradation. Approximately 35% of the world's mangrove forest has disappeared in the past two decades, putting mangroves in peril (Bosire et al., 2008, Valiela, et al., 2001). Furthermore, improvements in remote sensing have monitored a further 2.1% (3363 km^2) decline between 2000 and 2016, primarily from conversion to aquaculture and agriculture (Hagger et al., 2022).

In this context, significant efforts have been made to restore mangroves through various afforestation and restoration programs and address the decline. Since the 1970s, restoration programs have been started in different countries which had mangroves. While initially, the efforts were mainly on planting of mangroves, it then shifted toward livelihood restoration programs. In the last few years, these programs are often multi-stakeholder partnerships, with global initiatives being launched like Global Mangrove Alliance, REDD+, payment for environmental services, and national policy interventions (Pham et al., 2022). Along with it, the "New Ocean Report" considered restoration and conservation of mangroves as essential investment for a sustainable ocean economy.

This comprehensive report delves into mangrove afforestation programs worldwide, exploring the drivers and enablers of scaling. The first section of the report provides an overview of mangrove coverage, historical trends, and the factors contributing to mangrove deforestation. The subsequent section shifts the focus to global mangrove afforestation programs and examines their role in climate change mitigation and adaptation. It delves into various types of afforestation programs, the approaches employed, the stakeholders involved, and an assessment of the governance and institutional framework of these programs. The third section presents a case study of Vietnam, reviewing the country's efforts to afforestation programs and identifying opportunities for the development of new governance and institutional models. The last section concludes with lessons on the factors supporting successful mangrove restoration programs for Low Emission Food Systems.

2. MANGROVE: A GLOBAL OVERVIEW OF COVERAGE, HISTORICAL TRENDS AND DEFORESTATION DRIVERS

2.1. Historical status and current trends

The most recent assessment by Global Mangrove Watch 2022 estimated the global extent of mangroves to be at 14.7 million hectares, which occupy 14.93% of the world's coastline. In the 1980s, the FAO provided the first global assessment of the mangrove extent, estimating a total area of 15.6 million hectares. During the 1990s, the mangrove area estimates ranged from 16.9 million hectares to 18.1 million hectares (Spalding et al., 1997; FAO 2007). In the 2000s, the FAO estimated the global extent of mangrove forests to be 15.2 million hectares (Table 1). In 2020, there was another estimate by Giri et al, 2011, in which the mangrove area was reported at 13.7 million hectares. While different reports provide varying estimates of mangrove extent, the overall trend points towards a decline in mangrove area over time.

There has been an overall decline in the mangrove area of 1.04 million hectares between 1990 and 2020. Studies report that global mangrove forest cover followed an average annual rate of -1.04% from 1980 to 2000 and -0.66 % from 2000 to 2005 (FAO, 2007; Spalding et al., 2010). Mangroves are also the host of rich biodiversity, but with mangrove areas and quality reduction, it is estimated that 16% of mangrove species are at risk of extinction worldwide (Yessoufou and Stoffberg, 2016).

Table 1 - Estimates of extent of mangrove area

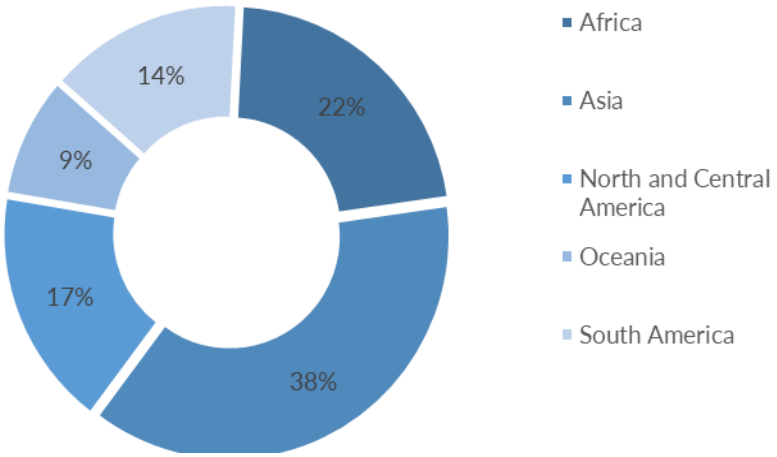
Year	Estimates of extent of mangrove area in millions of hectares (Source)
1980	15.6 (FAO, 2023)
1990	16.9 (FAO, 2023) 18.1 (Spalding et al.,1997)
2000	15.2 (FAO, 2007)
2020	13.7 (Giri et al., 2011) 14.7 (Global Mangrove Watch, 2022) 14.8 (Global Forest Resource Assessment. FAO, 2020)

Sources: Spalding et al., 1997, FAO 2007, 2020, 2023. Giri et.al, 2011; Global Mangrove Watch 2022.

Among the world's regions, Asia boasts the most extensive mangrove cover, with 5.5 million hectares accounting for 38% of the global total (Figure 1). Africa comes second with 3.2 million

hectares, followed by North and Central America with 2.6 million hectares, South America with 2.1 million hectares, and South America with 1.3 million hectares (FAO, 2020).

Figure 1 - Repartition of mangrove area by region



Source: FAO, 2020

Within the regions, Asia has seen a significant decline, with an annual average loss of 1030 hectares in 1990-2000 against 38,200 hectares in 2010-2020. Within Asia, South and Southeast Asia, have seen an increase in losses from 800 hectares between1990 and2000 to 38,300 hectares from 2010 to 2020. However, regions such as South America, and North and Central America, have seen gains in mangrove areas over the same year. This is explained by improved data collection methods and results from reforestation programs.

Estimations of the mangrove area and extent have evolved over time, transitioning from traditional methods like field surveys to more efficient remote sensing techniques. Remote sensing, which covers vast areas and assesses various mangrove ecosystem parameters using diverse sensors, has proven to be a useful tool for mangrove mapping (Maurya et al., 2021). The advancement of remote sensing technologies has further enhanced the accuracy and scope of mangrove estimation.

There have been several studies that have used Remote Sensing (RS) for monitoring and mapping the extent of mangroves in a region. Historically, studies before the 1990s focused only on mapping the extent of mangroves without accuracy assessment. In the 1990s, the Leaf Area Index (LAI) became an important indicator, and ground-based methods were the primary means of estimating the LAI for mangrove forests. These methods were time-consuming and were not able to capture the large-scale spatial and temporal variations in LAI, particularly in difficult terrains. Additionally, before 1990, the satellite RS data was low and insufficient to distinguish between the small patches and linear stands. During the 1990s, the emergence of high-resolution datasets helped in effectively characterizing the LAI. During the 2000s, through high-resolution remote sensing, indicators such as

species classification, estimation of height and biomass, estimation of the amount of carbon stored in mangroves, and health conditions of the mangroves were estimated. These estimates were key in understanding the carbon cycle and its implications for climate. From 2010 onwards and following these innovations in measurement, mangroves are considered as an ecosystem important for global carbon cycle and energy balance and respond to global climate change. It opens new field of research on carbon flux, eco-hydrology, and the impact of climate change on mangroves (Table 2).

Table 2 - Historical perspective on remote sensing research themes

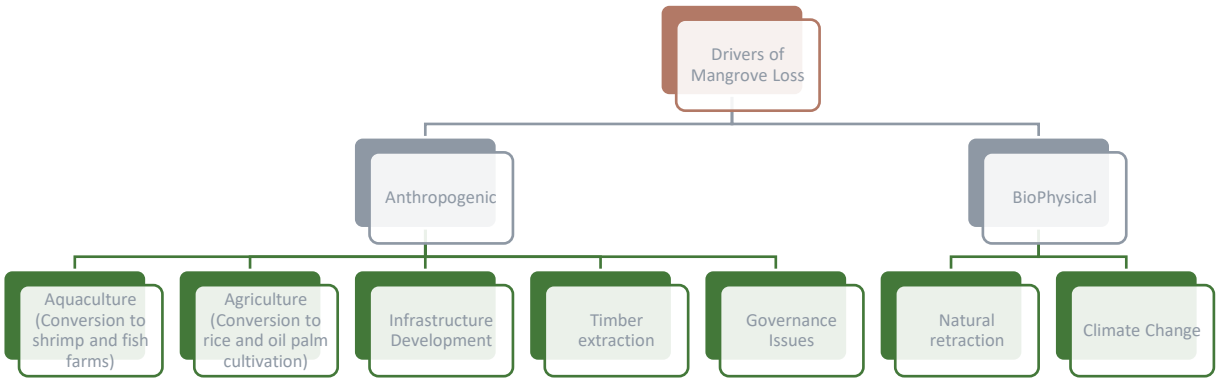
Indicators	Before 1990	2000	2010	After 2020
Distribution Mapping	Extent Mapping		Species Mapping	
Biophysical parameters Inversion		Leaf Area Index Biomass estimation	Height & Biomass Health	
Ecosystem Process Characterization			Carbon estimation	Climate Impact, Carbon flux, ET etc.

Source: Authors' Analysis

2.2. Drivers of mangrove loss

Nearly 25 to 30% of the world's mangroves have been lost in the past 50 years due to human activities such as deforestation and degradation (Polidoro et al., 2010; Dhyani et al., 2023). Several studies have examined factors explaining the loss of mangroves over the past decades, and these drivers are majorly categorized as either anthropogenic or biophysical drivers (Figure 2). These studies have primarily been undertaken at the Global level, where in using remote sensing data for various time periods, the drivers have been identified. However, studies specific to countries have combined remote sensing techniques with consultations with experts, community perception and socio-economic surveys to identify the drivers of mangrove losses.

Figure 2: Drivers of mangrove loss



Source: Authors' Analysis

2.2.1. Anthropogenic drivers

Globally, the loss of mangroves is significantly influenced by anthropogenic drivers. Among these, aquaculture, specifically, conversion to shrimp and fish farms, emerges as the foremost contributor to mangrove loss (Contessa et al., 2023). Several studies have delved into the extent of mangrove losses due to anthropogenic causes. Anthropogenic drivers account for 62% of the mangrove loss, with commodities, such as the conversion to rice, shrimp, and oil palm cultivation, constituting 47% of this total (Goldberg 2020). In a comprehensive review of 43 studies, 26 studies identified the conversion of mangroves for aquaculture as the primary cause of loss (Chowdhury et al., 2017). Other notable anthropogenic drivers include conversion to agriculture, particularly for rice and other crop cultivation, including oil palm. Infrastructure development, encompassing the construction of roads, ports, and markets, follows closely. Hagger et al. (2022) observed that increased access to markets is a robust driver of mangrove loss, likely due to associated pressures for conversion to aquaculture and agriculture.

2.2.2. Biophysical Drivers

The biophysical drivers or natural causes are the second highest major drivers which had contributed to significant loss in mangroves in the past two decades. Globally, 38% of the mangrove loss is attributed to natural causes, which are largely represented through shoreline erosion and extreme weather events (Goldberg, 2020).

2.3. Changes in drivers of mangrove loss

Recent studies have determined the changes in the extent of drivers of mangrove loss. It is observed that the main direct drivers of mangrove loss globally between 2000 and 2020 were first aquaculture development, constituting 26.7% of the total loss; second natural retraction at 25.9%; third conversion to rice and oil palm cultivation at 16.6%, fourth direct and indirect settlement at 13.3%,

and lastly conversion to other forms of agriculture and undefined uses for 12.3% (FAO, 2023). Yet, the significance of global drivers in mangrove loss underwent considerable changes between the two periods, namely 2000–2010 and 2010–2020 (Figure 3). While aquaculture remained a significant driver, its importance waned, primarily influenced by trends in South and Southeast Asia. Conversion for rice cultivation and direct settlement roles also experienced declines. Conversely, the significance of conversion to oil palm plantations substantially increased due to their expansion in Southeast Asia. The proportion of mangrove loss attributable to natural retraction also escalated during 2010–2020, signaling the growing impacts of climate change. Additionally, mangrove losses linked to indirect settlement and disasters exhibited noticeable increases between the two periods.

Figure 3 - Relative importance of drivers of mangrove loss, 2000-2010 and 2010-2020

Source: FAO, 2023.

2.4. Country-Specific Drivers of Mangrove Loss

Beyond the global trends, the drivers differ from country to country (Table 3). For example, conversions to aquaculture dominate, in Indonesia, Cambodia, Philippines and India (Sundarbans). But in Bangladesh, Indonesia, North & Central America and South America natural retraction, cyclones and natural disasters have significant impacts on mangroves. Myanmar sees significant impacts from rice agriculture, while Malaysia and Indonesia face challenges due to extensive oil palm plantations. In Africa and Indonesia, wood extraction takes precedence, followed by coastal development. Notable mangrove losses experienced in Thailand, Malaysia, and Vietnam are driven by urbanization. Beyond the primary drivers, there are additional factors that contribute to mangrove loss such as unsustainable exploitation practices, governance issues such as lack of effective management and enforcement, markets and tourism; these drivers are for example identified in Bangladesh.

The drivers of mangrove loss within these regions (Africa, Asia, and Latin America) are based on different factors. Economic factors such as higher access to markets and better income opportunities emerge as the primary driver. Policy and institutional weaknesses, including the lack of adequate enforcement of conservation measures and insecure land tenure, play vital roles. It is followed by demographic changes, such as the rise in population density and growing demand for mangrove resources. Cultural preferences, specifically for cooking and other uses of mangrove wood, constitute another important driving force for mangrove loss. Finally, technological factors such as poor site selection/management, waste in harvesting and processing, although less significant, still contribute to the complex landscape of drivers (Chowdhury et al., 2017).

Table 3 – Major drivers of mangrove loss at country level

Major Drivers of Mangrove Loss	Countries
Aquaculture/Shrimp farming and landuse change/Shrimp farm development/ Land conversion to shrimp ponds	Indonesia, Cambodia, Philippines, India Sundarbans
Conversion to rice agriculture/Conversion of Mangroves for agriculture/Plantation and agriculture/ Oil palm plantations/Bio-fuel Plantations	Myanmar, Indonesia, Malaysia
Urbanization	Thailand, Malaysia, Vietnam
Natural retraction and Cyclones and other extreme events/ Natural Disaster and Climate Change	Bangladesh, Indonesia North & Central America South America
Wood harvesting/Timber	West Central Africa, Indonesia
Coastal Development	West Central Africa, Bangladesh
Unsustainable exploitation practices	Bangladesh
Governance issues	Bangladesh
Markets and globalization	Bangladesh
Tourism	Bangladesh

Source : Richards and Friess. (2016) ; Feka and Ajonina (2011) ; Islam et al. (2016, 2017); Kumar (2012); FAO (2023)

2.5. Drivers of mangrove gains

During the last decade, significant efforts have been made to restore mangrove forests worldwide through restoration programs. Studies understanding the drivers of mangrove loss have also investigated drivers of mangrove gains. Although natural expansion is the major driver of mangrove gains, restoration efforts in South and Southeast Asia were found to have increased the proportion of mangrove gain (FAO,2023). Some of the supporting factors are community forestry support, indigenous land rights, mangrove restoration effort, NDC commitment and Ramsar Wetlands recognition. Community-based mangrove management has improved mangrove conservation and improved livelihood. Community forest management or co-management can lead to positive correlation and social outcomes, particularly in communities with de facto tenure rights and countries with low development and governance indicators. Also, mangrove restoration efforts and NDC commitments likely responding to deforestation, enhance mangrove conservation (Hagger et al., 2022).

3. MANGROVE AFFORESTATION PROGRAMS

To address the issue of mangrove loss, there has been a significant push to safeguard mangrove greenbelts. As a result, several restoration and afforestation programs have been initiated globally. In this section, we present an overview of the anticipated effects of these programs on both mitigation and adaptation. Additionally, we will examine various mangrove afforestation programs and discuss the key institutional and governance factors that drive these initiatives.

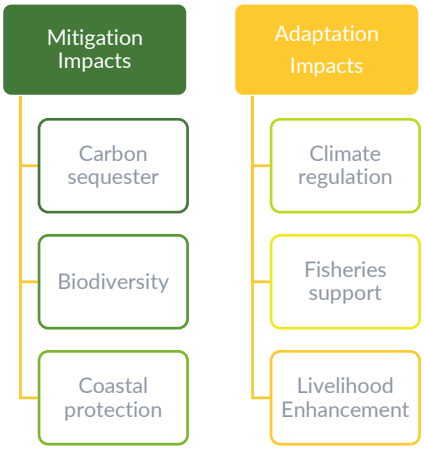
3.1. Expected impacts of mangrove afforestation programs on mitigation and adaptation to climate change

Mangrove afforestation programs are gaining global recognition for their positive impact on both mitigation and adaptation efforts regarding climate change. In terms of mitigation, mangroves have a high capacity for carbon sequestration due to their rapid biomass accumulation. By implementing afforestation programs, carbon storage can be enhanced, leading to a reduction in GHG emissions. Research studies have shown that restored mangroves play a significant role in carbon sequestration, making them valuable in climate mitigation efforts (Donato et al., 2011; Alongi, 2012). Moreover, mangroves are rich in biodiversity, serving as habitat for various species. Afforestation programs contribute to the conservation of plant and animal species, fostering ecosystem resilience and preserving genetic diversity. Additionally, mangrove forests act as natural barriers against coastal

erosion, storm surges, and tsunamis. Implementing afforestation programs can enhance coastal protection, thereby reducing the vulnerability of coastal communities to climate-related hazards.

Mangrove afforestation programs play a crucial role in mitigating the effects of climate change on coastal regions by preserving favorable microclimatic conditions (Figure 4). Mangroves act as vital nurseries and feeding grounds for numerous economically significant fish species. By implementing afforestation programs, fisheries productivity can be enhanced, thereby supporting the livelihoods of coastal communities that rely on fishing. Moreover, mangroves offer a wide array of goods and services, such as timber, non-timber forest products, and eco-tourism opportunities. Afforestation programs have the potential to improve the livelihoods of local communities by creating sustainable income-generating activities supported by a low-emitting food system.

Figure 4 - Expected impacts of mangroves afforestation programs in terms of mitigation and adaptation to climate change



Source: Authors' analysis

3.2. Review of mangrove afforestation programs

3.2.1. Inception of mangrove programs (1970-80s)

Several nations have made attempts to restore and protect mangroves. The first ever mangrove afforestation program was started in Bangladesh in 1966. During this period, the country faced various cyclones and the forest department of Bangladesh initiated a mangrove planting program in 1966 to provide additional protection to inhabited coastal regions outside of the existing embankments. The initial phase was successful, prompting the implementation of large-scale mangrove afforestation programs in Bangladesh and beyond. Thereafter, in the 1980s, the annual planting continued in the country with the World Bank funded Mangrove Afforestation Project I and II, and by 1990, 120000 hectares of mangroves had been planted. During the evaluation of these

programs, it was highlighted that there is a need for an intensive management-oriented research program in relation to mangrove plantations (Saenger and Siddiqi, 1993).

3.2.2. Community based mangrove management (1990s-2000s)

In the early 1990s, community-based mangrove management was promoted as part of a wider movement on community-based forest management. This approach was initiated, as communities were significantly affected by mangrove destruction caused by shrimp farming, mining, or infrastructure development. It was during this period that NGOs came into the picture and played a crucial role in assisting the community in claiming collective forest management rights and protecting mangroves from loss and degradation.

For example, in India the NGO MSSRF, along with the state forest department and community members initiated a science-based community-centered approach. MSSRF developed joint mangrove management plans. To develop these plans, a participatory approach was followed by integrating coastal livelihoods in restoration programs. Their primary aim was to engage and empower stakeholders, particularly the local communities, socially, technically, and organizationally to restore, sustain, and manage the mangrove wetlands (Selvam and Thamizoli, 2022). MSSRF then developed a 'Mangrove Atlas' which provided detailed information on mangroves through GIS maps and was designed as a tool for public policy and public action.

Another example comes from Thailand in the 1980s, as the country experienced a significant impact on its coastal communities due to the destruction of mangroves caused charcoal and mining concessions, shrimp farming and infrastructure development. With the loss of their livelihoods, community members had to migrate to work in cities. During this period, the NGO WWF played a crucial role by providing information about community forest rights and encouraging the communities to protect the remaining mangroves. They actively assisted the communities in understanding how to assert their collective forest management rights and safeguard mangroves from further loss and degradation (Kongkeaw et al., 2019).

Following these early examples, from 1990 to 2000, several programs emerged on a global scale for mangrove protection, spearheaded by national governments, NGOs, and local communities.

3.2.3. Restoration programs: Coastal protection, community-based natural resource management and multistakeholder partnerships (2000s – 2010s)

In addition to various anthropogenic factors, climate change, including rising sea levels, posed additional threats to mangrove ecosystems. The devastating Indian Ocean Tsunami in 2004 further highlighted the importance of mangrove development and restoration at the global level. Post 2004,

the effect of mangrove loss on coastal protection in case of cyclonic or tsunami events was widely recognized. Along with it, several countries adopted supportive legislation and set ambitious strategic plans for mangrove restoration. The mangrove afforestation programs were also aimed at contributing to the delivery of global targets, including the United Nations Sustainable Development Goals (SDGs), Aichi Biodiversity Targets, Bonn-Challenge, and the Paris Agreement on Climate Change (Ramsar Convention on Wetlands, 2018). In addition to these global targets, disasters triggered natural resource management behavior among communities. Several governments and NGOs sought to build the affected coastal 'communities' resilience by implementing ecosystem-based resource restoration programs through a community-based approach and adhering to the affected 'communities' cultures and customs (Pei-Shan, 2019).

For instance, in Thailand, efforts were made to restore community-based mangrove ecosystem after the 2004 tsunami. These projects primarily followed a community-based natural resource management approach, involving coastal communities in mangrove restoration programs while also increasing their livelihood opportunities to enhance their resilience (Pei-Shan, 2019).

Sri Lanka, various NGOs, and local institutions-initiated mangrove restoration activities. These initiatives ranged from small-scale projects funded by the local community to large-scale island-wide programs. The focus was on raising awareness about mangrove conservation and promoting community-led efforts, including the establishment of mangrove nurseries and tree-planting programs. Stakeholder groups involved in these programs included fishermen, farmers, people living around mangrove areas, women, educational institutions, members of local authorities, and government agencies (Wickramasinghe, 2017).

Another example comes from India where a multi-stakeholder approach was adopted to restore mangroves in Gujarat. The approach included community involvement to enhance their understanding of the importance of mangroves, financial contributions from industries to support restoration efforts, and assistance in monitoring newly planted mangrove trees. The Gujarat Ecology Commission, a government agency, played a significant role in facilitating the collaboration between communities and industries, and providing technical support for mangrove restoration.

Figure 5 gives an overview of the different approaches from Governmental programs to multi-stakeholder partnerships, and table 4 provides examples of national mangrove programs from the 1970s to present**.**

Figure 5 - Governance and institutional models implemented in mangrove restoration programs.

Source: Authors' Analysis

3.2.4. Evolution of global mangrove conservation: Nationally Determined Contributions and the Global Mangrove Alliance (post 2010- present)

In international and national dialogues, nature-based solutions such as protection, conservation and restoration of mangroves and other blue-carbon ecosystems have become important measures for mitigating and adapting to climate change. Thus, in 2017, five of the ''world's leading global conservation NGOs (Conservation International, the International Union for Conservation of Nature, The Nature Conservancy, Wetlands International and World Wildlife Fund) established the Global Mangrove Alliance (GMA). GMA is an alliance between multiple global conservation organizations, which has set ambitious targets for increasing the extent of mangroves globally. The GMA is building a global movement of hundreds of civil society organizations, technical experts, government agencies, corporations, funding agencies, foundations, and community groups to jointly work towards the ambitious goal of increasing global mangrove cover by 20% by 2030. It also sets targets related to biodiversity conservation, climate regulation, food security and human well-being. It acknowledges that collaborative action is required across sectors and regions for accelerating mangrove protection and restoration. Although 97 countries mentioned coastal and marine ecosystems, including mangroves, in their Nationally Determined Contributions (NDCs) to the Paris Agreement, and 61 countries have included conservation or restoration of blue carbon ecosystems as mitigation and/or adaptation measures (ICUN, 2023). There is still a lack of consistent and detailed inclusion. GMA therefore provides a platform to increase the potential of incorporating mangrove restoration into NDC as a way for countries to enhance their climate action targets.

Table 4 – Main mangrove programs from the 1970s to present

Years	Programs	Country	Objective	Technology/Innovation	Governance and Institutional Model
1970s-1980s	Coastal Afforestation Mangrove Afforestation I Mangrove Afforestation II	Bangladesh	Creating a shelter belt to protect the lives and properties of the coastal communities.	Annual plantings of mangrove trees	Government Program – Forest Department
1990s-2000s	Preparation of Mangrove Atlas	India	Collecting scientific information about mangrove resources.	Using GIS tool, the Mangrove Atlas was developed as the first of its kind, plan to be used to develop mangrove management plans	MS Swaminathan Research Foundation (MSSRF) and State Departments
	Joint Management Committees	India	Restoration and conservation of mangroves through participatory approach.	Participatory approach (i.e., integrating coastal livelihoods in restoration programs)	MS Swaminathan Research Foundation (MSSRF) and State Departments
	Mangrove Restoration Programs in Thailand	Thailand	Providing information to community on forest rights and encouraging communities to protect mangroves.	NGOs promoting collective forest management rights and safeguards	International NGOs (WWF) along with local communities
2000s-2010s	Mangrove Restoration Programs in Sri Lanka	Sri Lanka	Promoting mangrove restoration activities	Raising awareness about mangrove conservation and promoting community-led efforts	National NGOs and local institutions involving various local stakeholders' local authorities, and government agencies
	Restoration of Mangroves in Gujarat (till 2007) and Public Private Partnership model on	India	Creating an alliance between the industry, public agencies, and local communities to promote an ecologically and	Multi Stakeholder Approach including communities to enhance their capacity on importance of mangroves and industries, providing funds for restoration efforts and monitoring of newly created	Gujarat Ecology Commission along with India-Canada Environment Facility

	mangrove management		socially responsible mangrove restoration.	plantations) with technical support from GEC.	
	Mangrove Replanting and Restoration Programs	Sri Lanka	Restoring damaged mangroves	Planting of mangrove trees with community involvement	National Governments and NGOs.
2010s- Present	Global Mangrove Alliance	All countries	Increasing global mangrove cover by 20% by 2030. Additional targets related to biodiversity conservation, climate regulation, food security, and human well-being.	Seven broad initiatives: *restoration, adaptation, livelihoods, research, policy, blue carbon,* and *others.*	Alliance between multiple global conservation organizations and inclusion of civil society organizations, technical experts, government agencies, corporations, funding agencies, foundations, and community groups.
	Vietnam Forestry Development Strategy 2021-2030	Vietnam	Sustainable Mangroves Conservation.	Conservation policies and projects that not only expand the mangrove areas but also enhance their quality and capacity to support coastal communities' livelihoods.	Government Programs.

Source: Authors' Analysis

In addition, GMA provides a restoration tool that includes major initiatives by various countries. Presently, these initiatives are broadly categorized into restoration, adaptation, livelihoods, research, policy, blue carbon, and others. Among them, restoration, livelihoods, research, and policy initiatives are promoted in most mangrove programs:

- The *restoration* initiatives emphasize a science-based approach, which entails utilizing scientific knowledge and methods to guide the restoration efforts. The approach involves understanding the specific ecological needs of the mangrove communities and implementing restoration strategies that align with this understanding.
- In the *livelihoods* approach, the goal is to create income opportunities for local communities by restoring mangroves. For instance, making shrimp production sustainable and establishing a bee-keeping collective are examples of income-generating activities that can be incorporated into a mangrove restoration program. One specific example is Integrated Mangrove Shrimp (IMS) aquaculture implemented in Vietnam. This practice involves raising

shrimp in plots of land where mangroves are also grown, with government standards requiring a certain percentage of the plot to be dedicated to mangrove trees. Currently, there is an expansion in IMS aquaculture in Vietnam, with support from international NGOs.

- In terms of *research*, initiatives are exploring connections between mangrove biodiversity and natural hazards, such as cyclones and storm surges. They support raising awareness on the value of mangroves and inform conservation efforts.
- Finally in *policy*, efforts have been made to adopt national policies that protect mangroves and support restoration programs.

3.3. Challenges in mangrove conservation programs

The important role played by local, state, and national governments in successful management, conservation and restoration of mangroves have been recognized, but their efforts alone are not enough. This can be seen in countries like Indonesia and Vietnam, where well-intended science-based programs faced opposition from local communities. The main challenges therefore lie in the lack of communication and understanding between these different actors.

For example, in Indonesia, communities viewed science-based projects as benefitting only to the elite group and not providing practical solutions to their concerns. Similarly, in Vietnam, initiatives combining science and local knowledge initiatives operated separately, making it difficult for communities to access and participate in these programs (Romanach et al., 2018).

Local knowledge-based approaches often suffered from limited participation and insufficient scientific understanding, ultimately hindering sustainability. Additionally, some community-based programs solely focus on socio-economic aspects, neglecting the ecological needs of the restored habitat. Therefore, it is necessary to critically assess current practices to ensure the successful integration and long-term functionality of restored habitats.

Some recent research has also found that reforested mangroves in certain countries have experienced low survival rates or complete failure). This can be attributed to planting mangroves in unsuitable locations and selecting inappropriate species for specific sites (Zimmer et al., 2022).

4. MANGROVES IN VIETNAM

4.1. Coverage, historical trends, and deforestation drivers

In Vietnam, the mangrove forests account for 1.5% of the Vietnam total forest area (14.4 million hectares). They are majorly located along the coast of Vietnam and the 3260 km long coastline of Vietnam supports a significant proportion of mangroves, which are important for their ecological and economic value as well as their role in protecting the environment. They play an important role in biodiversity and coastal protection, particularly in mitigating and adapting to climate change. Vietnam as stated by the IMHEN and UNDP (2015), is at risk from climate change due to its extensive coastline. While coastal forests only make up 3.5% of the ' 'country's total forest area, they are crucial for various reasons such as providing income for local communities, reducing the effects of storm surges and coastal erosion, supporting carbon storage and biodiversity preservation. Mangroves make up approximately 86% of Vietnam coastal "protection forest" area, according to MARD (2018).

Several studies reported a loss of mangrove vegetation over the years. During the period 1977-1995, mangrove vegetation area declined by 23% due to extensive and unsustainable shrimp farming (Alongi, 2008). Another study mentioned that the area of mangrove forests in Vietnam decreased significantly from 408,500 to 155,290 hectares between 1943 and 2000. This loss can be attributed to numerous drivers, which include non-sustainable use of mangrove ecosystems for aquaculture, storms, waves and natural disasters, deforestation of mangrove forests for timber and natural resources, multi-source pollutants from agriculture and urban areas, and lack of sufficient regulatory mechanisms for the protection and sustainable development of mangroves. Despite these causes, there have been efforts to restore mangroves from the 2000s, and the mangrove area increased again by 164,701 hectares between 2000 and 2017.

4.2. Mangrove afforestation programs

The Vietnamese government acknowledges the significance of mangroves in coastal protection and has introduced various policies to safeguard and expand mangrove areas. Examples of such policies include the Vietnam Forestry Development Strategy 2021-2030 with a vision extending to 2050. These policies prioritize mangrove conservation and aim to establish a sustainable mangrove forest management plan for the northern part of Vietnam based on scientific analysis of past activities. Mangroves conservation is considered a critical policy in addressing the impacts of climate change and protecting coastal communities.

To align with these objectives, sustainable mangrove conservation has been identified as a key policy and investment priority in the National Climate Change Adaptation Plan for 2021-2030 and

the Vietnam Forestry Development Strategy for 2021-2030. The objective is to ensure that forested areas constitute a significant portion of the country's total land area. Sustainable mangrove conservation is also an essential aspect of 'Vietnam's Nationally Determined Contribution to climate change. A national program is currently being developed to invest in the protection of coastal forests and enhance local livelihoods using policies. It aims not only to expand the mangrove forest area but also to improve their quality and capacity to support coastal communities. Table 5 provides a summary of the objectives of the mangrove restoration programs in Vietnam.

Table 5 – Mangrove restoration programs in Vietnam

Sponsor	Period	Restoration objective					Reference
		Forest products	Fisheries	Coastal protection and stabilization	Mitigation and adaptation	Ecosystem restoration	
Oxfam UK	1990-1996						EJF (2003)
SCF - GB	1991-1996						Witter (1994)
JICA	1994-2005						Suda (2013)
JRC, DRC	1994-2010						Bolte et al. (2011)
TN	1996-1999						Benthem et al. (1999)
WB, DANIDA	1999-2007						WB (2008)
DANIDA	2003-2004						Lai (2008)
CARE	2006-2014						Reed et al. (2015)
JICA	2007-2012						Suda (2013)
FCNH	2010-2015						Que and Thinh (2012)
JRC, IFRC	2011-2015						AMDI (2015)
TRF	2012-2015						Nghiem and Tyler (2017)
IKI, BMUB	2012-2016						SNV (2016)
KfW	2013-2019						MARD (2014)
GCF, MARD, MC, UNDP	2017-2022						UNDP (2015)
WB, MARD	2017-2023						WB (2017)

Source: Hai, 2020

Despite the efforts made by national and international organizations to conserve mangroves in Vietnam, there is still a lack of sufficient financial resources (Macintosh and Ashton, 2002). One possible solution to address the funding shortage for mangrove conservation is through payments for ecosystem services (PES). PES entails providing financial support to individuals who enhance the health and biodiversity of the biomass, in return for the benefits received from the ecosystem. For instance, compensation could be provided to mangrove managers, including communities, for their role in carbon sequestration. This approach could also be applied to storm and flood protection, as well as the support of aquaculture. However, it remains unclear whether PES can fully or partially make up the lost profits of aquaculture farmers. In addition, sustainable mangrove management plans should be developed for the northern part of Vietnam, further scaling up of sustainable integrated mangrove shrimp by providing organic certification to shrimp

farmers and setting thresholds of 50% of shrimp farms areas to be covered with mangroves should be considered.

DISCUSSION AND CONCLUSION

Mangroves play a crucial role in mitigating climate change, acting as potent carbon sinks. They absorb and store massive amounts of carbon dioxide, far exceeding the potential of terrestrial forests per unit of coverage. Mangroves are also vital for food systems. They provide critical nursery grounds for fish and shellfish, supporting coastal and island communities' food security and livelihoods. This makes them particularly important in regions like Southeast Asia, where dependence on fisheries is high.

The 14.7 million hectares of mangrove globally are spread across Asia (38%), Africa (22%), North and Central America (17%), South America (14%), and Oceania (9%). But this vital resource is under threat. Mangroves have faced a significant decline since 1990, losing over 1 million hectares. Asia, particularly Southeast Asia, bears the brunt of this loss, witnessing an annual rate of loss of up to 38.2 thousand hectares per year. To combat this decline and better understand mangrove dynamics, scientists are employing remote sensing tools. These tools map the extent and health of mangroves, monitor carbon flux, and track the impact of climate change.

Additionally, restoration efforts have taken place overtime in various countries recognizing the value of mangroves. These efforts including annual planting programs, government plans, and participatory approaches involving communities and NGOs are crucial in reclaiming lost mangrove cover. Multi-stakeholder partnerships, in which the private sector provides funds, communities enhance their understanding of mangrove importance, and governments facilitate restoration through technical assistance and policies show positive outcomes. Zooming on Vietnam, the emphasis has been on mangrove restoration through policy such as ' 'Vietnam's Forestry Development Strategy which aims to protect and expand its mangrove area. Initiatives like developing a sustainable management plan for the North reflect this commitment. Vietnam is also exploring innovative approaches like "Ecosystem-based Adaptation" and integrated mangrove shrimp farming incentivizing mangrove conservation through organic certification programs for shrimp farmers.

The review of programs and policies presented in this report highlights that mangrove restoration programs can follow different goals which need to be well defined. These goals may include restoring habitats by increasing mangroves coverage in degraded areas, protecting coastlines from erosion and storm surges, enhancing carbon sequestration by promoting CO2 capture and

storage and improving livelihoods by supporting local communities through fisheries and eco-tourism. To deliver these objectives, be sustainable and upscaled these programs need to be carefully designed so that social, technical, economic, and political considerations be jointly considered (Wickramasinghe, 2017).

a) Social

- *Enhanced communication and engagement*: Building trust and addressing community concerns through active participation in program design and implementation.
- *Sustainable livelihood opportunities*: Integrating income-generating activities like sustainable fishing or eco-tourism and recognizing the value of mangroves through mechanisms like carbon credits payments to incentivize conservation efforts.
- *Community ownership and support*: Fostering a sense of shared responsibility and providing necessary resources and training. Involving local communities in planting, monitoring, and decision-making fosters ownership and sustainability.

b) Technical

- *Capacity building:* Equipping both organizers and participants with the knowledge and skills needed for effective restoration work.
- *Site-specific understanding:* Conducting thorough research on the ecological characteristics of each restoration site. This may involve matching suitable water regimes to different species, selecting species that are adapted to specific soil types, engaging local communities in planning and implementation, addressing existing pressures and leveraging existing resources. Several examples of successful mangroves restoration programs include the use of native species adapted to local conditions to improve survival rates and enhance ecosystem resilience.
- *Robust monitoring and evaluation:* Implementing consistent follow-up and data collection to assess progress and adapt strategies as needed. Indeed, scaling up restoration efforts requires replicable methods and efficient monitoring, which can be facilitated by tools like the Mangrove Restoration Tracker (REF) which provide standardized data collection tools and facilitate knowledge sharing. Monitoring and evaluation are essential for continual improvement and the adaptation of policies based on lessons learned from past projects. Continuous monitoring of restored areas is vital to assess progress, identify challenges, and adjust future efforts. This iterative process promotes long-term success and ensures efficient utilization of resources.

c) Economic

- *Securing diverse funding sources:* Establishing a mix of local, national, and international funding streams for long-term project sustainability.
- *Transparency and accountability:* Ensuring proper management of financial resources through community involvement and oversight.

d) Political

- *Integration with broader plans:* Aligning restoration programs with existing coastal management strategies for a holistic approach and e implementing of robust national mangroves policy can provide clear guidelines, prioritize restoration efforts, and incentivize sustainable practices. Stronger partnerships: Building effective collaboration between local authorities, government agencies, and research institutions.
- *Flexible and adaptable regulations:* Enacting laws that prioritize conservation while allowing for adjustments based on local context and evolving needs.

By adhering to these key principles, mangrove restoration projects can go beyond simply planting trees and create thriving ecosystems that benefit both nature and people. By setting clear objectives, tailoring best practices to local conditions, and effectively utilizing tools and policies, we can ensure that these coastal guardians continue to protect our coastlines, store carbon, and through low emission food systems ensure the sustainable development of communities for generations to come.

REFERENCES

Alongi M.D. 2008. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change, Estuarine, *Coastal and Shelf Science,* 76 (1), pp 1-13. https://doi.org/10.1016/j.ecss.2007.08.024

Alongi M.D. 2012. Carbon sequestration in mangrove forests, Carbon Management, 3:3, 313-322, DOI: 10.4155/cmt.12.20

Bosire J.O., Dahdouh-Guebas F., Walton M., Crona B.I., Lewis R.R., Field C., Kairo J.G., and Koedam N. 2008. Functionality of restored mangroves: A Review. *Aquatic Botany*, 89(2), pp 251-259. https://doi.org/10.1016/j.aquabot.2008.03.010

Blankespoor B., Dasgupta S., Lange G.M. 2017. Mangroves as a protection from storm surges in a changing climate. *Ambio*. 46(4), 478-491. doi: 10.1007/s13280-016-0838-x

Contessa V., Dyson K., Vivar Mulas P.P., Kindgard A., Liu T., Saah D., Jenneson K., and Rikkarinen A. 2023. Uncovering Dynamics of Global Mangrove Gains & Losses. *Remote Sens*. 2023, 15(15), 3872. https://doi.org/10.3390/rs15153872

Chowdhury, R. R., Uchida, E., Chen, L., Osorio, V., and Yoder, L. 2017. Anthropogenic drivers of mangrove loss: Geographic patterns and implications for livelihoods. *In Mangrove Ecosystems: A Global Biogeographic Perspective: Structure, Function, and Services* (pp. 275–300). https://doi.org/10.1007/978-3-319-62206-4_9

Dhyani S., Shukla J., Kadaverugu R., Dasgupta R., Panda M., Kundu K.S., Santhanam H., Pujari P., Kumar P., and Hashimoto S. 2023. Participatory Stakeholder Assessment or Driver of Mangrove Loss to Prioritize Evidence – based conservation and restoration in Bhitarkanika and Mahanadi Delta, India, Sustainability 15(2), 963. https://doi.org/10.3390/su15020963

Donato, D., Kauffman, J., and Murdiyarso, D. *et al.* 2011. Mangroves among the most carbon-rich forests in the tropics. *Nature Geosci* **4**, 293–297. https://doi.org/10.1038/ngeo1123

Ellison A., Felson A., and Friess D. 2020. Mangrove Rehabilitation and Restoration as Experimental Adaptative Management. *Frontier Marine Science,* Sec. Marine Conservation and Sustainability.7 https://doi.org/10.3389/fmars.2020.00327

FAO. 2007. The world's mangroves 1980–2005. Rome

FAO. 2020. Global Forest Resources Assessment 2020 – Key findings. Rome. https://doi.org/10.4060/ca8753en

FAO. 2023. The world's mangroves 2000–2020. Rome. https://doi.org/10.4060/cc7044en

Feka, N.Z. and Ajonina, G.N. 2011. Drivers causing decline of mangrove in West-Central Africa: a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 217–230.

Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J., and Duke, N. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecol. Biogeogr.* 20, 154e159.

Goldberg, L., Lagomasino, D., Thomas, N. and Fatoyinbo, T. 2020. Global declines in human driven mangrove loss. *Global Change Biology*, 26(10): 5844–5855. https://doi.org/10.1111/ gcb.15275

Global Mangrove Watch. 2022. https://www.globalmangrovewatch.org/

Hagger V., Worthington T.A., Lovelock C. E., Adame M.F., Amano T., and Brown M.B., et al. 2022. Drivers of global mangrove loss and gain in social-ecological systems. *Nat Commun*. 13, 6373. doi: 10.1038/s41467-022-33962-x

Hai, N. T., Dell, B., Phuong, V. T., and Harper, R. J. 2020. Towards a more robust approach for the restoration of mangroves in Vietnam. *Annals of Forest Science*, 77, 1-18. https://doi.org/10.1007/s13595-020-0921-0

Ilman, M., Dargusch, P., and Dart, P. 2016. A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. Land use policy, 54, 448-459.

IMHEN and UNDP [Institute of Meteorology, Hydrology and Climate Change and United Nations Development Programme] 2015. Vietnam special report on managing the risks of extreme events and disasters to advance climate change

IUCN, 2023. Legal & Policy Recommendations to Support International Mangrove Targets. Available at https://www.iucn.org/story/202312/legal-and-policy-recommendations-support-international-mangrove-targets.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp.

Islam, M.M., Sunny, A.R., Hossain, M.M. and Friess, D.A., 2018. Drivers of mangrove ecosystem service change in the Sundarbans of Bangladesh. *Singapore Journal of tropical geography*, *39*(2), pp.244-265. https://doi.org/10.1111/sjtg.12241

Kumar, P. 2012. Impact of economic drivers on mangroves of Indian Sundarbans: an exploration of missing links. *Environ Dev Sustain* **14**, 939–953 (2012). https://doi.org/10.1007/s10668-012-9361-9

Kongkaew, C., Kittitornkool, J., Vandergeest, P., and Kittiwatanawong, K. 2019. Explaining success in community-based mangrove management: Four coastal communities along the andaman sea, Thailand. Ocean & Coastal Management, 178, Article 104822. https://doi.org/10.1016/j.ocecoaman.2019.104822

Leal, M. and Spalding, M. D. (editors). 2022. The State of the World's Mangroves 2022. Global Mangrove Alliance.

Macintosh, D. J. and Ashton, E. C. 2002. A Review of Mangrove Biodiversity Conservation and Management. Centre for Tropical Ecosystems Research, University of Aarhus, Denmark

MARD. 2018. Report on the Implementation of the Project on Protection and Development of Coastal Forests in Response to Climate Change in the Period 2015-2020. Report No. 5200/BC-BNN-TCLN. Hanoi: MARD.

Maurya, K.; Mahajan, S.; and Chaube, N. 2021. Remote sensing techniques: mapping and monitoring of mangrove ecosystem—A review. Complex Intell. Syst., 7, 2797–281

Pei-Shan S. L., 2019. Building resilience through ecosystem restoration and community participation: Post-disaster recovery in coastal island communities, *International Journal of Disaster Risk Reduction*, Volume 39, 101249. https://doi.org/10.1016/j.ijdrr.2019.101249

Pham H.T., Richard A. MacKenzie., Tran Dang Hung, Troung Van Vinh, Hoang Thi Ha, Mai Huong Lam, Ngugen Thi Hong Hanh, Nguyen Xuan Tung, Pham Ming Hai and Bui Thanh Huyen. 2022. Mangrove Restoration in Vietnamese Mekong Delta during 2015-2020. Achievements and Challenges. *Frontier Marine Science.* Sect. Marine Conservation (9). https://doi.org/10.3389/fmars.2022.1043943

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Ellison, J.C., and Farnsworth, E.J. et al. 2010. The loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS ONE*, 4: e10095

Ramsar Convention on Wetlands. 2018. Global Wetland Outlook. State of the World's Wetlands and their Services to People. Gland. Switzerland: Ramsar Convention Secretariat.

Romanach S.S., DeAngelis D.L., Hock Lye Koh, Yuhong Li, Su Yean Teh, Raja Sulaiman Raja Barizan, Lu Zhai. 2018. Conservation and restoration of mangroves: Global Status, perspectives, and prognosis. *Ocean & Coastal Management*. 154.pp 72-82.

Richards DR and Friess DA 2016. Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. *Proc Natl Acad Sci U S A*. 113(2):344-9. doi: 10.1073/pnas.1510272113

Saenger P and N.A. Siddiqi, 1993. Land from the sea: The mangrove afforestation program of Bangladesh, *Ocean & Coastal Management*, 20(1) pp 23-39, https://doi.org/10.1016/0964-5691(93)90011-M

Selvam, V. and Thamizoli, P 2022. Science-Based and Community-Centred Approach to Restore and Sustain Mangrove Wetlands of India. *Curr. Sci*. 121, 1288. https://doi.org/10.18520/cs/v121/i10/1288-1296

Spalding, M., Blasco, F and Field, C. 1997. International Society for Mangrove Ecosystems, World Conservation Monitoring Centre & International Tropical Timber Organization, eds. World mangrove atlas. Okinawa, Japan, *International Society for Mangrove Ecosystems.*

Spalding, M., Kainuma, M. and Collins, L. 2010. World Atlas of Mangroves. London. Washington DC. Earthscan.

Stuchtey, M., A. Vincent, A., Merkl, M., and Bucher et al. 2020. Ocean Solutions That Benefit People, Nature and the Economy. Washington, DC: *World Resources Institute*. www.oceanpanel.org/ocean-solutions

Stephanie S. Romañach, Donald L. DeAngelis, Hock Lye Koh, Yuhong Li, Su Yean Teh, Raja Sulaiman Raja Barizan and Lu Zhai, 2018. Conservation and restoration of mangroves: Global status, perspectives, and prognosis, *Ocean & Coastal Management*, Volume 154, Pages 72-82, https://doi.org/10.1016/j.ocecoaman.2018.01.009

Valiela I, Bowen JL, York JK (2001) Mangrove forests: one of the world's threatened major tropical environments. *Bioscience* 51: 807−815

Wang, L.; Jia, M.; Yin, D.; and Tian, J. 2019. A review of remote sensing for mangrove forests: 1956–2018. *Remote Sens. Environ*. 231, 111223.

Wickramasinghe, Deepthi. 2017. Chapter 10: Regreening the Coast: Community-Based Mangrove Conservation and Restoration in Sri Lanka. in Participatory Mangrove Management in a Changing Climate: Perspectives from the Asia-Pacific, edited by Rajarshi Dasgupta, and Rajib Shaw https://doi.org/10.1007/978-4-431-56481-2

Yessoufou, K and Stoffberg G.H. 2016. Biogeography threats and phylogenetic structure of mangrove forest globally and in South Africa. A Review. *South African Journal of Botany*.107. pp 114-120. https://doi.org/10.1016/j.sajb.2015.11.002

Zimmer, M., Ajonina, G.N., Amir, A.A., Cragg, S.M., Crooks, S., Dahdouh-Guebas, F., Duke, N.C., Fratini, S., Friess, D.A., Helfer, V. and Huxham, M., 2022. When nature needs a helping hand: Different levels of human intervention for mangrove (re-) establishment. *Frontiers in Forests and Global Change*, *5*, p.784322. https://www.frontiersin.org/articles/10.3389/ffgc.2022.784322/full

Garima Taneja, Research Officer, G.Taneja@cgiar.org

Marie-Charlotte Buisson, Research Group Leader, M.Buisson@cgiar.org

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