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Mangrove Ecosystem Restoration

Edited by Sahadev Sharma

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Meet the editor

Dr. Sahadev Sharma obtained a DSc in Plant Ecology and Physiology in 2012. He is a mangrove ecologist and physiologist with research interests in mangrove forest ecology, physiology, and blue carbon dynamics from local site to the landscape level, using a wide spectrum of methods and technologies such as remote sensing and field-based monitoring and sampling, and integrating ecological, chemical and hydrological data. He is currently focusing on the Asia Pacific region mangrove ecosystem. He is a senior lecturer at the Institute of Ocean and Earth Sciences, Universiti Malaya, Malaysia. Formerly he was a research faculty at the Department of Natural Resources and Environmental Management, the University of Hawaii at Manoa, and a JSPS Postdoctoral Fellow at Tokyo Institute of Technology, Japan. He is currently involved in many national and international research projects for the Universiti Malaya. He is the author of more than sixty papers in international peer-reviewed journals and books, and a referee for about ten journals.

Contents

Preface

The mangrove ecosystem provides several ecosystem services such as timber, charcoal, wave attenuation, nursery and spawning area for fishes, food, tourism, and climate change mitigation. Although they provide these important ecosystem services, we have lost a significant number of mangroves over time. Mangrove degradation and deforestation are caused by both natural disasters (tsunami, cyclones, storms, disease, and erosion) and anthropogenic activities (illegal logging, aquaculture pond, agriculture, urban development and other exploitation). Climate change is happening, therefore we need to protect the remaining mangroves and restore them to enhance the ecosystem services they provide to achieve sustainable development goals. Recently, mangroves have been recognized as one of the nature-based solutions for coastal communities. We are now almost at the tipping point where we can restore mangroves ecologically to mitigate climate change and other important ecosystem services under the United Nations Decade on Ecosystem Restoration. This book is comprised of three sections containing eight chapters that focus on mangrove ecosystem restoration, the ecosystem services they provide, and how to manage and conserve mangroves.

The first section on restoration and natural regeneration includes three chapters. Chapter 1 examines the possibility of utilizing natural means of forest recovery through seedling recruitment and regeneration of mangroves. Chapter 2 presents a guide to rapid evaluation of mangrove degradation where later mangrove restoration can be done. Chapter 3 explains how mangroves regenerate naturally after natural disasters such as tsunamis.

The second section on ecosystem services includes three chapters that discuss how planted mangroves provide different ecosystem services. Chapter 4 discusses the perspective of pollutant deposition in mangrove wetlands, physiological ecology of mangrove species on the impact of heavy metal pollution, and seeking ecosystem restoration in terms of environmental education. Chapter 5 discusses mangrove-based natural dye for batik fabric from *Rhizopora mucronata* waste as a promising product to increase people's income. Chapter 6 talks about the use of advanced molecular biology in biotechnologies as a promising path to faster, more economically viable and ecologically correct mangrove restoration.

The third and final section includes two chapters related to the conservation and management of restored mangroves. Chapter 7 documents the various strategies and approaches used in mangrove restoration in the world generally, and then specifically in the Rufiji Delta, Tanzania. The chapter also presents related policies to protect mangroves. Chapter 8 explains how conservation management of restored mangroves can be done through evaluating ecosystem services such as tourism in Indonesia.

We hope this book helps in the restoration, conservation and management of mangroves to enhance the ecosystem services they provide and help in mitigating climate change.

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Section 1

Restoration and Natural Regeneration

Chapter 1

Mangrove Restoration under Different Disturbances Regime in the Niger Delta, Nigeria

Aroloye O. Numbere

Abstract

Mangroves of the Niger Delta are the largest in Africa and are the source of numerous ecosystem services such as firewood, seafood, building materials and medicinal herbs. Their sustainable use and protection are important for future generations. However, anthropogenic activities such as oil and gas exploration, urbanization, industrialization, dredging, overexploitation and sand mining are the major disturbances that have pushed the mangroves to the brink of extinction. Therefore, in other to restore lost areas of the mangroves natural and artificial means can be adopted to bring them to a restored state. More often than not emphasis of recovery had been placed on artificial remediation and restoration, where polluted sites are cleaned with chemicals and nursery seedlings transplanted to remediated such sites. Nevertheless, this chapter discusses the possibility of utilizing natural means of forest recovery through seedling recruitment and regeneration. This can be achieved by establishing the right environmental conditions such as setting up of a hydro-channel to ensure smooth inflow and out flow of river water carrying seeds, availability of parent mangrove trees to supply the seeds, and the availability of the right soil condition to enable seedling germination and growth. The use of dried and ground mangrove parts as a new way for restoring polluted soil is discussed; in addition, the unconventional proposition of using low key pollution to manage and increase forest resilience is highlighted in this work even though further studies are recommended. Future direction of mangrove restoration should be tilted towards the application of the force of nature, which has the potentials of reversing the adverse effect of anthropogenic activities in well managed and protected sites.

Keywords: ecology, hydrocarbon pollution, remediation, recruitment, succession, urbanization

1. Introduction

Mangroves of the Niger Delta are the most abundant and most productive forest in Africa [1]. It is also the third largest in the world. The significance of mangroves unlike other rain forest ecosystem e.g. Mahogany (*Khaya ivorensis*), obeche (*Triplochiton scleroxylon*) and iroko (*Malicia excelsa* is the kind of ecosystem services they provide [2]. This is because in addition to purifying the air, stabilizing the soil and being used as timber, mangroves play special role in the environment by serving as one of the biggest carbon sink in the world [3] based on the kind of terrain they occupy. They are the only tree species that grow within the swamps and at the fringes of the sea in highly saline environment [4]. They are adapted to one of the most gruesome environments for any tree to survive. For instance, apart from their salty environment, they grow in soft and muddy soil and are constantly bashed by violent tidal currents. In spite of all these environmental difficulties the mangroves had come out unscathed. Mangroves tend to survive very difficult environmental conditions. To deal with high salt, their system shuts off, sweats out or pumps out excessive salt to survive their environment. Their adventitious root system grows not only from the bottom of the tree but also grow out from the branches in an octopus-like manner to be rooted in the swamp, which provide additional support from the ground-based roots. These roots system if not carefully identified can easily be mistaken for mature stems. Excess salt that will easily kill off other trees act as nutrients for their rapid growth. The survival of mangrove in its difficult environment can be a lesson on resiliency for humans.

1.1 Natural mangrove recruitment

Seedling recruitment in mangroves occurs when juvenile organisms survive to be added to a population, by birth or immigration, usually a stage whereby the organisms are settled and are able to be detected by an observer in natural mangroves forest [5]. The Nigerian landscape has significantly changed over the last few decades and anthropogenic activities by man such as sand mining practices is one of the most important causes of this change. Rapid re-establishment of native vegetation, particularly after a large-scale disturbance, can be critical in preventing soil erosion, invasion by exotics, and other unwanted species such as *Nypa fruticans*. Re-colonization of disturbed sites may be slow and unpredictable, especially if seed sources are remote. Ecological restoration may involve not only artificial reintroduction of the original community dominants, but also nurse species that improve seed trapping and establishment [6], attract seed carriers, enhance soil conditions through organic matter or nutrient accumulation [7, 8], or provide protection of sensitive seedlings [9]. Ecological restoration approaches, however, must be based on a thorough understanding of the natural successional dynamics of the system as well as the growth requirements of the dominant plant species. The current challenge in ecological restoration is to manipulate development so that recovery of the entire suite of structural and functional features is achieved as quickly as possible [10]. Few studies have experimentally examined facilitation in the context of restoration [11, 12]. Facilitation may not only involve amelioration of environmental conditions that promote growth of a beneficiary species, but can also arise from effects of dispersal and establishment, e.g., trapping of seeds. Facilitation has been studied in extreme environments such as salt marshes [13, 14] where plants must cope with stresses such as salinity, flooding, and variable sediment and nutrient supplies such as mangroves. Mangroves are the tropical equivalent of temperate salt marshes, but in contrast to marsh grasses that can propagate vegetatively, these tidal forests are dominated by tree species dependent upon seedling recruitment for regeneration. Mangroves are frequently disturbed by hurricanes and human activities, which severely damage or eliminate the forest community [15]. Mangrove plant communities often contain herbaceous species, which are common components of the tropical beach habitat, salt marshes, or other wet coastal communities [16]. Although factors influencing mangrove recruitment such as seed and seedling predators [17, 18], flooding and salinity [19, 20], and sedimentation [21] had been studied in neotropical forests. Mangroves may be extremely slow to recolonize and grow, especially in harsh (e.g., arid, hypersaline) environments [22]. Mangrove ecosystems thus constitute not only a critical habitat with important ecological and societal benefits, but are systems in which facilitative interactions might be applied to improve restoration techniques.

1.2 Ecological restoration

Ecological restoration is defined as the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystem [23]. Ecological restoration includes a wide scope of projects including erosion control, reforestation, removal of non-native species (e.g. *N fruticans*) and weeds, revegetation of disturbed areas, day lighting streams, reintroduction of native species, and habitat and range improvement for targeted species. Hydrological connections to natural restoration site are also very important to allow in inflow of saline water and mangrove seeds [24]. Inflow of water will also clean the site from pollutants such as oil spillage [25].

Factors that affect ecological restoration include the following:

1. **Disturbance:** is a change in environmental conditions that disrupts the functioning of an ecosystem [26]. Disturbance can occur at a variety of spatial and temporal scales, and is a natural component of many communities. For instance, sand mining and oiling activities urban development are disturbances. Differentiating between human-caused and naturally occurring disturbances is important in restoration and minimization of anthropogenic impacts.

   Human disturbance: This is a kind of disturbance caused by humans e.g. urbanization and industrialization. Humans build bridges, shopping malls, roads, schools, hospitals etc. in cleared mangrove forests. These activities eliminate the natural wetland system and destroy numerous biodiversity that inhabit this environment (barnacles, mussel, periwinkles, crabs etc). During oil and gas exploration humans deliberately bulldoze and clear large acre of forest to make way for the establishment of booth camps, oil wells and crude oil pipelines. The pipelines conveys petroleum products from oil wells to the refinery while finished products are transported back via pipelines to tankers evacuating products at the port (**Figure 1A**). These pipelines are established by creating right of way passage (ROW) through deforestation (**Figure 1B**), furthermore, crude oil spills occur from these pipelines due to sabotage or mechanical failure leading to the destruction of vast amount of mangrove forest (**Figure 1C**).

   Natural disturbances: This is a disturbance that is caused by force of nature. This includes flood, erosion, hurricanes, tsunami and earthquake [27]. These disturbances are controlled by weather conditions and cause massive damage to mangrove forest, which changes the forest structure and composition (**Figure 2**).

2. **Ecological Succession**: is the process by which a community changes over time, especially following a disturbance [28]. In many instances, an ecosystem will change from a simple level of organization with a few dominant pioneer species to an increasingly complex community with many interdependent species. Restoration often consists of initiating, assisting, or accelerating ecological successional processes, depending on the severity of the disturbance. Following mild to moderate natural and anthropogenic disturbances, restoration in these systems involves hastening natural successional path.

3. **Habitat Fragmentation**: describes spatial discontinuities in a biological system, where ecosystems are broken up into smaller parts through land use changes (e.g. agriculture) and natural disturbance [29]. This reduces the size of the populations and increases the degree of isolation. Thus, the smaller and isolated populations are more vulnerable to extinction whereas fragmenting ecosystems decreases quality of the habitat.

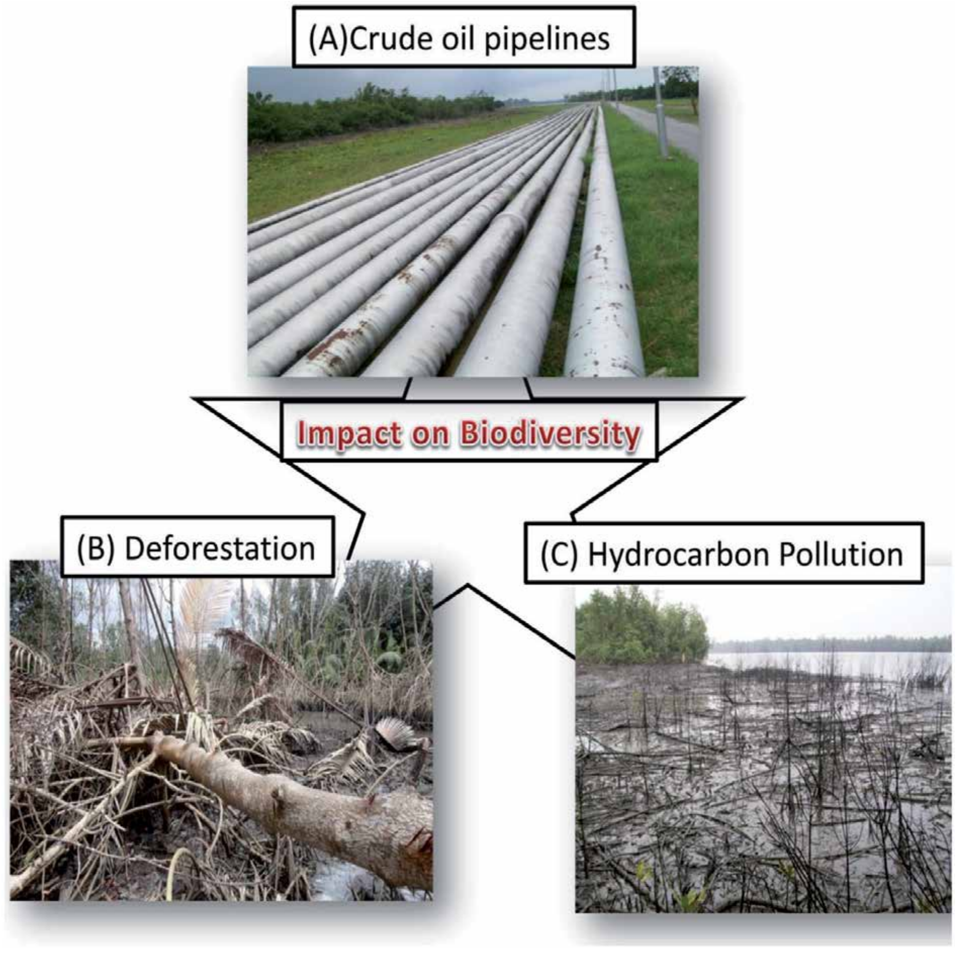

Figure 1.
Picture a: Pipelines' leading from Port Harcourt refinery to Okrika Jetty was taken in 2010. Spillages do occur, which affects neighboring mangrove forest. Picture B: Deforestation of mangrove forest at Okrika refinery Jetty to make way for pipelines right of way (ROW) taken in 2015. Picture C: Massive death of mangrove forest at Abbi Ama, Buguma Asari-Toru local government area of Rivers state following a major oil spillage. The picture was taken in 2010.

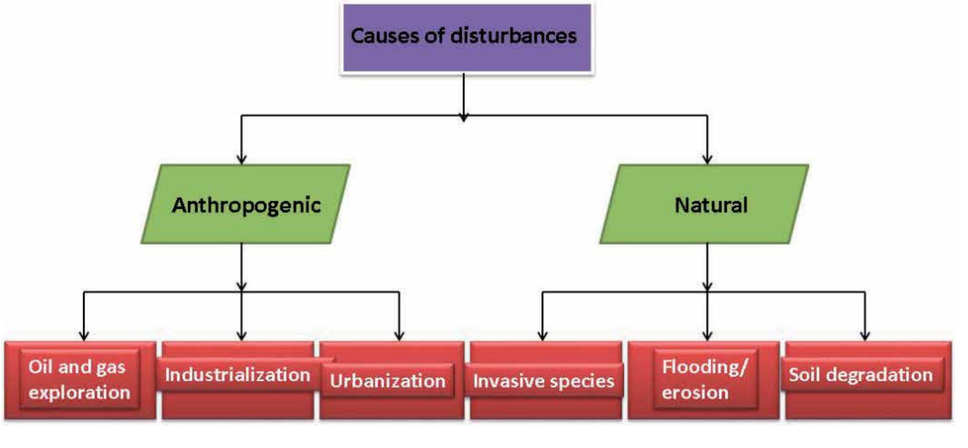

Figure 2.
Causes of disturbances in mangrove forest in the Niger Delta, Nigeria.

4. **Ecosystem function**: describes the most basic and essential foundational processes of any natural systems, including nutrient cycles and energy fluxes [30]. An understanding of ecosystem functions is necessary to address any ecological processes that may be degraded. Ecosystem functions are emergent properties of the system as a whole, thus monitoring and management are crucial for the long-term stability of ecosystems. Mangrove ecosystem functions include three major aspects namely: (1) good and services e.g. timber, fuel, food, medicine and dyes; (2) Environmental and ecological services such as (i) regulatory services e.g. coastal protection, climate regulation and (ii) supporting services e.g. nursery, biodiversity, nutrient cycling and soil formation; (3) Cultural services e.g. spiritual, esthetic, recreational and educational.

5. **Community assembly**: is a framework that can unify virtually all of community ecology under a single conceptual umbrella. Community assembly theory attempts to explain the existence of environmentally similar sites with differing assemblages of species [31]. It assumes that species have similar niche requirements, so that community formation is a product of random fluctuations from a common species pool.

6. **Population genetics**: Genetic diversity has shown to be as important as species diversity for restoring ecosystem processes [32]. Hence ecological restorations are increasingly factoring genetic processes into management practices. Such processes can predict whether or not a species successfully establishes at a restoration sit**e.**

7. **Pollution:** is the emission of toxic substances into the environment. Mangroves are impacted by hydrocarbon pollution [33], and this occurs during crude oil spillage from punctured pipelines at both offshore and onshore sites. The crude oil spilled into the water coat the roots of mangroves and suffocates them to death. Oil pollution in mangrove forest lead to the increase in heavy metal concentration, which creates toxic condition and lead to the death of immature mangroves [34].

1.3 Impact of pollution on mangrove restoration and ecosystem services

Pollution prevents propagule germination and growth, and causes mutation of mangrove which results to stunted growth and eventually death [35, 36]. Hydrocarbon pollution increases litter fall via defoliation, which increases the rate of productivity [37]. Pollution also slows, but do not stop the rate of decomposition [38]. Based on the action of pollution on mangrove structure it is as an impairing agent of its ecosystem functions. This is because it impedes the air purification role of mangrove trees because of increase in defoliation. Death of immature trees prevents their use as a source of firewood production, a major source of cooking energy by poor rural people already wallowing in poverty. The role of mangrove as a biodiversity hotspot is affected because of oil spill that kills other organisms that live on, within and around the mangrove forest.

1.4 Mangrove as a bio-remediation agent and pollution inhibitor

The ability of mangroves to survive in difficult terrain goes beyond the natural perturbations (sodium chloride, heat, waves etc) to anthropogenic activities (oil spillage, organic waste, pollutants etc.). This is because mangrove survive polluted environment by using similar means to survive a highly saline environment. This is because studies had revealed that mangroves growing in highly polluted sites have higher productivity than mangroves growing in lowly polluted sites [37]. The growth of mangroves in a polluted soil reduces the pollutant load by accelerating microbial action in the soil through decomposition of litter materials. Soil pollutants absorbed into mangrove parts are locked up and deactivated in guard cells which prevent the pollutants from becoming harmful to the internal organs of the plant just the same way salinity is controlled and eliminated in mangrove cells [39].

1.5 Mangrove resistance to pollution

Mangrove cope with pollution through the following means: (1) by acting as a sink for pollutants, this is because mangroves absorb heavy metals and prevent them from circulating in the ecosystem, (2) through defoliations of leaves that have absorbed pollutants. Here the leaves accumulate pollutants and later fall off to prevent the contamination of the tree [40]; (3) Tough giant root system, the adventitious root system of mangroves grow to a maximum height of above 5 meters from the ground and have only 25% of the root embedded in the swamp and 75% hanging in the atmosphere. This therefore makes oil spill or any pollutant to have limited focus of attack and thus less effect on the tree because of the low root-soil contact. (4) Mangrove root is tough and coated with algal growth, which further provides a layer of protection against external pollutants from the watery environment. This prevents the diffusion of crude oil into the root of mangroves and (5) Tidal flushing, is a process where the tides wipe away oil spills from the forest floor.

Nypa palm (*N fruticans*) is invasive in the Niger Delta because it is a foreign species brought in from Indonesia [41], and over the years they have driven away the mangroves and colonized their territory. *Nypa fruticans* are from the family palmae and have different bio-physical properties from the mangroves, which makes them to have an antagonistic relationship with the mangroves. Currently, nypa palms have limited ecosystem services as compared to the mangroves in the Niger Delta. This is the reason why they are removed from most location in favor of the mangrove forest. Although, there are ongoing research to manufacture manure and life buoy from the palms.

1.6 Mangroves (*Rhizophora* spp) parts as tools for bio-remediation of degraded forest

Mangrove parts (leaf, stem, root and seed) can be used in attenuating pollutants load in the soil. A recent study using ground mangrove parts on polluted soil shows a drastic reduction in oil pollution level (**Table 1**). The preliminary results shows that roots of mangrove and nypa palm performed better than other parts whereas the stem of mangrove had the least remediating effect (Numbere unpublished). Mangrove of the Niger Delta has one of the highest productivity levels in the world [29]. High litter fall causes high microbial activities, which in turn leads to high decomposition rate [38]. This has made the mangrove of the Niger Delta to survive a 50 year period of constant pollution from oil spillages. During major oil spillages (**Table 1**) hydrocarbon pollution suffocates the trees causing death and fragmentation of the forest. In addition mangrove response to stress includes the following (adapted from [42]):

1. Tree mortality
2. Defoliation of canopy
3. Root mortality
4. Bark fissuring/epithelial scarring
5. Development of abnormal adventitious root pneumatophores
6. Leaf deformities and chlorosis
7. Propagule shrinking
8. Alterations in the numbers of lenticels
9. Reduction in tree snail and crab mortality
10. Changes in in-faunal density

Mangrove survives pollution by shutting down pollutants from being absorbed into the root. It also survives by concentrating pollutants in the leaves which are later expelled from the tree via defoliation.

In addition, to pollution, construction or industrial activities carried out by government and private agencies lead to increased deforestation. It causes difficulty in the restoration of the mangrove forests. However, to recover such areas those structures have to be removed by bulldozing the buildings, excavating the soil and replacing them with mangrove swamp soil. Mangrove propagules should then be transferred from the nursery to the restoration sites after two years. The removal of invasive *N. fruticans*, which thrives in disturbed environment, is also important because they are the second most significant threat to mangrove forest after hydrocarbon pollution [33]. The palms grow mainly in fresh water but have adapted to salt water conditions having lived several years in this environment, where they compete effectively with mangroves [41].

Types of oil spills	Land	Swamp	Offshore	Total
Minor spills (1–249)				
Number of spills	457	446	130	1, 033
Quantity of spills (barrels)	7, 565	14, 317	21, 297	43, 179
Medium oil spills (250–2499 barrels)				
Number of spills	596	91	31	712
Quantity of spills (barrels)	17, 203	33, 139	49, 359	99, 701
Major oil spills (over 2500 barrels)				
Number of spills	206	32	16	256
Quantity of spills (barrels)	76, 996	44, 775	1, 379, 2423	1, 921, 013
Source: [43].				

Table 1.
Size of spills with respect to ecological zones in Nigeria 1976–1985.

2. Methodology

2.1 Sample collection

1. **Plant parts**: Mangrove *Rhizophotra* (branch, leave, root, seed and stem) and nypa palm (leave, root and seed) parts were retrieved from the forest at Eagle Island (4°43'N and 7 °58′E). These parts were put in polyethylene bags and sent to the laboratory. They were oven-dried at 70 °C for 48 hours and then ground into fine powder by a hand grinding machine. The powdered form of the leaves were bagged and labeled (**Figure 3**).

2. **Soil**: soil samples were collected randomly at ten points with a soil augur 5 cm below the soil surface from a polluted site at Okrika. Some samples of the collected soil were bagged and sent to the laboratory for physicochemical analysis. The soil is then put in 27 (9 plant parts × 3 replicates) seedling containers for the remediation experiment.

Physicochemical analysis of the soil and ground parts were analyzed for Cadmium (Cd), Iron (Fe), Lead (Pb), total hydrocarbon content (THC) and Zinc (Zn).

Remediation experiment: the ground plant parts are applied to the soil surface and monitored for six months with monthly soil samples sent to the lab for physicochemical analysis.

Figure 3.
Remediation experiment using ground parts of mangrove (Rhizophora spp.) and Nypa palm (N. fruticans).

3. Results

The result (**Table 2**) shows that there was no significant difference in heavy metal concentration in the soil samples treated with the ground plant parts ($P > 0.05$).

Metal				Mangrove parts				Nypa palm parts	
	Control	M.branch	M.leaf	M.root	M.seed	M.stem	P.leaf	P.root	P.seed
Cd	0.36 ± 0.01	0.94 ± 0.01	0.04 ± 0.01	0.06 ± 0.01	0.001 ± 0.00	0.4 ± 0.01	0.2 ± 0.01	0.001 ± 0.00	0.001 ± 0.00
Fe	2562.2 ± 0.25	454.2 ± 1.29	419.4 ± 0.46	431.9 ± 0.18	453.2 ± 0.61	436.8 ± 0.48	434.1 ± 0.48	457.6 ± 0.59	421.1 ± 0.45
Pb	12.02 ± 0.24	0.002 ± 0.001	0.001 ± 0.00	0.001 ± 0.00	0.001 ± 0.00	0.002 ± 0.001	0.001 ± 0.00	0.001 ± 0.00	0.001 ± 0.00
THC	607.9 ± 0.6	218.2 ± 2.15	118.3 ± 0.4	6.3 ± 0.11	224.1 ± 0.25	1137.9 ± 0.6	67.8 ± 0.65	15.3 ± 0.35	91.2 ± 0.39
Zn	14.18 ± 0.4	6.79 ± 0.02	6.9 ± 0.22	3.5 ± 0.01	12.2 ± 0.51	6.9 ± 0.15	8.0 ± 0.06	11.8 ± 0.46	5.3 ± 0.01

Where M refers to mangrove and P refers to Nypa palm species.

Table 2.
Concentration of total hydrocarbon content (THC) and heavy metals in soil samples after treatment with ground mangrove and nypa palm parts.

4. Discussion

Heavy metal concentration in mangrove versus nypa palm parts in soil.

The result reveals that there was significant difference in the heavy metal concentration between mangrove and nypa palm parts ($P < 0.05$). Soils treated with ground *N. fruticans* parts have lower concentration of THC and heavy metals as compared to *Rhizophora* species parts. This result revealed that *N. fruiticans* parts remediated the soil better than the *Rhizophora* species parts. *N. fruiticans* parts can therefore be used as a biological remediating agent to clean crude oil contaminated soil. This will be an advantage and a reason for protecting the palms in the long run because they have been seen as having no usefulness in this region.

4.1 Post-remediation of mangrove forest

After the remediation of polluted mangrove forest soils intensive re-planting can be done to recover the devastated forest [44]. This can come through natural or artificial process depending on the nature of the terrain. If it is an area that has the natural setting for recruitment, this strategy can be used. The set up that facilitates natural recruitment are an enclosed coastal channel, connection to an active river with good tidal pressure (i.e. fluctuation of high and low tides) or hydrology, swampy soil that contains soil nutrients such as Nitrates and Iron, nearby parent plants that supplies viable seeds, high litter fall, and high microbial activities. If these conditions are not already set up it can be deliberately established to accelerate the natural process of seedling recruitment as long as it is close to a river. Natural remediation can be facilitated by practically changing coastal structures to create a barrier to trap mangrove seedlings once they are brought in by tidal current to enable the seeds to settle down and grow. An example is the research at Eagle Island, which facilitated mangrove seedling recruitment and growth. But for a non-coastal area such as upland mangroves that are far away from the river natural recruitment will not be possible except artificial recruitment is done where seedlings are grown in nursery and transplanted to the field to facilitate growth. However if the disturbance type was sand mining activity the remediation, recruitment and regeneration methods will vary as given below.

Restoration of Mangrove Forest For a sand dump the sand on the surface has to be scooped away and replaced with swamp soil collected from nearby mangrove forest. After piling the area with mangrove swamp, it should be left for some weeks to settle and consolidate. River connection should be established if it does not exist already so that tidal water will flow in and out to deposit seeds and seedlings from parent trees in the catchment area. In flow of estuarine water will also change the soil chemistry through increase in salinity level. In addition, seedlings can be brought in from the nursery to supplement the ones recruited naturally. Details of the different regeneration methods that can be adopted are given below.

4.2 Mangrove forest regeneration

Forest regeneration is a process by which forest is renewed, and mangrove forest can be regenerated in two ways: (1) Natural and (2) Artificial (**Figure 4**).

1. **Natural regeneration**: This occurs when seedlings of mangroves sprout naturally without human intervention. It involves the provision of suitable environment for the growth and development of volunteer tree species, which are growing in the area. Mangrove forests require suitable environmental condition for them to grow such as high temperature to enhance productivity, precipitation and saline water. Natural regeneration usually occur after

disturbance such as deforestation, dredging, urbanization, clearing of forest to create right of way (ROW) passage for oil and gas pipelines [45]. The success of natural regeneration in mangroves is dependent on some factors, which are:

1. Presence of sufficient numbers of parent trees that would supply enough seeds that would be carried by tides to the regeneration sites.

2. Connecting hydrology that would bring in the seeds

3. Presence of an enclosure containing wire gauze to filter debris, but allow water to flow. Similarly, litter materials in the enclosure trap seeds and prevent them from being flushed away into the open river by tidal currents.

4. The right soil type (swamp locally called “chikoko”) and chemistry that would accelerate the growth of the seeds

5. Production of viable seeds by the parent plant that would germinate fast within short period of time.

6. Low population of fiddler crab (*Uca tangeri*) that feed on the seeds

7. Reduction in anthropogenic disturbances in mangrove wetland can lead to the proliferation of fiddler crabs. The action of *U. tangeri* consuming seeds do not entirely affect seed growth negatively, but also helps to redistribute and bury mangrove seeds around the forest, which causes zonation and rapid growth of seeds [46].

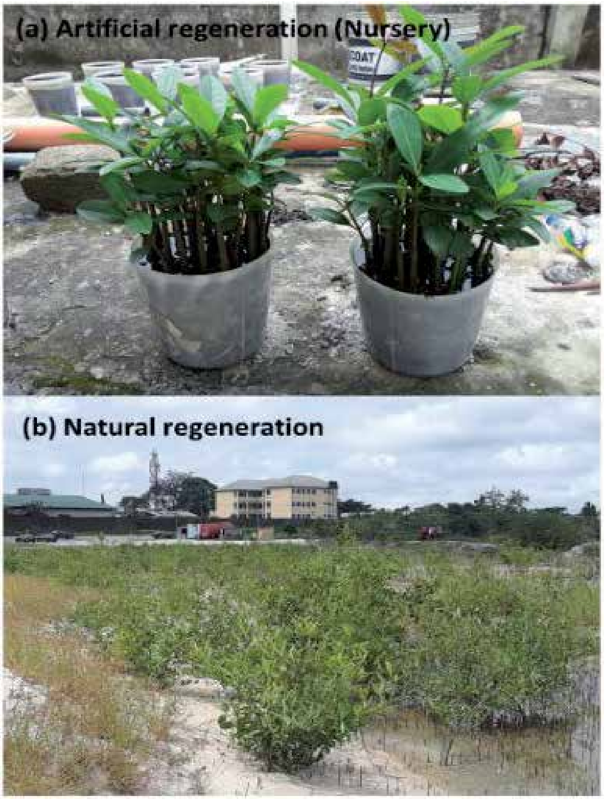

Figure 4.
The growth of mangrove seedling can occur through (a) artificial and (b) natural means of regeneration. The natural regeneration is occurring at Eagle Island, Niger Delta, Nigeria.

Advantages of natural regeneration: (i) The forest is established naturally and is not expensive when compared with artificial regeneration that involves finances; (ii) Natural regeneration of the forest do not require site recreation, a forest which naturally recreates will have much forest species; (iii) It brings about the establishment of natural ecosystem in an area of its choice. Natural regeneration does not permit the outbreak of pest and disease epidemic; (iv) It does not require management skill, it is rather based on experience. Mangrove forest restoration is mainly carried out using *Rhizophora* species (i.e. monospecific restoration). This is because of its ability to grow speedily in both nurseries and natural environment. However, in the natural environment many species (e.g. red, white and black mangroves and nypa palm) (See **Table 3**) are carried into restoration sites and grow at different pace depending on their ability to adapt to soil physico-chemical conditions, for instance natural mangrove recruitment site at Eagle Island, Niger Delta (**Figure 4**).

Disadvantage of natural regeneration: (i) It results in lack of uniformity of trees because there are differences in size classes; (ii) Lack of uniformity of stands, so that they cannot be used for suitable purpose such as logging that provides same size stems; (iii) It lacks uniform management e.g. rate of growth, and maturity of each tree is slow.

The development of forest via natural regeneration takes 10 to 20 years to grow to maturity and start fruiting. For the forest to develop quickly there need to be salt water that will facilitate growth, since most mangrove species are halophilic. Furthermore, there need to be adequate soil nutrients such as nitrate, phosphorus, calcium and zinc to aid growth. Mangrove forest is also facilitated by litter decomposition through microbial action that converts organic materials (leaves, seeds, and branches) to soil nutrients.

Artificial regeneration: This is the total replacement of old stand that has been cut down or affected by any form of disturbance with new seedlings, which are deliberately planted in nurseries and later transferred to the field. It involves deliberate establishment of forest trees in remediated polluted site. Direct planting of seedlings on the remediated site can also be done, especially if there is barrier created by swamp embankments to slow down tidal pressure to prevent erosion from carrying away the seeds. Artificial regeneration is used because there is adequate nurturing of seeds for 1 to 2 years to enable them to develop root system so that when planted in the field they will start to grow immediately to withstand environmental changes such as erosion, climate change and pollution. Similarly, during growth in nursery pest can easily be controlled and diseases prevented through the administration of chemicals to mitigate against future attack by

Species	Common name	Abundance	Proportion (p_i)	Ln (p_i)	P_i*Ln (p_i)	H	Rank
R. racemosa	Red mangrove	63	0.0334	−3.399	−0.114	−0.114	3rd
L. racemosa	Black mangrove	1079	0.5721	−0.558	−0.319	−0.319	2nd
A. germinans	White mangrove	709	0.3759	−0.978	−0.368	−0.368	1st
N. fruticans	Nypa palm	35	0.0186	−3.985	−0.074	−0.074	4th
Total		1886					

Table 3.
Abundance and diversity of different species of mangroves and nypa palms in a natural regeneration site at Eagle Island, Niger Delta.

disease-causing insects. Operations of artificial regeneration involve the following: (a) Site preparation such as clearing and removing of thorns, tree stems and other dirt (b) Seedling collection, which is very important in the establishment of a forest (c) nursery practice, i.e. raising the seeds in the nursery or seeds pots or bags. Nurseries are places where seedlings are raised before they are taken to the planting site. Its success lies in the production of adequate number of seedlings of the right quality and fast growing ability.

Two types of nurseries are permanent and temporary nurseries, permanent nursery is meant for large scale, continuous and sustained production of seedlings while temporary nursery is for a short term period of seedling growth.

Advantage of artificial regeneration: (i) There is a high rate of uniformity of the growth of the trees; (ii) Uniformity results in the production of trees very suitable for specific purposes e.g. red mangroves (*Rhizophora* spp) for firewood; (iii) The trees grow and mature faster than in natural regeneration.

Disadvantage of artificial regeneration: (i) It is very expensive and requires a lot of skills; (ii) Environmentally, it brings about change in existing ecosystem particularly in the area of its establishment; (iii) It may result into an outbreak of pest and diseases.

4.3 Species diversity

Species diversity describes the diversity of important ecological entities that span multiple spatial scales from genes to communities. This has to do with species richness and evenness in a specific area. In a second study of species abundance and diversity done at Eagle Island, which measures about 3900 m^2, it was found that black mangroves (*Laguncularia racemosa*) were the most abundant species (n = 1079) followed by white mangroves (*Avicennia germinans*) (n = 709), red mangroves (*Rhizophora racemosa*) (63) and nypa palm (*Nypa fruticans*) (35) (**Table 3**). *A. germinans* had the highest species diversity while *N. fruticans* had the least species diversity.

4.4 Mangrove reserve management

There are three aspects of mangrove management, the ecological, human and the ecosystem.

1. **Ecological management**: This occurs when there is a disturbance like hydrocarbon pollution, deforestation to establish urban areas and sand mining and shortly after these events take their courses through ecological succession. It involves a progressive change of plant growth through the replacement of destroyed mangrove with new mangrove community. An example is successional process of different species of mangrove seedlings including nypa palm colonization of an abandoned sand mining site at Eagle Island, Niger Delta (**Figure 5**).

The four stages of succession to be encountered in the above kind of environment include:

1. Pioneer species (P): This is the first species after a disturbance. It is common 1—5 years after a major disturbance had occurred such as earth quake, flood or volcano. An example of this species is annual plant such as weeds and grasses. Everything is killed leaving behind bare soil, but after a period of time there is a dramatic increase in weed,

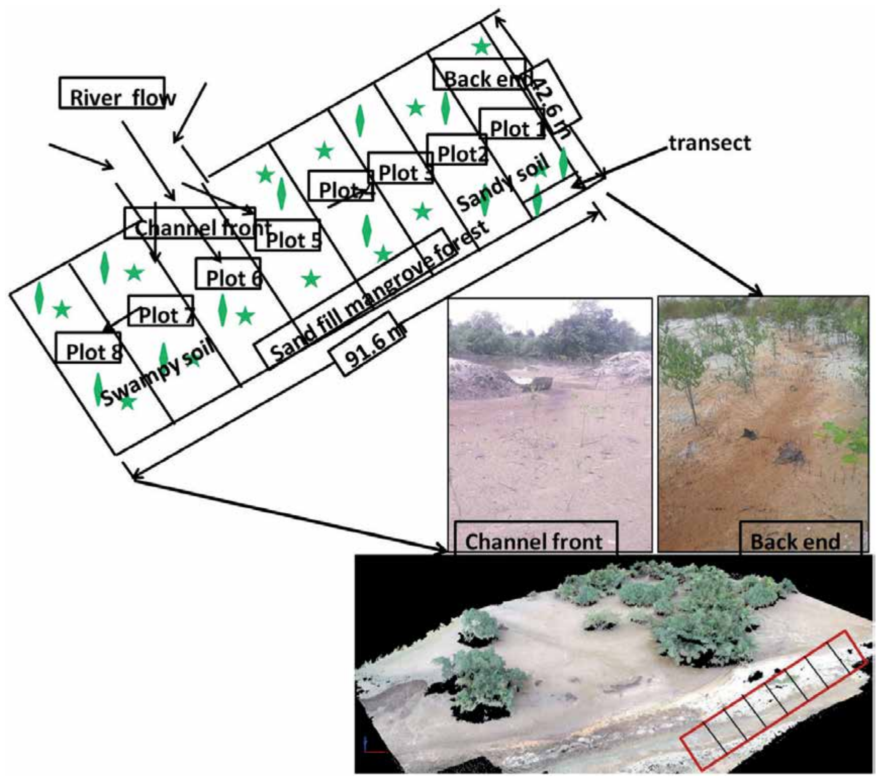

Figure 5.
Plant succession in deforested mangrove forest at Eagle Island, Niger Delta, Nigeria.

2. Early successional species (E): They are a group of species that replace pioneer species. They are dominant for 5–10 years e.g. woody shrub

3. Mid successional species (M): They are large shrubs or small trees that are dominant for 10–30 years. They basically replace their early successional species.

4. Late successional species (L): They are also called climax community. They are tall tree communities that exist in the absence of disturbance.

The cause of the regular progression of change in the mangrove community is seed dispersal, which is facilitated by water. Mangrove takes a long time to mature between i.e. 10–20 years. But the annuals like grasses grow faster and colonize the disturbed site few weeks after disturbance. The mangroves are the top species in the intertidal marine environment because of their ability to withstand the tough environmental conditions created by nature and humans.

4.5 Theoretical basis of succession as a means of restoration of mangrove forests

There is evidence to support the above successional pattern in marine intertidal system where progressive change in disturbed area lead to increase in diversity. One of such hypothesis is the intermediate disturbance hypothesis (IDH). It is an empirical relationship between the time a disturbance occurs and the time species diversity increases in a given location. This is because the climax no longer has the highest diversity. It explains why in some areas we have high diversity while in others we have low diversity. The cause of decline in diversity is competition. Low diversity is also caused by the suppression of early species. The implication for mangrove management is that classical pattern minimizes disturbance to maximize diversity whereas IDH pattern manages disturbance at an intermediate level. Therefore, to identify an IDH system the following should be noted: (a) there will be complete replacement during succession; (b) climax species need to competitively suppress all other successional species, (c) The climax species does not create a new species.

4.6 Regional versus local forest management

In mangrove forest restoration, regional management is better than local site management. This is because disturbance is managed to maximize diversity but make sure all successional stages exist within the management area. Secondly, at the regional level everything is reproducing. Moreover, disturbance does occur at different time and at different places so each one of four successional processes are often dominant. This is done by introducing disturbance in the system in other to maximize diversity. For example, after the Ozark forest is burnt down different species begin to sprout rapidly that were not originally present. This means humans can play a role in natural disturbance to maximize natural biodiversity. In the Niger Delta low level of hydrocarbon pollution i.e. minor crude oil spill (See **Table 1**) does not impact mangrove growth and development, even when deliberately added it will have little or no effect on plant growth. However, in major oil spill it may be harmful to growth by deforming the seedlings or killing them outright. Years of study mangrove forest in Niger Delta has shown that low level introduction of crude oil in mangrove forest could help facilitate the growth of seedling that has resilient qualities, and the elimination of weak species. However, further studies are needed to validate this field observation. This will ensure a long term positive feedback of rejuvenated growth, as recorded in previous findings, where it was discovered that highly polluted sites had higher productivity, species diversity and mangrove tree structure than less polluted site [29]. Although, this revelation has not been thoroughly studies to make a conclusive statement, there are some observations that point to the fact that crude oil pollution in low amount can facilitate mangrove growth in some areas in the Niger Delta. However, the implication is that there might be bioaccumulation of pollutant up the food chain. This suggestion is made because the mangroves of the Niger Delta had been growing in polluted environment for over fifty years without dying. Rather the major killer of mangroves is deforestation through urbanization and fire wood production. It is suspected but not proven that the DNA of this set of mangroves might have been imprinted with "pollution resisting genes" that has made them less vulnerable in the face of high pollution. The complete removal of a disturbance regime is a form of disturbance in itself because we are basically altering the order [47].

Human management: Humans are the ultimate problem of biodiversity especially the mangroves. This is because of their affinity for the mangroves due to the ecosystem services they render. All aspects of the mangroves are useful to humans such as the leaves, stem, root, leaves and seeds, which are used for producing medicinal herbs, fire wood, food etc. Hazardous climatic effect such as earthquake, tsunami, hurricane, cyclone and flood do not affect the mangroves of the Niger Delta rather humans are the greatest threat to the mangroves in this region. The aim of human management is to prevent negative anthropogenic effect on the mangroves by keeping people away from the forest. This is because human activities such as deforestation, logging, and oil and gas exploration are the major threats of mangroves. Since people cause problems for mangroves it is necessary to create zones of use, buffer and transition zones to protect forest resources. The purpose of this method is to allow plants and animals to be protected [32].

Ecosystem management: It is a new way of managing reserve to benefit biodiversity and people. It is a strategy for protecting or restoring the function, structure and species composition of an ecosystem while providing for its sustainable socio-economic use. The tenets of ecosystem management of mangrove forest are as follows:

1. Ecosystems are dynamic- This means they change during succession because they are not static.

2. Ecosystems are subject to unpredictable events or disturbances such as fire, pest and insect attack, crab and animal herbivory, hydrocarbon pollution, earthquake and cyclone, so management need to be flexible in a process called adaptive management.

3. Humans are integral part of the ecosystem

4. Ecosystem requires constant monitoring of populations.

4.7 Sustainable management of mangrove forest

Sustainability means the ability to preserve an environmental resource to last for future generations. Therefore, sustainable management of mangrove forest is the process whereby mangrove forest is managed to last long for the benefit of incoming future generations. Studies have already shown that 5% of mangrove forest has already been lost in the Niger Delta due to oil and gas exploration, urbanization and invasive nypa palm species [48]. To manage mangrove sustainably, those aforementioned key factors that lead to their decimation need to be eliminated. Both onshore and offshore oil and gas exploration results to many cases of oil spillages recorded in the Niger Delta which has devastated large amount of mangrove forest for a period of over a sixty years (1956 to 2020). The rate of oil spillage has to be reduced drastically by the oil companies through the constant maintenance of old pipelines. In the same vein, sabotage of pipelines by local vandals has to be checked to prevent incessant oil spillages. Urbanization is a necessity to modernize the city, but the mangroves areas can be avoided or put into the city plan through urban ecology, where city and forest would exist side-by-side with each other, this will guarantee the survival of the forest. As for the *N. fruticans* they can be removed within the mangrove forest through the use of bulldozers so as to provide breathing space for the mangroves. When all these suggested changes are executed mangrove forest can last for centuries and become beneficial to future generations.

4.8 Mangrove restoration ecology

It is a process of intentionally altering a site to establish a given indigenous historic ecosystem. In this method we try to bring degraded location to what it was originally. There are four ways of accomplishing restoration; three are active method while one is passive method.

1. **Passive method**; It involves the stopping of degradation and allowing succession to occur. This method is good because it is predictable and attains climax. It involves natural succession. Here degraded land can be sealed off

and allowed to recuperate through natural seedling recruitment and regeneration. A classical example of this method is the natural mangrove seedling recruitment at an abandoned sand fill site at Eagle Island (**Figure 4**). Three year (2016—2019) monitoring of this area shows that seedlings that were carried into the site by tidal water had been growing naturally for the past 3 years without human intervention. This method holds great potentials in re-populating many polluted and destroyed sites in the Niger Delta. To achieve this method we need to create the right environmental condition such as establishing water channels, creating an enclosure to trap the seeds from escaping, improving soil chemistry and increasing microbial population of the soil. An example is the natural regeneration of mangroves at Sungei Api-Api, a man-made estuarine channel in Singapore [49]. Factors considered in this study include: the establishment of mangroves include: slope gradients, salinity and tidal inundation levels substrate type, tidal currents and propagule establishment.

2. **Active method**: This is required for areas that have been severely degraded. There are 3 active methods, and these include:

    a. **Replacement** – instead of going back to the original forest, which is impossible a new set of forest or plant community is established as a replacement. For instance, changing mangrove forest to another type of tropical forest (i.e. inter-species replacement) will not be the best option, this is because mangroves are habitat-specific and can only occupy swampy areas. Therefore to restore mangroves, the right soil condition need to be established. This method will work if nypa palm forest is replaced with mangrove forest and soil conditioning carried out. Why it would work out is because both species occupy nearly similar environment. Another kind of replacement that can be done is intra-species replacement where red mangroves (*Rhizophora* spp) are replaced by white (*Avicennia germinans*) or black mangroves (*Laguncularia racemosa*). This one is better than bringing in a completely different species. Mangrove fern (*Acrostichum aureum*) is a species that can grow in disturbed area. It can be planted as a pioneer species in remediated site.

    b. Rehabilitation- In this method an attempt is made to restore the original ecosystem, but it cannot be fully restored because most of the species had gone extinct. Mangrove forest can be rehabilitated after damage by carrying out artificial seedling regeneration or direct planting.

    c. Restoration- It is the attempt to fully restore the original ecosystem. Here the degraded mangrove forest can be restored through the provision of more species to enhance ecosystem structure and function. For instance, mangrove forest in Armacao dos Buzios Brazil was managed by establishing environmental protection unit, education and enlightenment campaigns to support active regeneration [50].

5. Conclusion and recommendation

Mangroves are unique species of plants that are useful to the environment therefore, their protection is important to prevent their extinction as a result of harmful practices such as sand mining, oiling activities, dredging, urbanization etc.

The resilience of mangroves in the face of pollution should not be overestimated because just like other species they have a threshold of resistance against environmental perturbation. And once this limit is surpassed they will become vulnerable to the slightest environmental change. There is therefore a need for repopulating lost mangroves to recover lost stands. Increase in population through natural and artificial means will ensure that mangroves become dominant again in their coastal habitat so as to withstand invasion by foreign species such as *N. fruticans*, which are the most dominant invasive species wreaking havoc to the mangroves. It is recommended that more emphasis should be placed on natural recovery of mangrove forest by deliberately facilitating this process. This can be achieved by the removal of foreign species, the establishment of connecting water channels, soil conditioning and seed transportation to sites of restoration. Finally to accelerate recovery process there can be a combination of natural and artificial seedling recruitment and regeneration methods.

Definition of terms

Replacement: This is to process of bringing in a new set of species in place of a destroyed system.

Rehabilitation: This is the process of fixing the damage caused by disturbance in other to take the system to look like the former system.

Restoration: This is to bring back a disturbed area to almost 100% similar to the previous system.

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Chapter 2

A Visual Assessment Scale for Rapid Evaluation of Mangrove Degradation, Using Examples from Myanmar and Madagascar

Christoph Zöckler, Dominic Wodehouse and Matthias Markolf

Abstract

Mangroves are globally threatened, disappearing and degraded. They are lost due to land use changes, mostly agricultural expansion and aquaculture, but also degraded by cutting by villagers and logging and timber extraction for domestic and economic purposes. Extent and conversion of mangroves can usually be estimated by applying remote sensing and modern drone technology, but the scale of degradation of mangrove habitats is not easily detected by such methods. In this paper we propose an assessment tool for a rapid evaluation on the degradation, using examples from different regions in Myanmar and Madagascar. We propose a visual and practical guide listing a range of 1–6 to identify and quantify the level of degradation. We demonstrate the application by displaying various examples from Myanmar and Madagascar and how this tool can be used for wider applications, discussing advantages scope, and limitations.

Keywords: Mangroves, Myanmar, Madagascar, degradation, scale, restoration

1. Introduction

Globally mangroves are one of the most threatened ecosystems. In 1980 there were globally 198,000 km^2 of mangroves [1], but by 2003 this had reduced to 154,000km^2 [2]. By 2010, 38% of the global mangrove cover had been lost and for Asia the figure is over 50% [3] and the trend is still continuing [4]. The main drivers are agricultural expansion and aquaculture, while a growing rural population increasingly encroach remaining areas [5]. Moreover, the remaining mangroves are widely subjected to degradation, threatened by legal and illegal logging for domestic and commercial use, consequently reducing the ecosystem services that they provide as summarised for Myanmar [6].

In 2000, Myanmar still had the seventh highest mangrove forest cover in the world, but between 2000 and 2012 had lost mangroves at a much faster rate than almost any other country [5–7]. Myanmar continues to have a relatively high rate of loss of 0.8% per annum (p.a.) in the 21st century [7]. Specifically, 1924–1999, 83% of the mangroves in the Ayeyarwady Delta in Myanmar were cleared [8, 9]. While this central delta area has suffered most of the losses, the southern region of Taninthary still holds vast swathes of pristine mangrove.

Madagascar still holds large areas of mangrove forests, but many of them are also subjected to pressures from a growing local population. In 2013, the total area of mangroves for the country, situated almost exclusively on the West coast, was estimated at 303,000 ha. From 1990 to 2010 Madagascar experienced a net loss of about 21% of its mangroves, a total of 2,868 ha per year [10, 11]. These losses are mainly due to the massive exploitation of mangroves for firewood, charcoal and timber (housing and fencing), the development of aquaculture, cyclones and other causes [11, 12].

However, the rate of loss declined in recent years and globally mangroves have become prime conservation targets [13]. While in the period from 1990 to 2000 there was a net loss of almost 12% (or 34,418 ha) of Madagascar's mangroves, the net loss in the period of 2000–2010 was estimated at 22,941 ha or 8.6%), the most significant of which is in the Tsiribihina Delta (4,177 ha/25.5%) [11]. The mangroves of the area, however, are still one of the largest remaining dense mangroves in Madagascar [10].

Restoration and rehabilitation efforts have largely focused on areas previously covered by mangroves (e.g. Lewis et al., [14]), but little attention has been paid to rehabilitating degraded mangrove areas. It is important to be able to describe degraded mangrove areas that would benefit from improvement activity such as the enhancement of hydrological connectivity and protection measures. Rehabilitation will increase their ability to provide the full range of ecosystem services as well as preserve the whole ecosystem integrity. Therefore, the proposed degradation scale can also provide a reliable and cost-effective methodology to accurately describe mangrove conditions, also in recently restored mangroves.

Despite constantly improving technologies, remote sensing and more recently drone-based surveys, have struggled to depict accurately the condition of mangroves [7, 15]. Although mangrove conversion and deforestation can be reliably monitored using such techniques, mangrove loss is only one indicator of mangrove status. The importance of mangrove degradation has gained considerably less attention [16]. Modern technologies still fail to reveal the scale and the extent of forest degradation and hence poorly describe the state of the remaining forest [10, 17]. While it is acknowledged that there have been great strides in the development of remote sensing and drone/LIDAR capability, this technology will not be available to local NGOs, government mangrove agency field offices and village conservation groups until it becomes much cheaper and simpler.

Therefore, we propose here a rapid assessment tool that is ground- or boat-based, which uses visible features of the mangrove forest structure. This is a simple tool to describe and categorise mangrove forest degradation for Indo-West Pacific non-arid areas, using photographic examples from Myanmar and Madagascar. Comments and suggestions from the mangrove community are welcome to improve this degradation scale.

There is an increasing need to identify the real status of a mangrove, its ecosystem health and the scale of degradation. Degraded mangroves can give a false impression of being superficially healthy but might no longer fully provide the full range of expected ecosystem services, such as the buffering of storm surges, benthic biomass production and others [18].

2. Methodology

The authors visited several different sites between 2013 and 2019 in SE Asia and Africa to assess their conservation status and degree of degradation. The mangroves of Taninthary in southern Myanmar were visited eight times between Dec 2013 and Nov 2019. Mangroves further north on the west coast of Myanmar in the Ayeyarwady Division were surveyed in January and February 2016, [19, 20].

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Scale			
1	**Shape**: Very low / very few mangroves. **Height**: <1 m due to possible presence of ferns, herb layer or climbers (e.g. *Acrostichum*, *Acanthus*, *Finlaysonia, photos on right side, which can block natural regeneration.)* **DBH of remaining mangroves**: NA **Logging**: Everything cut. Visible stumps, clearly cut by blade. **Light to Floor**: 100% **Notes**: Reliant on external seed / propagule sources. Ensure area was originally mangrove. Substrate might be eroding, revealing dead mangrove roots. In extreme cases the area might erode so much as to be below an elevation suitable for mangrove growth.		
2	**Shape:** Low. Bushes, establishing seeds and propagules, saplings, regenerating stumps, dead stumps and roots possibly still visible. **Height**: <2 m **DBH of remaining mangroves**: Could be large if species like *Xylocarpus* present, otherwise small (<5 cm DBH) **Logging**: Mangrove has been clear cut of everything but low bushes. Some stumps might be growing back, if species 'coppice', e.g. *Sonneratia*, *Heritiera*, *Avicennia*, *Laguncularia* and *Xylocarpus*, sometimes creating a 'bonsai' effect, lowest left photo. (N.B. *Rhizophora* and *Ceriops* will not grow back as they have no reserve meristem.) **Light to Floor**: 95% **Notes**: Ensure area used to be mangrove. Few or no seeding trees. Reliant on external supply of seeds / propagules.		 

Scale		
3	**Shape**: Low forest. Dense, bushy vegetation. Young trees, saplings. Often a heterogeneous mix of gaps and a few young trees. **Height:** 2-5 m. Very few trees taller than 5 m / 20 cm DBH. **DBH of Remaining Mangroves**: <15 cm DBH. **Logging:** Larger trees (>15 cm DBH) were removed, stumps of which might be visible. Gaps might also have been produced by logged trees damaging neighbouring trees / saplings when felled. **Light to floor**: 25–75% **Notes**: Forest will have a lot of gaps, but is likely to have enough seeding trees to regenerate. (Difficult to depict as similar to level 4, but overall tree height lower and less homogeneous in structure.)	  

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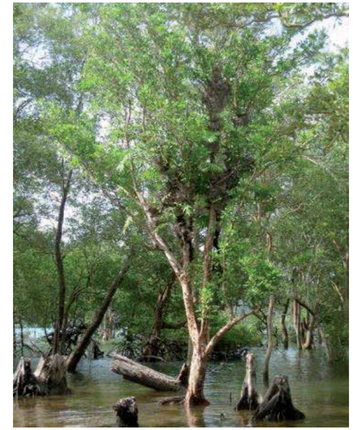
Scale			
4	**Shape**: Mangrove clearly defined in the shape of forest with gaps in between few larger trees, but more even canopy than in Level 3. **Height**: > 6-12 m **DBH of Remaining Mangroves**: 20 cm and larger unless a densely stocked plantation. **Logging**: All the very big trees have been logged as well as some of the mid-sized trees. **Light to Floor**: 25–75% **Notes**: In a plantation forest, the majority of trees are in place, but some stems have been removed (<30%). If the planting density was high, there will be little light to the forest floor.	 	
5	**Shape**: High forest with large trees. Plantations will have an even height canopy. Limited understory. Canopy undisrupted. **Height**: > 12 m **DBH of Remaining Mangroves**: Up to 1 m DBH **Logging**: Only a few trees extracted and few cut stumps evident. **Light to Floor**: <25%. Canopy largely closed. **Notes**: Mature mangroves, particularly *Sonneratia* / *Avicennia*-dominated can be naturally quite open forest.		

Scale			
6	**Shape**: Tall forest. Limited to no understory. Continuous cover except for natural disturbance or gaps. **Height**: >12 m. **DBH of Remaining Mangroves**: Up to and over a 1 m. **Logging**: N/A. Trees intact. Very limited extraction. **Light to Floor**: <25%. Canopy largely closed. **Notes**: Likely to have limited understory where canopy is closed. As in 5, areas at the front low zone and back can be naturally quite open, with significant spaces between trees, and tree form very open, e.g. *Avicennia*, *Sonneratia*.		

Table 1.
Mangrove degradation scale 1–6, based on mangrove forest structural features such as shape, height, visible logging, light reaching the mangrove floor and stem diameter of the remaining trees. This scale is not applicable in northern latitudes where cryptic mangrove stands are reaching their limits of range, such as in southern China, North Vietnam, the Red Sea and North Africa. This scale is also not relevant within arid mangrove zones.

Most of the surveys were conducted using small boats, but many mostly non-estuarine mangroves were surveyed on foot and some even accessed by motorbike. These ground surveys were essential to access the interior of mangrove areas [21].

Georeferenced point assessments were conducted using a specifically designed KOBO smart phone app that uses our proposed mangrove degradation scale from 1 (very poor) - 6 (excellent), see **Table 1**. Inevitably the GPS point taken with the smart phone app is likely to be several meters up to 200 m distant from the actual observed mangrove stand providing inaccuracies that can be ignored as they give a rough first assessment of the mangrove nearby. However the GPS points do not allow accurate analysis using remote sensing tools. Where possible, visible additional information on the causes of mangrove loss were noted. The app is designed to be simple and user friendly.

3. Selected examples of application

Myanmar has suffered large losses of mangroves and the remaining forest has been subjected to many pressures. While huge areas have been lost or been

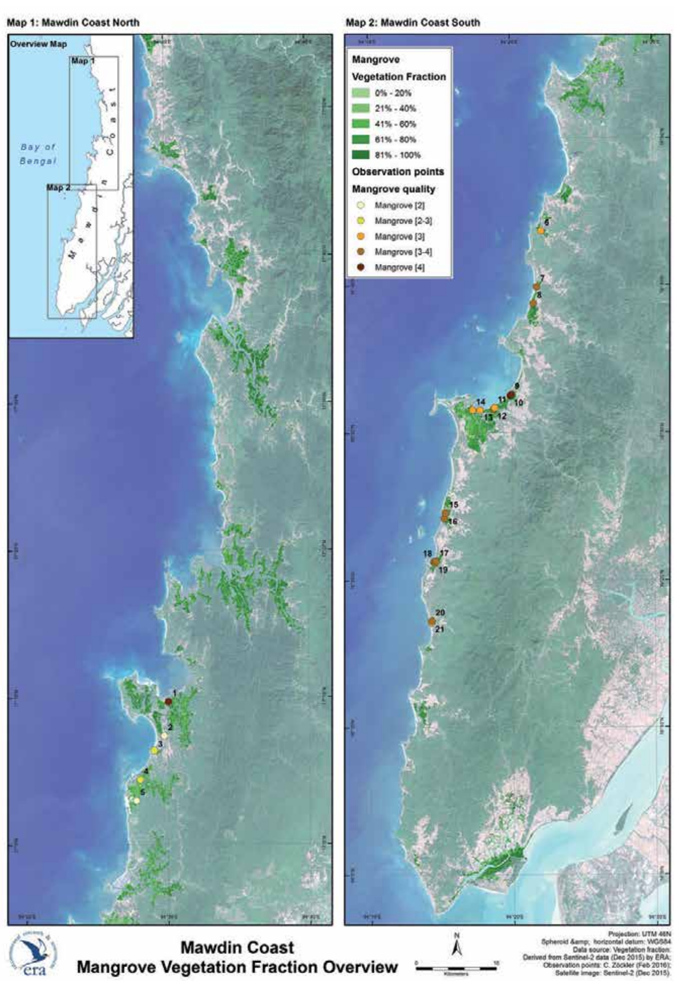


Figure 1.
Mangrove status of non-estuarine mangrove stands on the Mawdin coast in the Ayeyarwady Region on the west coast of Myanmar [22]. Each symbol represents an assessment point (21).

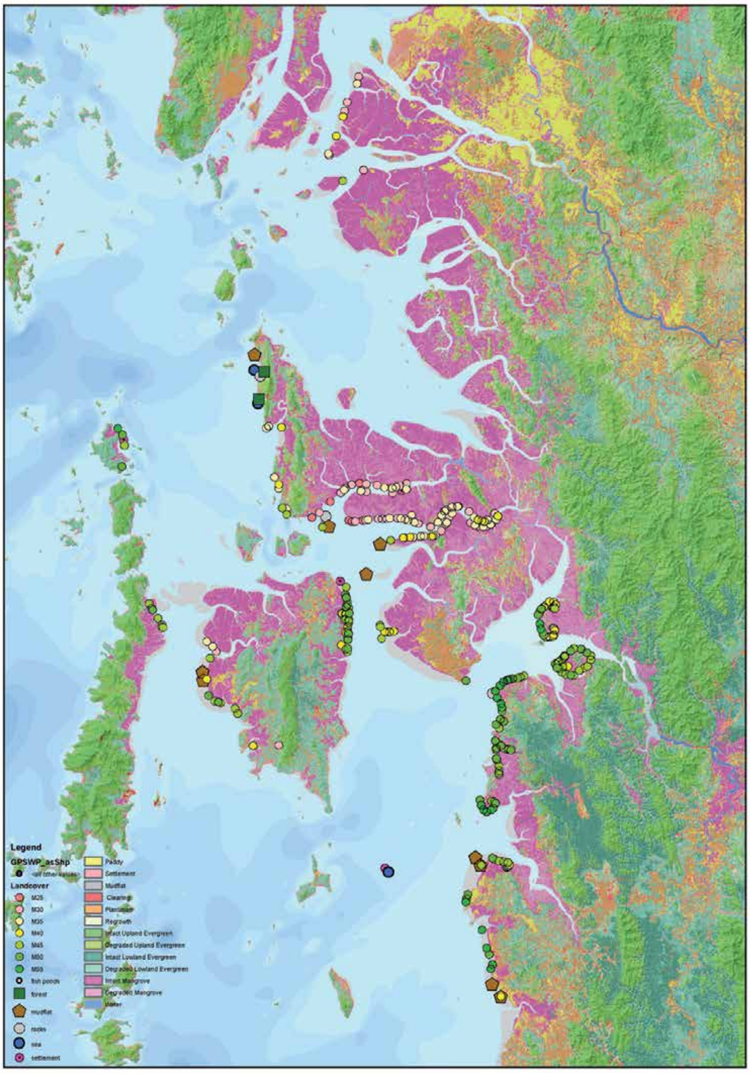


Figure 2.
Mangrove distribution (pink) and status of the mangroves within the Myeik archipelago, Taninthary, Myanmar in 2016, based on our scale with symbols from 2.5 (pale pink) to 5.5 (dark green) and based on 282 assessment points (100 in the northern part and 182 in the southern part, [19]). See also ***Table 2****.*

converted to agricultural land or aquaculture, many of the remaining areas have been heavily degraded by local logging and timber harvesting for building materials. Recently and with increasing severity, mangroves have been extensively harvested for charcoal production [6]. Our degradation scale has been applied to several mangrove sites in Myanmar in 2016 and 2017. **Figures 1** and **2** show the results mapped at two distinct coastal areas. **Figure 1** shows the Mawdin shoreline on the west coast in the Ayeyarwady Division which has only marginal and often small coastal mangrove areas. This region also includes minor areas that have been recently selected for small-scale mangrove restoration. **Figure 2** depicts the mangrove rich region of southern Taninthary, south of Myeik town. These large estuarine mangroves contain mature mangrove stands of well over 150,000 ha. Although most of the mangroves are still in good condition, recent increased usage and harvesting by local communities have left signs of degradation which this rapid assessment tool has depicted.

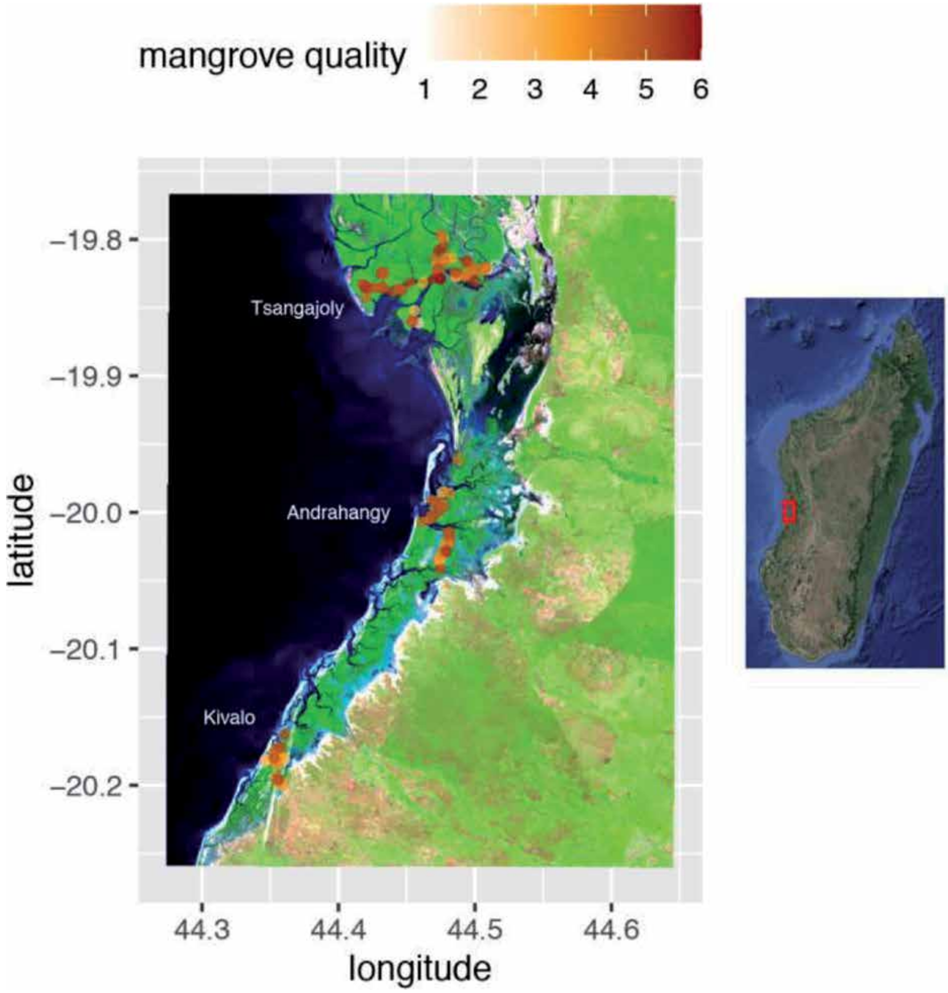


Figure 3.
Left: Landsat 8 image with remaining vegetation and the mangrove degradation status in three sub-regions in the Menabe Antimena protected area, Western Madagascar. A total of 114 assessment points were taken across all three areas. Right: Location (red square) of surveyed area in Madagascar.

No	Site	Average mangrove quality and range of assessments	No of mangrove assessment points
	Myanmar (see Figures 1, 2)		
1	Mawdin Coast, Ayeyarwady Division	3.2 (2.0–4.0)	21
2	North of Myeik, Taninthary	3.4 (3.0–5.5)	100
3	South of Myeik, Taninthary	4.5 (3.5–5.5)	182
	Madagascar (Menabe) (see Figure 3)		
1	Tsangajoly/ Baie de Borongeny	4.0 (3.5–5.0)	58
2	Andrahangy	3.8 (3.0–4.5)	29
3	Kivalo	3.3 (3.0–4.5)	27

Table 2.
Average mangrove degradation (range from 1 = much degraded to 6 = intact, high-quality) at selected sites in Myanmar and Madagascar between 2016 and 2019 [6, 19, 20].

Examples from Madagascar, show similar patterns and demonstrate the value of a scale that can be widely applied across the Indian Ocean. **Figure 3** shows the results of the application of this degradation scale in 2019 on the western coast within the Menabe Antimena Protected Area. **Table 2** shows the average assessment scale as a measure of the overall status of the mangrove quality in each region or sub-region.

4. Summary assessment of selected mangrove areas

Table 2 shows the average degradation levels observed in different coastal regions in Myanmar and Madagascar. The first area on the Mawdin coast was based on a small sample size (n = 21). It suggests a relatively low average of just over 3, reflecting the wide-scale destruction and degradation of mangroves in the region as well as early stages of rehabilitation efforts.

In the Taninthary region, the northern side, closer to the business capital Myeik, appears to have suffered more mangrove losses and disturbances, the degradation is lower with a score of 3.4 than the southern more remote mangroves around Whale Bay and Kan Maw island which averaged over 4.5 (see **Figure 3**). This suggests that the southern mangroves are healthier than the northern mangroves of Taninthary.

Madagascar also displayed differences in mangrove status in the three selected sub-regions (see **Table 2** and **Figure 3**). Kivalo, followed by Andrahangy and Tsangajoly/Baie de Borongeny showed the highest overall degradation. Although this was not specifically tested, it might well be due to higher population densities in the southern areas, which are closer to the biggest regional city of Morondava. All three areas show significant signs of degradation of which most are rather unlikely to be detected using remote sensing methods. Most signs of degradation were spatially associated with local communities depicting increased pressure on the mangroves mainly due to logging for fire wood and construction material. Over-exploitation of mangrove wood in the region by local fisherman for cooking, treatment of fishery products, and construction of boats and houses was already described by Rasolofo [23]. In some surveyed areas, grazing of zebu or goats also present increasing threats to mangroves.

5. Discussion

This simple, rapid degradation assessment tool allows the assessment of the present status and degree of degradation of a mangrove forest, but it also demonstrates the state of forest succession and rate of restoration after intervention and restoration activities have taken place. The tool is applicable over at least the Indo-West Pacific and West-Indian Ocean regions in non-arid situations, where high salinity is not the limiting factor. In the northern margins of the mangrove belt, mangroves develop much smaller 'dwarf' versions, which do not allow the application of the full range of the degradation scale, particularly the assessment of height. We hope that beyond these areas, where similar species at genus level provide comparable forest structures, this assessment tool will also allow comparisons across regions and possibly also for mangroves across the Pacific, Caribbean and South America.

Like any tool this degradation scale approach has its limitations. It only provides a restricted window from the sea front or from a boat, at best within navigable channels or small access roads, excluding large areas of the inner part of the mangroves, which are often, especially in levels 3 and 4, inaccessible on foot. While this is certainly a restriction, this rapid assessment tool is only meant to provide an initial, qualitative assessment of damage by logging and cutting or other degrading activities. We are encouraging assessors to get out of survey boats as much as possible to provide additional survey points on foot. In addition, assessments might be hampered by observer bias or difficulty in allocating local degradation to the appropriate class.

This degradation scale has not been tested and verified, but initial comparisons by different observers using the same locations did not indicate a significant difference in the assessment results. This first draft would benefit from further testing in other mangrove systems including non-deltaic mangroves to develop a more robust scale of degradation. Later on, a combination of this rapid assessment tool together with drone surveys would provide a more accurate scale of degradation and present status of any chosen mangrove forest. Repeated surveys are encouraged as they could reveal changes in the status of a mangrove stand over time. This would be particularly valuable to assess the effectiveness of in-situ protection measures, community forest agreements and active restoration schemes if baseline data is collected before, and then at intervals afterwards. Additionally, it is hoped that the scale can be tested and used on its own by community groups and government mangrove agency field officers to assess and rank their mangroves in order to prioritise rehabilitation and protection measures. Being simple and cheap the proposed rapid assessment tool has major advantages in comparison with remote sensing and LIDAR approaches and could provide substantial benefits to community-based mangrove conservation projects.

The tool offers the identification of degraded areas that have not appeared to be in need for restoration based on superficial consideration or often remote sensing. In addition, the tool can also be applied in recently restored mangroves and plantations and could also provide a good measure for success of restoration projects and activities, whereby the age of the restoration activities needs to be taken into consideration. It also allows comparisons and can point to errors and failures of the restoration efforts and highlights mitigation measures required.

In comparison to deforested mangroves, areas with reversible mangrove degradation represent opportunities for rapid and effective conservation interventions, and thus can substantially facilitate mangrove restoration initiatives [24]. The tool provides rapid and effective identification of sites most suitable for mangrove rehabilitation.

We would welcome input, comments and improvements, including extra photos, particularly from groups that have tried to use this scale. Eventually it will be available for download and printing as well as a smart phone app. It is suggested that a version of it is laminated for use in the mangrove while conducting surveys.

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Chapter 3

Secondary Ecological Succession of Mangrove in the 2004 Tsunami Created Wetlands of South Andaman, India

V. Shiva Shankar, Neelam Purti, Ravi Pratap Singh and Faiyaz A. Khudsar

Abstract

Andaman and Nicobar Islands (ANI's) being situated in the Tropical zone is the cradle of multi-disasters viz., cyclones, floods, droughts, land degradation, runoff, soil erosion, shallow landslides, epidemics, earthquakes, volcanism, tsunami and storm surges. Mangroves are one of the first visible reciprocators above land and sea surface to cyclonic storms, storm surges, and tsunamis among the coastal wetlands. The Indian Ocean 2004 tsunami was denoted as one of the most catastrophic ever recorded in humankind's recent history. A mega-earthquake of Magnitude (9.3) near Indonesia ruptured the Andaman-Sunda plate triggered this tsunami. Physical fury, subsidence, upliftment, and prolonged water logging resulted in the massive loss of mangrove vegetation. A decade and half years after the 2004 tsunami, a study was initiated to assess the secondary ecological succession of mangrove in Tsunami Created Wetlands (TCWs) of south Andaman using Landsat satellite data products. Since natural ecological succession is a rather slow process and demands isotope techniques to establish a sequence of events succession. However, secondary ecological succession occurs in a short frame of time after any catastrophic event like a tsunami exemplifying nature's resilience. Band-5 (before tsunami, 2003) and Band-6 (after tsunami, 2018) of Landsat 7 and Landsat-8 satellite respectively were harnessed to delineate mangrove patches and TCWs in the focus area using ArcMap 10.5, Geographic Information Systems (GIS) software. From the study, it was understood that *Fimbrisstylis littoralis* is the pioneering key-stone plant followed by *Acrostichum aureum* and *Acanthus ilicifolius* facilitating *Avicennia spp/Rhizophora spp* for ecological succession in the TCWs.

Keywords: natural disasters, Landsat (7 & 8), satellite image, Short Wave Infra-Red, GIS (Geographic Information Systems), fluvial influx, mangrove biodiversity

1. Introduction

A befitting example of the interaction of Sea, land, and air is the 'coastal frontier'. This Coastal frontier comprises of fragile, sensitive, dynamic, and diverse ecosystems like forests, estuaries, coral reefs, tidal mudflats, salt marshes, seagrass, and mangroves [1, 2]. Mangroves are circum-tropical halophytes representing an ecotone between terrestrial and marine habitats which are adapted to wet and saline conditions having a vital ecological and economic relevance at global, regional, and local scales [3]. These mangrove forests comprise of 65 true mangrove species and 6 hybrids [4], housed in one hundred and twenty-three countries between 32°N and 38°S covering an area of 1.5 million sq. Km [5]. The highest concentration (60%) of global mangrove species (44) are reported from southeast Asia [5, 6]. The mangroves of Andaman and Nicobar Islands (ANI's) represent the third-largest cover on the Indian subcontinent next to Gujarat and Sunderbans respectively [5]. ANI's comprise 38 true mangrove species belonging to 19 genera, and 13 families. Thus, ANI's houses 50% of the global mangrove species [7, 8].

Globally mangrove forests are known as among one of the most productive and biologically important ecosystems because they deliver a variety of vital and distinctive ecosystem goods and services to humankind and other coastal marine ecosystems like the mudflats, coral reefs, seagrass, etc [9]. Since time immemorial mangrove is been conventionally used for firewood, charcoal, alcohol, folk-lore therapeutics, roof thatching [10, 11]. They act as nursery and breeding ground for the juveniles of many commercial fish, crustaceans, including avifauna and reptiles [12–15]. Also, they reduce coastal erosion, stabilize the shoreline, provide sediment and nutrient retention, improve water quality, and provide both flood and flow control as well as protection against storms, hurricanes, and tsunamis [16–21]. Carbon sequestration is presently recognized as the most important service of the mangrove owing to the growing appreciation of the efficacy of these habitats in climate regulation through fixing carbon from the atmosphere [22–24].

The mangrove forests of the world are dwindling at a rate of 1–2% annually and if this trend continues the mangrove and its ecosystem shall be erased from the face of the earth by the 21st century [25–27]. The deterioration of mangrove is more alarming than any other ecosystem like the coral reef and marine forests. At this rate of destruction, the world would be deprived of mangrove and its ecosystem services by the end of this century [28]. The loss of mangrove forests can be attributed to anthropogenic and natural factors. Anthropogenic factors such as dumping of wet and solid wastes generated by the urban population, deforestation, conversion for aquaculture, agriculture, industrial discharge, petroleum spills, the combustion of fossil fuels, automobile exhaust are responsible for the loss of mangrove forests [25, 27, 29–33]. Although the mangrove forest act as a bio-shield against natural disasters such as climate change, cyclones, hurricanes, typhoons, storm surges, and tsunamis [3, 16–21]. On the contrary, these natural factors are also partly responsible for the loss of mangrove forests [34]. However, Mangroves demonstrates the ability to be resilient to natural eventualities [18, 35–40] by following the fluvial influx [39, 41].

The resilience of mangrove is naturally ensured by ecological succession. It is rather a slow process of development and adjustment of species compositions of the mangrove communities over time and space. Further, the ecological succession is dependent on the vital driving factors such as growth potential of the mangrove species, dispersal, settlement, competition, and external or biogenic changes in abiotic conditions [42]. The fluvial influx in the landmass subsided zones due to the 2004 tsunami created a conducive environment for mangrove colonization (ecological succession). Hence, the present study aims at understanding the secondary ecological succession of mangrove in Tsunami Created Wetlands (TCWs) of South Andaman so that it would help in initiating anthropogenically induced massive restoration and rehabilitation of it in the future [6, 28, 43–47].

2. Study area

ANI's is a union territory of India in the Bay of Bengal between peninsular India and Myanmar, trending in a north-south direction. Bounded by the coordinates (92° to 94° East and 6° to 14° North), it is an archipelago with > 500 islands/islets, stretching over 700 km [39]. They are closer to the Indonesian landmass than to mainland India (1200 km), with the southernmost island only 150 km from Sumatra and the northernmost landfall, 190 km south of West Myanmar. ANI's being the cradle of multi-disasters like cyclones, storm surges, earthquakes, and tsunami, the mangroves of this region are vulnerable to disaster. However, nature has its own plans for resilience after any disaster. The present study illustrates the ecological succession of mangrove in south Andaman after the 2004 devastating tsunami. Subsidence and Upliftment of landmass were observed in ANI's due to the 2004 tsunami [48]. Subsidence of landmass around the coastal frontiers rendered it to be permanently waterlogged thus creating wetlands that are very conducive for the mangroves to colonize [37–39]. The area under focus is bounded by the coordinates 11°27′00″and 11°45′00"N and 92°30′00″and 92°46′47″E (**Figure 1**) covering a land area of 333.18 km^2 that encountered destruction from the 2004 tsunami and subsidence as well [48, 49].

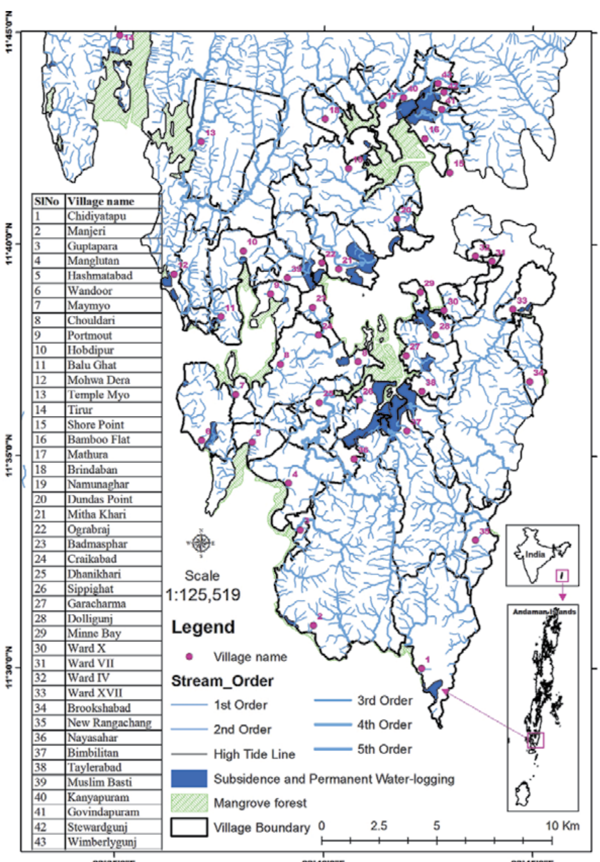

Figure 1.
Study area map showing TCWs with mangrove forest.

2.1 Geology, soils, geomorphology, and drainage

The origin of the Andaman-Nicobar islands is approximately dated as late Pliocene to Pleistocene [50]. The subsidence of landmass is defined by the rock type. Two types of rocks are encountered in the study area viz., (1) Sedimentary rock (Andaman flysch), and (2) Ophiolite suite of volcanic origin [51, 52]. Sedimentary rock comprises of greywacke, siltstone, chalk, limestone are soft and more susceptible to subsidence due to tectonic activity when compared to the Ophiolite suite (**Figure 2a**).

Geomorphogically the study area is dominated by the structural hill, valley trending N-S direction followed by pediments and coastal plains (**Figure 2b**). The coastal plains are dominated by alluvium and colluvium.

The soils of the study area have developed under the dominant influence of vegetation and climate and over diverse parent material. The soil is either present on the hill tops or deposited in the valleys or along the coast as escorted soil. Along the coast, the soil is sandy and contains shingles and old corals, etc. It is extremely porous. In the valley and in the lower slopes of hills, the soil is clayey loam. On the hills, it is rigid clay and dark red loam. There are three orders of soil Entisols, Inceptisols, and Alfisols [53] in six soil texture class viz., Clay, Clay loam, Loamy sand, Sandy, Sandy Clay, Sandy Clay loam. Clay loam is the dominant textural class of soil well distributed throughout the study area followed by clay. Sandy texture was seen along the coastal fringes (**Figure 2c**).

The drainage in the area under investigation exhibits dendritic and trellis patterns a typical structurally controlled drainage pattern of volcanic origin. In general, almost all the drainages are very young and terminate their first or second-order

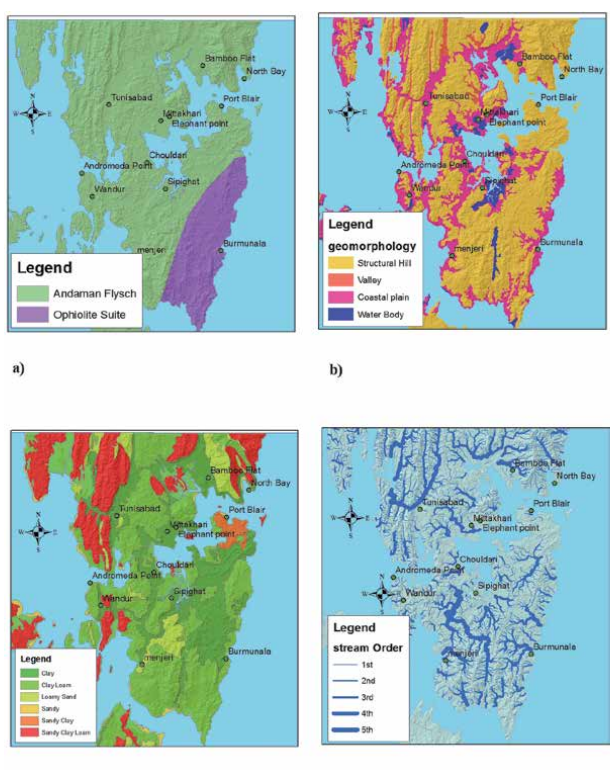

Figure 2.
Maps of (a) Geology, (b) Geomorphology, (c) Soil texture, and (d) Drainage.

stream within a short distance. There are no landlocked watersheds hence all the streams empties into the adjacent sea (**Figure 2d**).

2.2 Meteorology

The study area is situated south of Tropic of Cancer and the region is surrounded by warm seas. The climate of this region is categorized as Warm and Humid. The recorded average temperature ranges from 25°C to 30.5°C. The prevalent temperature along with relatively high humidity gives rise to perceptible and sultry weather. However, this type of weather is moderated with pleasant sea breezes. The relative humidity is high throughout the year reaching > 90 % during the northeast monsoons. The maximum temperature recorded at Port Blair is 32°C. The average annual rainfall is around 3000 to 3500 mm. May to August is the rainiest months and April is the warmest month in this region. It is observed that the South-West monsoon brings in most of the rainfall. During May-June, the onset of the monsoon occurs and in September-October withdrawal of monsoon is observed. The North-East monsoons beginning in November and persists till the end of February. This transitional period is nonetheless disturbed by cyclonic storms which may be accompanied by thundershowers. Most of the storms experienced by the mainland and the area under investigation originate in the Bay of Bengal [54].

3. Conducive environment for mangrove ecosystem

The prevalent geology, soil, geomorphology, drainage system, and climatic conditions in the study area favour the tall and gregarious growth of mangrove flora. The rocks of sedimentary origin are more susceptible to weathering than volcanic rocks. Tropical rains weather the rock material and escort them to the coastal front through the natural drainage system along with abundant freshwater. The climate of any tropical intertidal zone acts as a vital and requisite factor for the natural growth, development, and succession of mangroves. Among these necessary climatic factors are (i) the temperature fluctuation-ranges between 20°C and 30°C [55, 56], (ii) the humidity is of a higher range [57], (iii) the total annual rainfall is above 1000 mm [58], (iv) there is regular wind flow, (v) the area is frost free [59], (vi) radiation and (vii) sedimentation along with upstream water supply plays a very dominant role for the growth and viability of mangrove in a holistic manner [60].

4. Materials and methodology

Landsat (7 & 8) satellite data products before (2003) and after (2018) tsunami respectively, for the study were downloaded from the website (www.earthexplorer.usgs.gov/). The study area is covered by the scene with path (134) and row (52). Mangrove patches and water bodies decipherably picked up very well by band-5 and band-6 by the short-wave infrared (SWIR) sensor of Landsat 7 and 8 satellites respectively from other features like the forest, human settlements, etc. Using ArcGIS Desktop 10.5 software mangrove patches and TCWs were demarcated.

Apart from the demarcation of TCWs, stream networks were delineated from the 1979 Survey of India (SOI) toposheet. An overlay analysis of stream network was comprehended over (1) satellite imageries, (2) geology map, (3) geomorphology map, (4) soil texture map, and (5) village administrative boundary map to understand the source of fluvial Influx dynamics and ecological succession.

Village-wise mangrove stand and TCWs (subsided landmass and permanent waterlogging thereafter) were inferred from before and after tsunami satellite image interpretation. A fishnet grid of 1 km^2 covering mangroves and TCWs was generated with unique ID's and the same was converted into Global Positioning System (GPS) compatible format (*.gpx). These grids were loaded in the handheld Garmin 62CSX, GPS for field investigation. Enumeration of mangrove species was carried out through a 150 m line transect technique [61] with a 50 m interval between each transect within the 1 km^2 grid during the dry season (January-May, 2019 and March-April, 2020). These line transects were laid orthogonal to the coast either ways (land to sea and sea to land). A subplot of 4 m^2 dimension was laid for enumerating individual plants [8]. Mangrove phenology and habitat description were carried out as per Debnath 2004 [62].

5. Results and discussion

Through field survey, a total of twenty-eight mangrove species around existing mangrove and TCWs in forty-three village locations were enumerated and presented in **Table 1**. Also, village-wise pre-tsunami landuse with soil type and the maximum distance from the existing mangrove patch (km) were tabulated in **Table 2**.

Tsunami is rather a rare disaster in the Indian Ocean [63]. A mega-earthquake of magnitude 9.3 on the Richter scale struck near Indonesia On December 26th, 2004 at 07:58:53 local time [64, 65]. The epicenter was located 80km west of the coast of Northern Sumatra (at approximately 95°51' W and 3°25'N). The earthquake advanced thereafter approximately northward rupturing 1200 km to 1300 km (with an average rupture speed of 2.5 to 3 km/s) of the Andaman-Sunda plate in about 8 to 10 minutes [66–68] causing up to ~6 m of bottom subsidence and ~10 m of uplift parallel to the rupture and about100-150 km wide across the subduction area [69]. Upliftment and subsidence of landmass [38] were generated as a consequence of earthquake elastic rebound, offshore of Banda Aceh, the northern tip of Sumatra [70]. Rupture of the plate and coseismic activities spontaneously triggered a tsunami catastrophic devastation ever witnessed in the modern history of humankind [70–73]. All the above sequential events just occurred in a short span of few hours resulting in unprecedented destruction and mangroves were one of the first visible responders of the tsunami [3, 74–77].

Voluminous literature speaks about mangrove demonstrating resilience after a disaster like hurricane, cyclone, and tsunami [18, 35–40, 78, 79]. However, very few studies were conducted to understand the dynamics of the ecological succession of mangroves after natural disasters like hurricanes and tsunamis [80]. The mangroves of the study area faced the double impact of mortality due to 26th December 2004 tsunami viz., (1) physical fury, and (2) prolonged submergence due to subsidence of land mass [38–48]. Zones of subsided landmass were waterlogged permanently resulting in (TCWs). Nudation of mangrove (**Figure 3**) occurred due to a catastrophic event [81].

Overlay analysis of geology geomorphology and stream network of pre-post–tsunami satellite imageries suggest that subsidence of landmass (TCWs) has occurred in the regions of sedimentary rock and on the coastal plains. Sedimentary rocks (Andaman flysh) being soft are more susceptible to deformation due to tectonic activity when compared to volcanic rock (Ophiolite suite). Also, the streams once which were emptying itself in the shallow depths of the coastal frontiers started depositing in the TCWs (**Figures 1, 3**, and **4**). Mineral-rich fine sediments and abundant freshwater were deposited into TCWs through the

Species Name	1*	2*	3	4	5	6*	7	8*	9*	10*	11*	12*	13	14*	15	16	17	18	19*	20*	21*	22*	23	24	25	26*	27*	28*	29	30	31	32	33*	34	35	36**	37**	38**	39**	40**	41**	42**	43**
Acanthus ebracteatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	*+	+	+	+	+	–	–	–	–	–	+	+	+	–	–	–	–	–
Acanthus ilicifolius	*+	*+	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	+	*+	+	+	+	*+	*+	+	+	+	–	–	*+	+	+	+	+	+	+	+	+	+	+
Acrostichum aureum	*+	*+	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Aegiceras corniculatum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–
Avicennia marina	*+	*+	+	+	+	*+	+	*+	*+	*+	–	–	+	*+	+	+	+	+	*+	*+	*+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	–	+	+	+	+	+	+	+
Avicennia officinalis	*+	*+	+	+	+	*+	+	*+	*+	*+	–	–	+	*+	+	+	+	+	*+	*+	*+	–	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Bruguiera cylindrica	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Bruguiera gymnorhiza	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	–	–	–	–	–	–	–	–
Bruguiera parviflora	+	–	–	–	–	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–
Ceriops tagal	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–
Cynometra iripa	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Dolichandrone spathacea	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Excoecaria agallocha	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Heritiera littoralis	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Lumnitzera littorea	+	+	+	+	+	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lumnitzera racemosa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–

Species Name	1*	2*	3	4	5	6*	7	8*	9*	10*	11*	12*	13	14*	15	16	17	18	19*	20*	21*	22*	23	24	25	26*	27*	28*	29	30	31	32	33*	34	35	36**	37**	38**	39**	40**	41**	42**	43**
Nypa fruticans	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Pemphis acidula	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Phoenix paludosa	–	–	–	–	–	–	–	–	–	–	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pandanus tectorius	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhizophora apiculata	*+	*+	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	*+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Rhizophora mucronata	*+	*+	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	*+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Rhizophora stylosa	+	+	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–
Scyphiphora hydrophylacea	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Sonneratia alba	+	+	–	+	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Sonneratia ovata	+	–	–	+	+	+	+	+	+	+	–	–	–	–	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Xylocarpus granatum	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Fimbrisstylis littoralis	*+	*+	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	*+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+

"" -Village-wise distribution of Mangroves, "**" -Village-wise distribution of Mangrove in new venues of TCWs, "–" - Indicates absence of Mangrove species, "+" - Indicates presence of Mangrove Species, "*+"- Indicates presence of Mangrove species in TCWs*

Table 1.
Village-wise distribution of mangrove and its associated species.

Sl no	Village name	Soil texture type	Pre-tsunami land use land cover	Max distance from the existing mangrove patch (km)
1*	Chidiyatapu	Clay loam	Agricultural Land & Settlement	1.2
2*	Manjeri	Clay loam	Agricultural Land & Settlement	0.12
3	Guptapara	Clay and loamy sand	—	—
4	Manglutan	Clay loam	—	—
5	Hashmatabad	Sandy clay loam	—	—
6*	Wandoor	Clay	Agricultural Land	1.14
7	Maymyo	Clay	—	—
8*	Chouldari	Loamy sand	Agricultural Land & Settlement	0.55
9*	Portmout	Clay loam	Agricultural Land & Settlement	0.29
10*	Hobdipur	Clay	Agricultural Land & Settlement	0.35
11*	Balu Ghat	Clay loam and sandy clay loam	Open jungle	0.15
12*	Mohwa Dera	Sandy and sandy clay loam	Open jungle	1.5
13	Temple Myo	Clay loam	—	—
14*	Tirur	Clay loam, Loamy sand, clay, sandy clay loam	Agricultural Land & Settlement	0.25
15	Shore Point	Clay loam	—	—
16	Bamboo Flat	Clay loam and clay	—	—
17	Mathura	Clay and clay loam	—	—
18	Brindaban	Clay and clay loam	—	—
19*	Namunaghar	Clay and clay loam	Agricultural Land & Settlement	0.27
20*	Dundas Point	Clay loam	OpenJungle	0.65
21*	Mitha Khari	Clay	Plantation/ Agricultural land	1.5
22*	Ograbraj	Clay and clay loam	Agricultural Land & Settlement	0.22
23	Badmasphar	Clay and clay loam	—	—
24	Craikabad	Sandy and clay loam	—	—
25	Dhanikhari	Clay and clay loam	—	—
26*	Sippighat	Clay and clay loam	Agricultural Land & Settlement	1.01
27*	Garacharma	Clay and clay loam	Agricultural Land & Settlement	0.45
28*	Dolligunj	Clay and clay loam	OpenJungle	1.05
29	Minne Bay	Clay and clay loam	—	—
30	Ward X	Clay loam	—	—

Sl no	Village name	Soil texture type	Pre-tsunami land use land cover	Max distance from the existing mangrove patch (km)
31	Ward VII	Sandy clay	—	—
32	Ward IV	Sandy clay	—	—
33*	Ward XVII	Clay	Agricultural Land	1.01
34	Brookshabad	Clay	—	—
35	New Rangachang	Clay loam	—	—
36**	Nayasahar	Clay and clay loam	Agricultural Land & Settlement	2.5
37**	Bimblitian	Clay and clay loam	Agricultural Land & Settlement	1.2
38**	Taylerabad	Clay and clay loam	Agricultural Land & Settlement	0.87
39**	Muslim Basti	Clay and clay loam	Agricultural Land & Settlement	1.32
40**	Kanyapuram	Clay loam and clay	Agricultural Land & Settlement	0.95
41**	Govindapuram	Clay loam and clay	Agricultural Land & Settlement	1.47
42**	Stewardgunj	Clay loam and clay	Agricultural Land & Settlement	1.91
43**	Wimberlygunj	Clay loam and clay	Agricultural Land	2.02

Indicates TCWs in the vicinity of pre-existing mangrove.
**Indicates new venues of TCWs.*

Table 2.
Village-wise soil texture, pre-tsunami landuse pattern and maximum distance from the existing mangrove patch.

conduits of natural streams network (**Figure 4**). Freshly deposited fine sediments are barren and are called as mud banks.

These mud banks in the TCWs were wet, saline, and poorly aerated proves unfavourable for higher plants [82] so, microbes and algae prepare the mud banks for the utilization of higher plants by aerating them [83, 84]. Also, sediments are counteracted by compaction and consolidation of both mud and peat [82]. Coaction of non-woody key-stone species like *Fimbrisstylis littoralis*, *Acrostichum aureum*, and *Acanthus ilicifolius* subsequently colonized the TCWs (**Figure 5**, **Tables 1–3**). The aforementioned key-stone species were the pioneer plants to colonize the landmass subsided zones thus trapping the sediments and nutrients resulting in the invasion of novel mangrove species [85, 86]. Basically, key-stone species for the initial succession perform the role of nurse plants which start on the bare aerated soil, modifying its conditions like decreasing interstitial salinity and increasing nutrient, enabling the succession of mangroves and can thus be called facilitator species [87, 88]. key-stone species like *Fimbrisstylis littoralis and Acrostichum aureum* were invariably found in all the forty-three sites. Similarly, mangrove species like *Rhizophora* and *Avicennia spp* were also encountered in all the stations. *Pandanus tectorius* and *Pemphis acidula* were found in Mitha Khari and Ward XVII respectively (**Table 1**). Basic soil textures like clay, sand, and loam in different

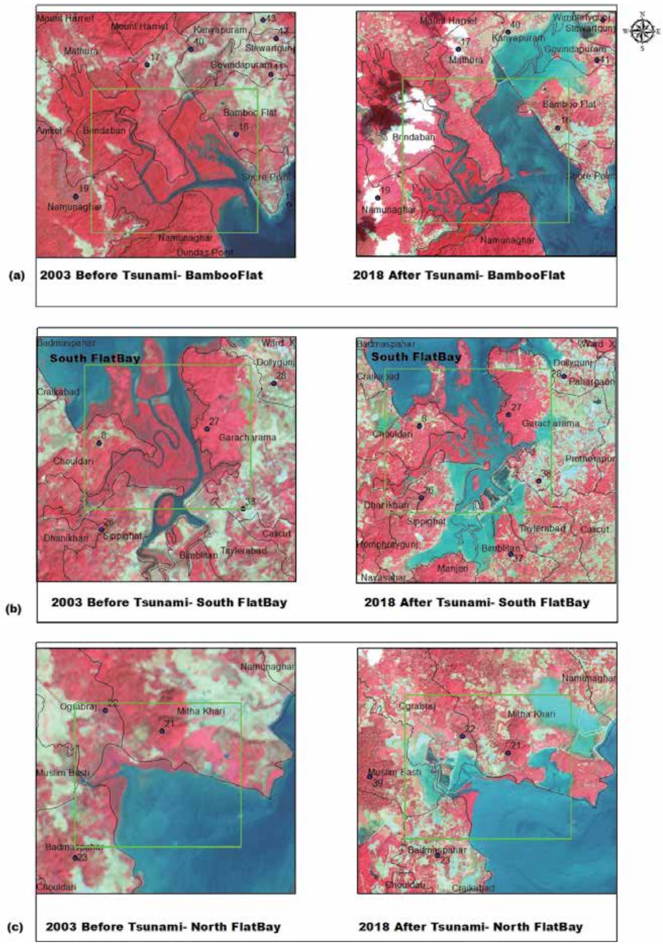

Figure 3.
Satellite image showing before and nudation of mangrove after tsunami (a) Bambooflat, (b) South Flat Bay and (c) North Flat Bay.

combinations were found in the focus area (**Table 2**). The flowering and fruiting phenology along with the habitat descriptions are presented in **Table 3**.

The mangrove seedlings were transported to the TCWs through the tidal influx from pre-existing mangrove (**Tables 1** and **2**) and thus had a stable environment. TCWs being situated in the shallow sheltered bays with low tidal amplitude favours the rooting of propagules [82, 89]. Mangroves follow the existing patterns of fluvial influx and their distribution is determined by the formation of banks, deltas, channels, levees, lagoons, and bays [55, 90–92]. Mangroves respond to geomorphic changes [93, 94] and attain a steady-state system in low energy tropical saline environments [95]. Mangrove succession is a continuous process, where the species recruitment and replacement is systematic and anticipated [96]. It has to be noted here that the likelihood of this phenomenon is of enormous benefit in assessing the evolution towards the climax species complex. The ecological succession from land towards the sea in TCWS in south Andaman is as follows: *Fimbrisstylis littoralis* is the pioneering key-stone plant followed by *Acrostichum aureum* and *Acanthus ilicifolius*. *Avicennia spp/Rhizopara spp* are the prime mangroves to colonize. The ecological succession of mangrove in TCWs are

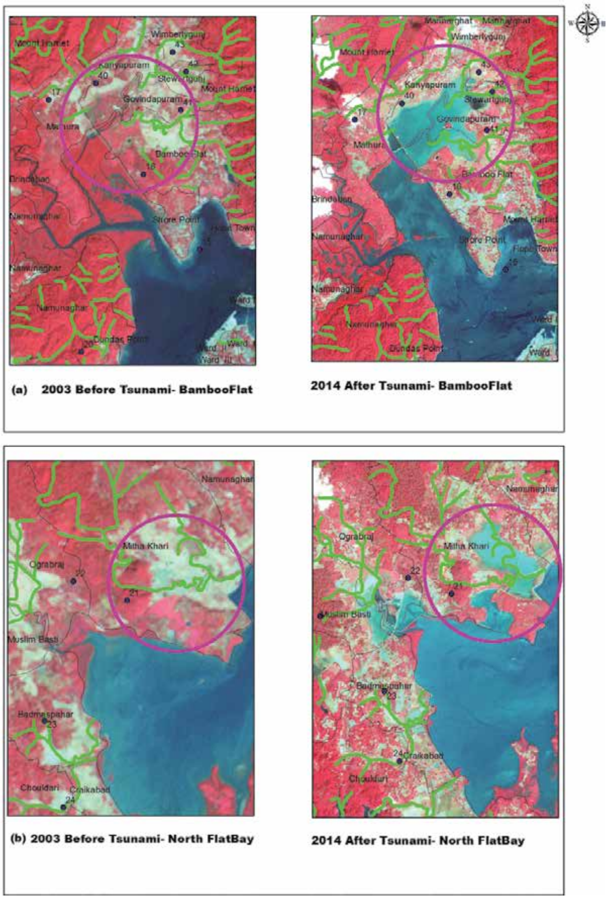

Figure 4.
Siltation and freshwater influx by natural stream network in TCWs.

considered as secondary ecological succession, which is caused by a natural disaster like the tsunami, subsidence of landmass followed by permanent waterlogging. This type of succession was studied worldwide [35, 37, 38, 80].

6. Conclusion

From the present study, it is understood that secondary ecological succession has occurred in Andaman after the catastrophic 2004 tsunami. Key-stone species like *Fimbrisstylis littoralis, Acrostichum aureum* and *Acanthus ilicifolius* acting as a facilitator species were first to colonize the TCWs and followed by mangrove species like *Avicennia spp/Rhizopara spp*. Infact the key-stone species were the pioneer lower plants to colonize the landmass subsided zones of the 2004 tsunami. The nutrient-rich upstream sediments trapped amongst the roots of the key-stone species provides a conducive environment for the mangrove to colonize. The present study provides a window for anthropogenically induced rehabilitation and restoration of mangrove forests. For any rehabilitation and restoration endeavor of mangrove firstly, the area should be seeded with key-stone species after couple of years mangrove species like *Avicennia spp and Rhizopara spp* has to planted. Thereafter it may take 15–20 years for dense patch of mangrove. A broad avenues for future

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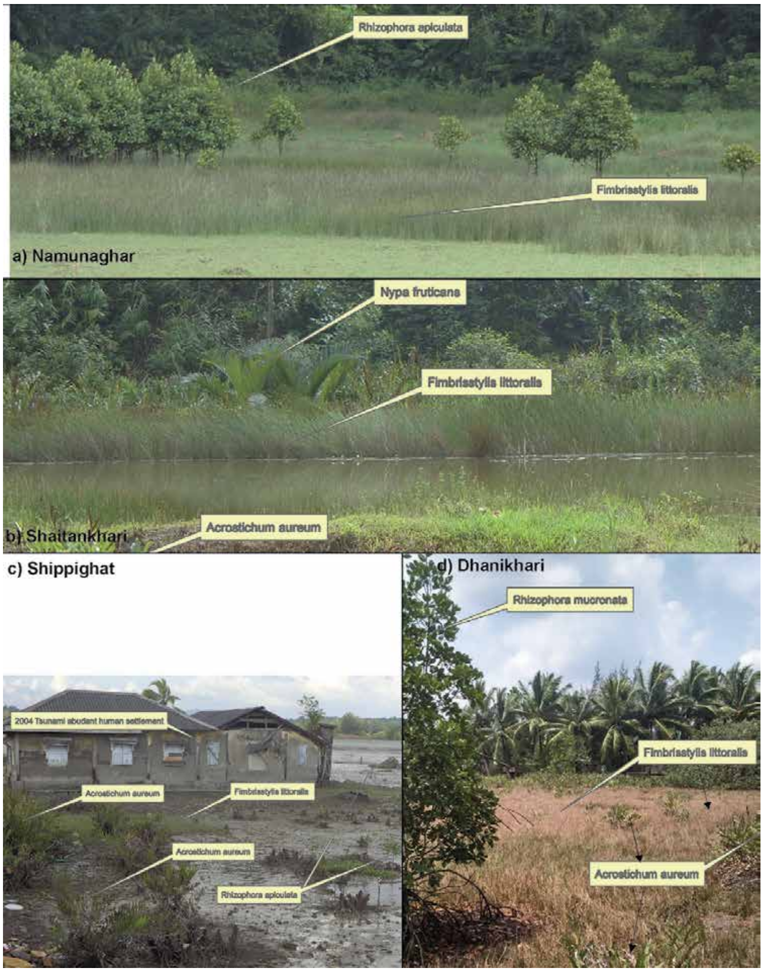

Figure 5.
Field photos of key-stone species and mangroves TCWs.

Sl no	Species name	Phenology		Habitait
		Flowering	**Fruiting**	
1	*Acanthus ebracteatus*	Mar-Jun	Jun-Aug	Common along tidal streams, inland borders of Mangrove swamps under the influence of salt or Brackish water
2	*Acanthus ilicifolius*	Apr-Jun	Jun-Aug	Gregarious in brachish swamps along the seashore and tidal streams
3	*Acrostichum aureum*	NA	NA	Landward side of mangrove, survives in TCWs completely cut off from sea
4	*Aegiceras corniculatum*	Throughout the year		Often found in inner mangroves along with *Bruguiera* spp., *Ceriops* spp., and *Xylocarpus* spp. Also present at landward margin of mangroves inundated during normal high tides and fringing the banks at upstream region.
5	*Avicennia marina*	Apr-Jun	Jun-Aug	Often found in high intertidal and intermediate estuarine position also present in downstream and low intertidal areas. It is a dominant species in highly polluted areas

Sl no	Species name	Phenology		Habitait
		Flowering	Fruiting	
6	*Avicennia officinalis*	Jun-Aug	Aug-Oct	Often found in low and high intertidal position and also occur in mid and upper estuarine position along the banks of the creek.
7	*Bruguiera cylindrica*	Mar-Jun	Jun-Aug	Gregrious on stiff clay behind Avicennia, sometimes in association with Bruguiera gymnorrhiza
8	*Bruguiera gymnorhiza*	Throughout the year		Commonly occur in intertidal zone, along creeks, usually associated with Rhizophora apiculata and R. mucronata
9	*Bruguiera parviflora*	Apr-Jul	Jul-Sep	Occur in intertidal zones of esturaine swamps in association with Bruguriera gymnorrhiza,Rhizophora apiculata and R. mucronata
10	*Ceriops tagal*	Mar-Jul	Jul-Oct	Occur in intertidal banks of mangrove, also in areas nearer to and under esturaine influnce
11	*Cynometra iripa*	Sep-Nov	Dec-Feb	Frequent to back mangrove in the Heritiera littoralis zones
12	*Dolichandrone spathacea*	May-Jun	Jun-Aug	Sporadic occurrence, found around the inner edge ofmangrove swamps in association with Sonneratia caseolaris and Heritiera littoralis
13	*Excoecaria agallocha*	Mar-Jun	Jun-Aug	Occurs in muddy or sandy shores, commonly found in intertidal
14	*Heritiera littoralis*	Mar-Jun	Jun-Aug	Commonly found in intertial zone, frequently extending into muddy or sandy shores
15	*Lumnitzera littorea*	Jan-Apr	Apr-Oct	Occurs in middle zone of mangrove forest, where soulble salts are more
16	*Lumnitzera racemosa*	Jan-Apr	Apr-Jul	Occurs in muddy or sandy elevated zones of esturaine and backwater
17	*Nypa fruticans*	Feb-Jun	Jun-Sep	Sheltered intertidal creeks of mangrove swamps, preferably low saline regions
18	*Pemphis acidula*	Aug-Dec	Dec-Apr	Occur along the edge of mangrove forests
19	*Phoenix paludosa*	Jan-May	May-Aug	Elevated muddy swamps, esturaine banks, can tolerate higher percentage of salt, even found on the sea coast too
20	*Pandanus tectorius*	Sep-Nov	Nov-Marp	Littoral shrub,often found in the tidal forests
21	*Rhizophora apiculata*	May-Jul	Jul-Sep	Occur in intertidal regions of the creek in the in sheltered parts of mangrove
22	*Rhizophora mucronata*	Jul-Sep	Sep-Nov	Occur in intertidal banks of creeks or in estuaries
23	*Rhizophora stylosa*	Jul-Sep	Sep-Nov	Often found in mid to low intertidal and downstream tidal creeks; grows in a variety of habitats and disrupted mangrove areas. One distinctive niche is its ability to grow on edges of small coral islands, establishing on the coral substrate.
24	*Scyphiphora hydrophylacea*	Mar-Aug	Mar-Aug	Along mangrove creeks
25	*Sonneratia alba*	Mar-Jun	Jun-Sep	Occurs along the mouth of tidal creeks, grows on sandy or rocky soil

Sl no	Species name	Phenology		Habitait
		Flowering	**Fruiting**	
26	*Sonneratia ovata*	Mar-Jun	Jun-Sep	Often occurs on the landward edge of mangrove swamps in brackish water and muddy soil.
27	*Xylocarpus granatum*	Throughout the year		Occur in the sheltered banks in association with Kandelia candel, Rhizophora sp and Sonneratia alba

Pehonology and habitat description is as per Ref. [62].

Table 3.
Phenology of mangrove and it associated species.

research are generated like role of benthic community, avian population, physico-chemical and biological parametric studies, etc., in TCWs.

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Conflict of interest

None.

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Section 2

Ecosystem Services

Chapter 4

Environmental and Education Trials for Mangrove Ecosystem Rehabilitation in China

Ruili Li, Minwei Chai, Xiaoxue Shen, Cong Shi, Guoyu Qiu and Takayoshi Koike

Abstract

Based on Chinese ecological policy, we have been studying mangrove ecosystems in southern China, especially from the perspective of pollutants deposition in mangrove wetlands, physiological ecology of mangrove species on the impact of heavy metal pollution and seeking ecosystem restoration. For these, we explored in three aspects: 1) pollutants distribution and ecological risk in main distribution of mangrove, China, 2) eco-statistics and microbial analyses of mangrove ecosystems (including shellfish) in representative locations where mangrove plants are well developed, especially in Shenzhen, a rapid developing economic city in Guangdong Province, 3) ecophysiological experiments on a representative species of mangrove for evaluating combination effects of major nutrient elements and heavy metal pollution on growth and physiological responses of the seedlings. Based on the results, we proposed how to rehabilitate mangrove ecosystem in China under rapidly changing environmental conditions, with a view to our future survival and to provide nature-based solution as well as the public with more ecosystem services.

Keywords: ecosystem, wetland, pollution, restoration, subtropical mangroves, nature based solution

1. Introduction

Well-developed mangrove forest in southern China has increased their values of environment, eco-tourism resources, and conservation of biodiversity, etc. [1–3]. Mangrove ecosystems are also expected to provide many ecological services: (1) provisioning, (2) regulation, (3) culture, and (4) basic service [4, 5]. Basic service, i.e., means primary productivity of plants, soil formation and nutrient cycling, etc. The rest services are depending on basic services. Therefore, ecophysiology of mangrove is the most fundamental and essential information for this chapter.

In terms of ecological functions, mangroves can provide (1) many foods including fish, shellfish via offering their habitats, dye materials, wood and materials for high quality charcoal, etc., (2) maintain marsh ecosystems: soil conservation, reduction of storm disasters, wave attenuation, acceleration of reclamation, contaminant degradation, clean the atmosphere and marine environment, (3) eco-tourism, culture, scientific resources, etc., (4) CO_2 fixation and O_2 evolution, biomass production, nutrient circulation [6]. However, an increase of anthropogenic activities in coastal areas reduced mangrove cover and functions, with environment deterioration to be important factor, such as pollution caused by heavy metals. Recent degradation of mangrove functions, such as offering habitat for many living organisms is also reduced by persistent organic pollutants (POPs) including micro-plastics (MPs), etc. [7–9].

In China, large area of mangroves mainly distributed in six provinces (Zhejiang, Taiwan, Fujian, Hainan, Guangxi, and Guangdong), and two special administrative regions (Hong Kong and Macao). There were 37 mangrove species, representing 20 families and 25 genera, with thermophilic eurytopic species being the dominant components [10]. Mangrove could accumulate various pollutants derived from rivers and tidal waters due to its unique properties, such as high productivity, organic-rich matter scrap, fine grains of wetland soil, and anoxic environment [11, 12].

Pollutants like heavy metals and organic contaminants are generally toxic and persistent in mangrove ecosystems. In estuarine mangroves of New Zealand, the soils were characterized with lower Eh and currents upstream trapped more macro-nutrients and heavy metals compared to downstream [13]. In Southeast Sulawesi of Indonesia, mangrove species significantly bioaccumulated heavy metals (such as Cu, Hg, Cd, Zn, and Pb), with different partitioning and uptake capacity of heavy metals to be detected in tissues of mangrove species [14]. Marchand et al. (2011) explored the relationships between heavy metals and organic matter cycling in mangrove sediments of Conception Bay, New Caledonia [15]. Currently, various pollutions caused by anthropogenic activities are well recognized in mangrove in Shenzhen, the most rapidly developed city in China [16, 17]. Especially, Futian mangrove in Shenzhen has been recognized as one of the most typical urban mangroves located in a big city (**Figure 1**), which has been receiving more and more attention. Shenzhen municipal government has decided to keep their environment in order to achieve the sustainable development goals (SDGs) and adopt mangrove as the iconic plant.

Figure 1.
Futian mangrove located in the center of Shenzhen, China (http: //mcf.org.cn/mobile/).

In this chapter, first, we briefly summarized the history of studies in East Asia; then, we take China as an example to explore current progress in mangrove management and research: i.e. heavy metal distribution and ecological risk in mangrove sediment, as well as POPs (such as polybrominated diphenyl ethers). POPs could affect photosynthesis via belowground root vigor and function, and transfer along food chain/web to bio-accumulate [18]. Thirdly, the status of education effect of mangroves in China, especially for Shenzhen was stated. At last, the future perspective of mangrove research in China was provided. These mangrove functions under current and rapid environmental changes in China may provide a hint of conservation and restoration of mangrove ecosystems in the rest of the world.

2. Brief history of mangrove studies in East Asia

In recent years, intensively research have been conducted on the productivities of mangrove forests in tropical and sub-tropical areas of southeast Asian countries, including Indonesia, Philippines, Thailand, and southern Japan, etc. [19–22]. As a contribution to the IBP (International Biological Program), we globally estimated the biomass productivity of different types of vegetation and ecosystem. This IBP is dedicated to human survival from the perspective of biomass production as well as conservation of biodiversity including local people's lives [23–25]. In this project, general empirical models for estimating above-ground biomass, especially universal equation for root biomass was developed (**Figure 2**) [26].

Mangrove plants are characterized by their unique growth characteristics [28]. They can grow and develop along with brackish region of estuaries, wetlands and sea-shores, and are well-known as "marine forest." Furthermore, the growth of mangrove plant would be affected by other climate factors. For example, from dendrometer monitoring of the diameter growth of *Avicennia alba* growing at brackish region, a pioneer species in east Thailand, diameter growth increased with flooding of fresh water during rainy season [26]. In fact, "annual" ring was found in this species even though *A. alba* grows in western Mahachai bay, Thailand (tropical region without any clear dry season) [29] . This species may use intensively fresh

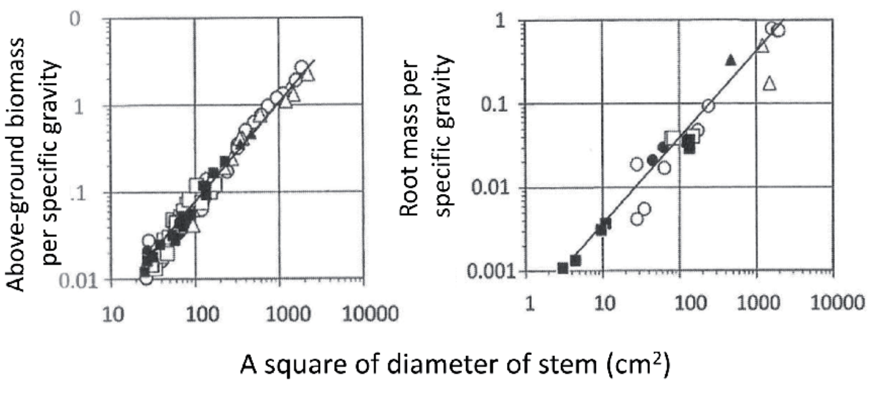

Figure 2.
Universal allometry equation of above- and below-ground biomass of mangrove forests in Asia (Adopted from Komiyama 2017 [26] modified Komiyama et al. [23] and Komiyama et al. [27]. Sampling; ○: Rhizophora *sp. at south Thailand ● n of above- and below-ground bioma △:*Rhizophora *sp. at east Indonesia, ▲: The other species at east Indonesia, □:* Rhizophora *sp. at east Thailand, ■:* Rhizophora *sp. in east Thailand.* $W_{top} = 0.251\ sD^{4.46}$; $W_{root} = 0.199\ sD^{2.22}$.

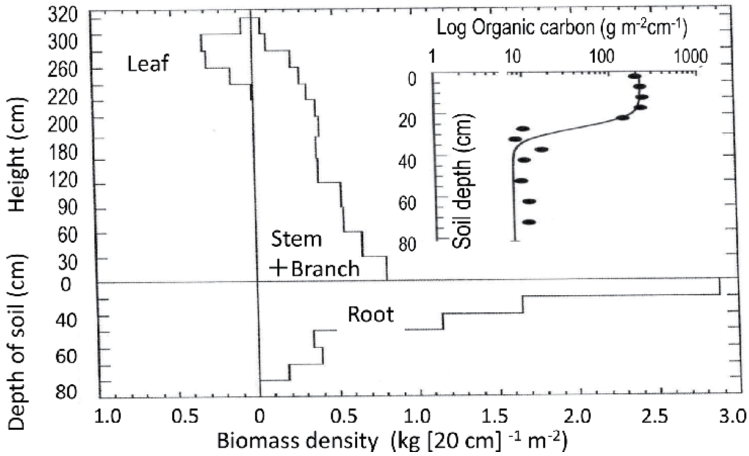

Figure 3.
The stratification diagram of a mangrove stand at the northern boundary in the Ryukyu islands, south Japan (Adopted from Hagihara [35]).

water for its growth. These areas are usually zoned by different species of mangrove depending on their adaptive traits in salt tolerance [30–33] and light utilization characteristics of each species [34]. Mangrove species grow in the front of seashore are light demanding type while a component of well-developed stands is low-light utilization type based on chlorophyll fluorescence.

Hagihara (2006) reviewed production ecology and carbon cycling of mangrove stand (*Kandelia obovata*) in the Ryukyu Islands (**Figure 3**): i.e. northern limit for the distribution of mangrove plants in Japan [35]. This species is very popular in China for ecological study [26, 32]. Hoque et al. (2011) found that Top/Root (T/R) ratio of *K. obovata* in Manko wetland, Okinawa, Japan was around 1.87 [36].

Generally, T/R ratio of mangrove stands was around 1.0 [26, 37] whereas it is ranged between 3 ~ 4 for most forests. From the stratification diagram, estimated value of the extinction coefficient (K_F) including branches for *K. obovata* stand was 0.50. The K_F was 0.56 ~ 0.69 for *Bruguiera gymnorhiza* stands in Ryukyu Islands, 0.54 ~ 0.57 for *Rhizophora apiculate* in Thailand. K_F values of deciduous conifer larch (Larix kaempferi), evergreen oak (*Quercus phillyraeoides*) and Hinoki cypress (*Chamaecyparis obtusa*) were 0.31, 0.36, 0.67 and 0.37, respectively. Thus, compared with other plants, *K. obovata* stand can make good use of incident sunlight in their canopy with their photosynthetic capacity [37].

People recently have again recognized that mangroves have played an important role in preventing Tsunami tide wave after earthquakes in Indonesia, which lead to tsunami in Southeast Asia and cause huge losses and casualties to Southeast Asian Countries, particularly Indonesia [38, 39]. In fact, the mangrove stands along with seacoast of Indonesia protected and lessened destructive power of tide wave at the time [4]. In China, though very few typical examples were available for weaken effect of mangrove on tsunami, the storm prevention of mangrove is one important aspect of mangrove ecosystem services, which have been evaluated to be 10473.3×10^4 RMB in terms of energy value [40].

Recently, due to our concern that global warming will cause rapid rise in sea level, new aspects of salt resistance (tolerance and avoidance) of mangrove species has been studied intensively [33, 41–43]. Sea level rise would increase tidal inundation period and make mangrove species beyond the specific thresholds of flooding tolerance [44, 45]. With intense environmental change, the related knowledge about mangroves have also been systematically summarized through publish of revised editions of botanical books on mangroves as well as ethnobotanical books [31, 32, 46, 47]. On the other hand, researchers recognized the impact of polluted water caused by anthropogenic activities on growth of mangrove plants, without paying much attention to negative impact of heavy metal pollution on mangrove ecosystems [26, 31, 46, 48].

The exploration on heavy metal pollution in mangrove wetlands would understand the source, history, and status of heavy metals, and obtain the relationship between heavy metals and mangrove ecosystem, which is important for coordination between economic development and environment protection. With positive leadership of Chinese ecological policy [49], we have been studying on heavy metal pollution, such as mercury (Hg), cadmium (Cd), copper (Cu), and its counter effects on physiology and growth of the representative mangrove plants dominated around southern China. A typical example of pollution is an intensive study on mangrove ecosystems in Shenzhen city where is located north of Hong Kong, one of the most dramatically developed cities in China. Shenzhen City has decided to adopt mangrove plants as the symbolic trees and well organized ecological and environmental education by establishing mangrove museums and field education parks [7]. Environmental education trail will also be briefly discussed in latter part of this review.

3. Mangrove management and research in China

3.1 Mangrove management

Mangrove species in China belong to the Indo-Malaysia Northeast subgroup of East group and covered >50,000 ha in 1950s [47]. Before 1990s, mangroves in China had been degraded and the areas greatly reduced, with only 22,752 ha remained [47]. Furthermore, mangrove ecological exploitation in China existed many problems, including imbalance between protection and utilization, simple ecological development mode, low economic benefit of ecological development, planning management and related policies and insufficient regional cooperation. Since then, increased government investments have greatly improved the research on mangroves in China.

In 1995, China's Biodiversity Conservation Action Plan included the action plans, which called for "Increasing mangrove conservation areas". As a result, majority of the national mangroves have been protected as a part of the national wide mangrove nature reserves (**Figure 4**). On the announcement of the leader Mr. Xi Jinping, one of the Chinese ecological policies orients us how to conserve mangrove forest as an ecological unit [49]. Based on this statement, conservation of mangrove ecosystem is one of the national key projects, especially at Fujian and Guangdong Province, especially Shenzhen city government, the most rapid developing economical city in China.

Over the past decades, large number of studies have significantly improved our understanding of structure and function of the mangrove ecosystems, however, there are still many areas needed to be strengthened: (1) The construction of sea walls plus many skyscrapers behind natural mangrove wetlands may prevent migration landward into areas of higher elevations in response to sea level rise; (2) Biological invasions such as those of *Spartina alterniflora* may compromise habitats. Their invasive mechanisms and efficient measures for controlling such invasion is still unclear; (3) There is still a lack of universal standard system for evaluating the efforts and achievements of mangrove afforestation and restoration in China; (4) Cooperation among related mangrove research institutions should be strengthened to ensure successful conservation, restoration of mangroves in China.

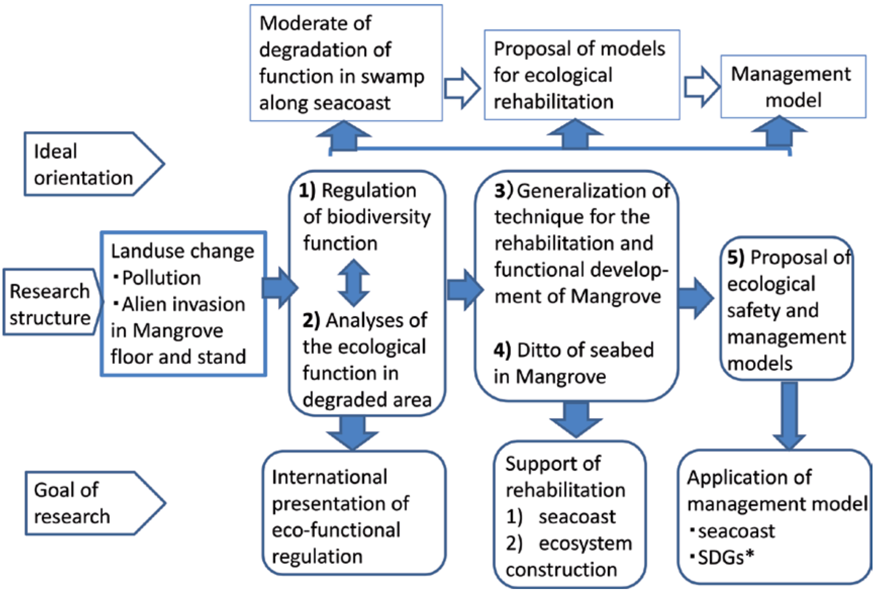

Figure 4.
A Flame work of conservation strategy of mangrove ecosystem in China proposed by Dr. Hailei Zheng at Ningde, China in 2019 [49].

3.2 Mangrove researches

Since 1970s, mangrove researches in China have mainly focused on taxonomy and ethno-botanical view point, medical use and practical use of mangrove plants [6, 50, 51]. According to uncompleted statistic, China researchers have published 24 monographs or proceedings related with mangrove, including comprehensive basic research, ecological restoration, macro-benthos, birds, pest control, and ecological location, remote sensing monitoring and evaluation, resource management, and popular science [52]. The Shenzhen City Office strongly supports researches and education in mangrove ecosystem (see education section).

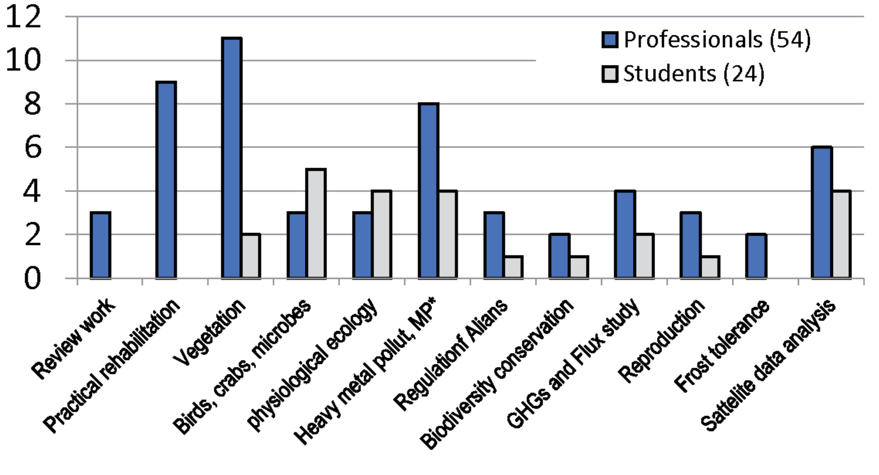

Figure 5.
Research topics on mangrove forests in Chinese Ecological Society (CES) in 2019 (Adopted from program leaflet of the meeting of CES [49, 53]).

Chinese mangrove ecologists hold workshop every two years to make further progress in mangrove researches and practical works. For most researchers, they are engaged in the topics such as remote sensing, biodiversity in mangrove ecosystems, physiological ecology, heavy metal pollutions, etc. These topics are relatively regarded as short-term target compared to those topics more professional (**Figure 5**).

At the 9th workshop in Ningde 2019 (in Fujian Province) [53], the recent ecological efforts on mangrove conservation in accordance with the SDGs (Sustainable developmental goals) was summarized as follows (**Figure 6**) [49].

The contents were: i.e. policy making, scientific review, practical forestry, and frost resistant researches, which were mainly reported by national and regional research institutes. Among them, one unique research is how to increase mangrove's frost tolerance and freezing avoidance research (**Figure 7**) [56, 57]. In 2010, sudden snow-fall caused death of newly planted mangroves because they were originally grown in sub-tropical and tropical, where there would not be a severe

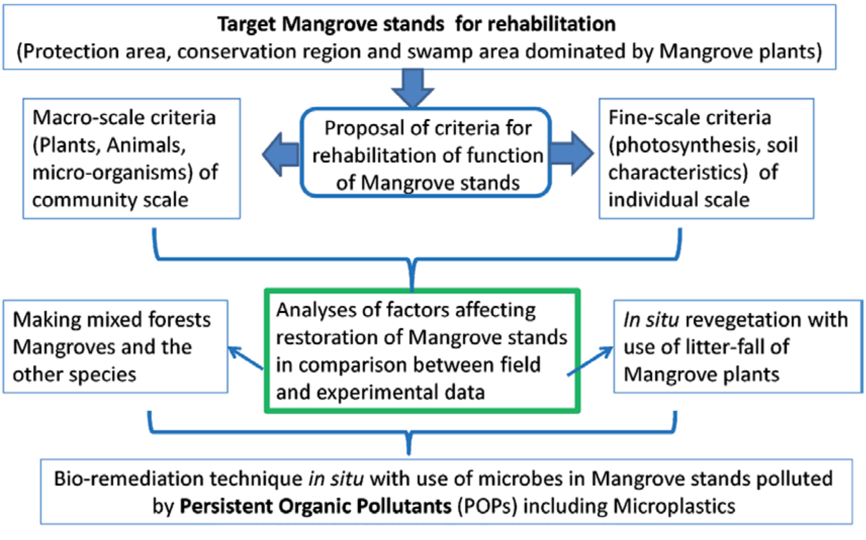

Figure 6.
Rehabilitation strategy of mangrove forests under pollution, (Adopted from the statement by Dr. Hailei Zheng, 2019) [52–54].

Figure 7.
Photos of snow on mangrove seedlings planted in Zhejiang Province, China in 2010. Left photo was offered by Dr. Jianbiao Qiu of Zhejiang Mariculture Research Institute. And right photo at nursery was offered by Dr. QiuXia Chen of Zhejiang Sub-tropical research institute [55].

low temperature environment. Glycine-Betaine was employed as a target chemical for species selection and breeding, as this compound is also common in relation to increase of desiccation and frozen tolerance [57]. Clearly, more work is needed to perform practical applications in the future.

4. Ecological statistics and diagnoses of heavy metal pollution in China

The current situation of heavy metal pollution of the southern part of China from ecological statistics was reported by Shi et al. [58]. As the first integrated analysis of heavy metal pollution in mangrove sediments across China, this study covered whole mangroves in China by selecting 6 sites including Hainan Island and near the border of Vietnam. If we focus on common mangrove species of these regions, *Avicennia marina* (characteristics: this species has pneumatophores [looks like young shoot of bamboo] for respiration in few centimeters from muddy soil) [59], the heavy metal pollution of this species shows very strong correlations in polluted condition of tideland soil (**Figure 8**).

From data of heavy metal pollution at the 6 sites, the pollution level in Futian district of Shenzhen city has higher pollution level. We detected representative heavy metal pollutants cause by high concentration of zinc (Zn), chromium (Cr), lead (Pb), nickel (Ni), arsenic (As) and relatively low concentration of molybdenum (Mo), cobalt (Co) and cadmium (Cd). Although proportion of Cd in the total heavy metal concentrations was low (based on evaluation of geo-accumulation index, contamination factor, potential ecological risk coefficient, pollution load index, and potential ecological risk index), Cd is a cause of the "Itai-itai" disease in Japan [60] and was detected as 0.66 ~ 3.30 μg/g at Futian district of Shenzhen city [61].

The factor affecting capture of heavy metal is particle size of soil with different specific surface areas and adsorption capacities [60, 61]. In fact, the heavy metal concentration was lower at Fangchenggang in Guangxi province where sand is dominant, while it was higher at Dong fang, Yunxiao and Futian district of Shenzhen where silt (between sand and clay) is dominant [62, 63]. We regarded mangrove stands, coral-reef and seaweed fauna as three major inshore marine ecosystems [1, 64, 65]. Furthermore, we explored the heavy metal pollution in Futian mangroves of Shenzhen, China. Futian mangrove is a mangrove forest area of 304 ha located in the Guangdong Province, and is the only mangrove forests located in the middle of Shenzhen, China. Futian mangrove was adjacent to the Mai

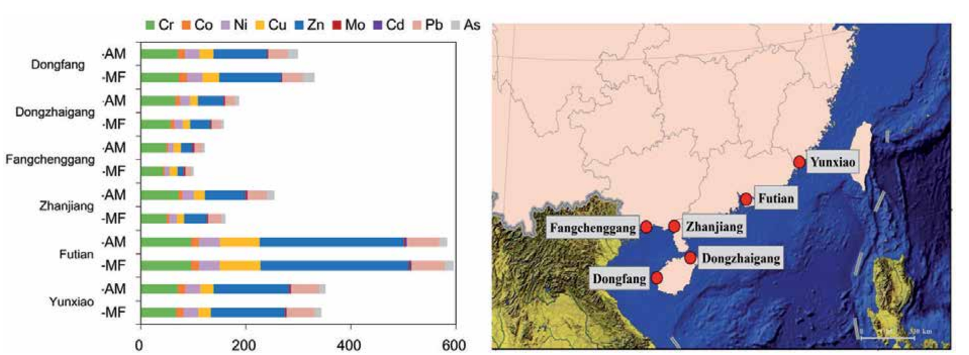

Figure 8.
Ecological statistics of heavy metals pollution in south China (AM, Avicennia marina a kind of mangrove; MF, mudflat) (Adopted from Shi et al. [58]).

Po Nature Reserve, Hong Kong, and has suffered serious heavy metal pollution since the early 1990s [62].

In order to systematically explore ecological risk of heavy metal contamination in Futian mangrove forest, being important for designing management and conservation policy, we quantify the concentrations of heavy metals (Cd, Cr, Cu, Pb and Zn) in mangrove sediments, assess the potential ecological risk and sources of heavy metals, and identify the speciation of heavy metals [66]. The results showed that heavy metal concentrations in surface sediments (0–20 cm depth) varied greatly along the coastline, demonstrating the heterogeneity of sediment to some extent. As for different heavy metal species, the concentrations reduced in the order of Zn > Cr > Pb > Cu > Cd [66]. Furthermore, the combination of studied metals had a 21% probability of being toxic, based on analysis of mean probable effects level quotient. Similarly, high heavy metal contamination was also revealed in term of potential ecological risk index and geo-accumulation index. Among all heavy metals, Cd has higher potential for adverse biological effects, being of primary concern. Take into account the sediment characteristics, clay and silt were important in raising deposition/accumulation of Cr, Cu, and Zn. As for different speciation of heavy metals, the percentage of mobile heavy metals was relatively higher than other fractions; while, no considerable ecological risk to the biota was detected in terms of the risk assessment code. The mobile heavy metals referred to the sum of acid-soluble, reducible, and the oxidizable fractions in terms of heavy metal speciation [67].

5. Ecophysiology of heavy metal resistance for mangrove plants

Mangrove plants have specific nutrient balance for growth and survival because they grow in very special environment (i.e. high NaCl, flooding environment, etc.).

Therefore, response of mangrove plants to various environmental stresses is a key information of rehabilitation of degraded regions. Cadmium (Cd), a non-essential element, can easily be taken up by plants and cause chlorosis [69], wilting [70] and cell death [71]. Heavy metals and large amounts of nutrients including nitrogen from domestic sewage also accumulate in mangrove sediment, and change its oligotrophic state [72] and pH [73]. We quantified the effects of ammonium nitrogen on the accumulation, subcellular distribution, and chemical forms of cadmium (Cd) in *K. obovata* [68]. The concentration and total amounts of Cd in leaves, stems and roots increased with NH_4^+-N supply (**Figure 9**).

In terms of subcellular distribution, Cd in roots of *K. obovata* was mainly deposited on cell wall, and the largest chemical forms of Cd was pectate and protein integrated form in all treatment. Under Cd treatments of 1 and 5 mg/L, 50 mg/L NH_4^+-N enhanced the transfer of root cell wall-combined Cd into cell, improved bioaccumulation of pectate and protein integrated Cd in cell to reduce toxicity caused by Cd. Under 10 mg/L Cd treatment, NH_4^+-N addition improved bioaccumulation of Cd on root cell wall, and limited enter of Cd into cell, which were also verified by decreased bioaccumulation of pectate and protein integrated Cd in root cell to some extent. Thus, under Cd stress, NH_4^+-N supply improved Cd immobilization in roots of *K. obovata*; the results of subcellular distribution and chemical forms showed that root cell wall combination and integration with pectate and protein acted as the mainly detoxification strategies of *K. obovata*. Plant transpiration transfer coefficient performed well in indicating the water and high temperature stress conditions plants experienced [74].

The use of chlorophyll florescence for diagnose of plant health status under stress, especially for mangrove plants is important in the rapid non-destructive

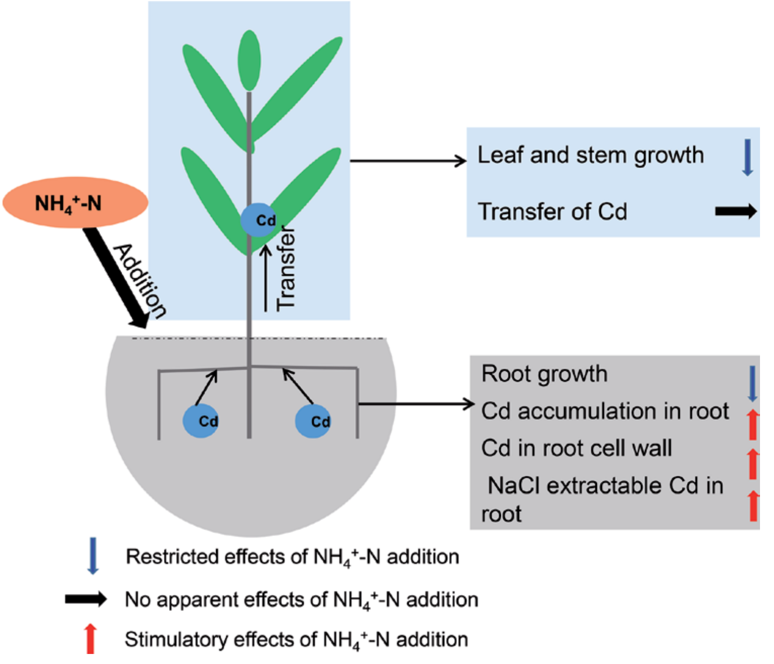

Figure 9.
The distribution of cadmium (Cd) in Kandelia obovata under nitrogen addition (Adopted from Chai et al.) [68].

assessment [34]. Physiological activity of coastal mangrove species is evaluated based on a three-temperature (3 T) model using high-resolution thermal infrared remote sensing. This evaluation method is based on growth evaluation of the representative mangrove species, *K. obovata* seedlings treated with different concentrations of Cd and nitrogen input as a simulation of environment at estuary of Shenzhen, China [75].

The cultured *K. obovata* seedlings were promoted for their photosynthesis due to the application of nitrogen, which brought a decrease leaf temperature detected by remote thermometer. In contrast, leaf temperature of *K. obovata* seedlings treated Cd increased due to stomatal closure with Cd toxicity [75]. The toxicity of Cd may be moderated by the existence of nitrogen addition, which can be clearly detected by the images from thermometer. The high-resolution thermal infrared remote sensing +3 T model is practicable for diagnosing plant health status. We should always consider synergy and antagonism in each element including heavy metals and nutritional elements [76]. Generally, the information in single metal contamination research does not reflect the biological toxicity when multiple metals are present together, with their combination toxicity having complicated mutual interactions on plants [77].

Furthermore, the interactive effects of multiple heavy metals (Cu, Pb, and Zn) on growth of *K. obovata* were studied, including plant biomass, photosynthetic parameters, lipid peroxidation and compatible osmolytes [78]. The results showed no significant reduction of biomass under heavy metal stresses, except for decreased root biomass under higher Pb + Cu treatment. This evidence indicates that *K. obovata* is highly tolerant to heavy metal stress. With increasing heavy metal stress (except for Pb + Cu and Pb + Zn + Cu), the photosynthetic parameters detected by a potable porometer (LI-6400; NE, USA) (net photosynthetic rate [Pn], transpiration rate [Tr], and stomatal conductance [Gs]) decreased at ambient CO_2 concentration (about 400 ppm) [75].

Compared to external binary metal treatment, trinary treatments (Pb + Zn + Cu) improved plant biomass and the photosynthetic capacity. As for root of *K. obovata*, binary treatment reduced biomass and soluble sugar content compared with ternary treatment. These results showed that in Pb combined treatments, the combination of Zn and Cu improved alleviating toxicity than each of them alone. Malondialdehyde (MDA) can reflect the degree of cell membrane lipid peroxidation and plant response to stress conditions [79, 80].

In leaves of *K. obovata*, Zn-containing combined treatments significantly reduced MDA, soluble sugar, and proline content under low concentration, demonstrating antagonistic effects; while, Pb + Cu treatments significantly promoted these parameters, indicated synergistic effects. Furthermore, there were negative correlations between leaf MDA and proline content with Zn concentration ($P < 0.05$). Leaf MDA content was positively correlated with the osmotic parameters, indicating co-existence of osmotic stress and lipid membranes oxidation under multiple heavy metal stresses. Thus, as for *K. obovata*, the toxicity caused by multiple heavy metals could be indicated by responses of leaf biomass, Tr, leaf MDA, leaf proline and soluble sugar [75, 78].

6. Evaluation of mangrove ecosystem: microbes and shellfish

6.1 Microbe in mangrove sediments

At the ecosystem level, mangrove plants, microbes in the soil, any other living organisms, and their natural environment cooperated with each other [3, 81, 82]. There are many places in mangrove stands producing sulfate compounds (e.g. hydrogen sulfide, H_2S). We can identify the smell of H_2S, implying importance of sulfate producing microbe activities. In the field conditions, heavy metal accumulation is important environmental factor regulating bacterial communities [83, 84]. Sulfate-reducing bacteria (SRB) could utilize sulfate as an electron acceptor in the dissimilatory reduction of sulfate [85]. How about the impacts of heavy metals pollutant on SRB? The effects of heavy metal contamination on sulfate-reducing bacteria (SRB) with both field survey and experimental approaches have been revealed [3]. SRB communities were investigated in mangrove sediments (0–30 cm depth) from 3 districts of mangrove wetlands in Shenzhen with different heavy metal contamination levels.

The results revealed that SRB community abundance was correlated with depth of mangrove sediments, especially significant correlation was found in soil concentration of Cd and Ni concentrations. From 1980 to 1990s, almost no analysis was done from the view point of biodiversity [81]. The α-diversity index of SRB community was significantly correlated with Cd level in mangrove sediments. Dominant 3 SRB groups (Desulfo-bacteraceae, Desulfobulbaceae, Syntrophobacteraceae) were isolated in the mangrove sediments of Shenzhen mangrove, China [3]. Among these families, Syntrophobacter-aceae was most sensitive to heavy metal contamination. The Unifrace clustering analysis revealed that SRB community structure was influenced by heavy metal stress. Moreover, redundancy analysis (RDA) indicated that Cd and total phosphorus were the major element affecting the SRB structure in the mangrove sediments [3].

Generally, the structure of mangrove sediment bacterial community could be affected by various factors, including plantation species [86], sediment depths [87], physico-chemical properties of sediment [88], and anthropogenic activities [87]. Different mangroves might reveal the specific biogeographic distribution pattern of bacterial community [89]. We explored the biogeographic distribution of sediment bacterial community in six mangroves across China, including two mangroves in Hainan Province, two in Guangdong Province, one in Guangxi Province and one in Fujian Province [90]. Among all six mangroves, the sediment bacterial demonstrated different characteristics in terms of bacterial abundance, bacterial richness and diversity, and bacterial community structure. Compared with intertidal mudflat, *A. marina* planted zone improved sediment bacterial abundance, richness, and diversity. Furthermore, *Proteobacteria* acted as the largest bacterial phylum in sediments in both intertidal mudflat and *A. marina* planted zone. Therefore, the biogeographic distribution of bacterial community across six mangroves in China was driven by variable wetland tropic status and other physicochemical factors (such as salinity) [90].

In mangrove sediment, *Archaea* sp. played important role in biogeochemical processes, such as ammonia oxidation [91] and methanogenesis [79]. Understanding biogeographic distribution pattern can be helpful to increase the knowledge of microbial function and to predict ecosystem responses to environmental variability [89]. We explored the effect of geographic location on mangrove archaeal community in six mangroves of China [92].

In different geographic location, mangrove archaeal have different community characteristics, which might be related to various environmental factors, including pH, carbon, and nitrogen contents in sediment. Furthermore, the main archaeal communities in mangrove sediments were genus *Thaumarchaeota* and *Euryarchaeota*, with their percentages to be 54.7–85.2% and 11.8–43.9%, respectively. This work would be useful for understanding the characteristics of archaeal community in mangrove ecosystem, which may provide new insight for exploring microbial function and ecosystem responses to variable environment.

6.2 Shellfish as food resources

Shellfish is an important component in mangrove ecosystems similar to well-known crabs [32]. Recently, people have eaten more shellfishes as healthy food than before; however, the bio-accumulation of heavy metals in the shellfish can endanger the health of consumer [93]. Shenzhen is a fast-developing city in south China, and has been developed from a small fishermen village to a modern metropolis with about 12 million populations since the reform and opening policy in 1978 [94].

A case study on 3 markets of Shenzhen has received increasing attention. Arsenic (As), Cd, Cu, Hg, and Pb in 10 popular shellfish species and associated health risks were analyzed for Shenzhen's consumers by evaluation of estimated weekly intake (EWI), non-carcinogenic and carcinogenic health risks to the 3 stages in a human life-cycle (children, adolescents, adults) [95]. Based on 50 shellfish samples in each site of market there, they found that the levels of inorganic arsenic (iAs) in *Babylonia areolata* exceeded the maximum permissible-limit decided by the food safety guidelines (0.5 mg/kg), while other elements were below the limit of the guidelines as shown in Ministry of Health of the PR. China: GB 2762–2012. EWI values of the 3 stages of human development were lower than provisional tolerable weekly intakes (PTWIs) of all shellfish species. Analysis of the total target hazard quotients (TTHQ) showed that the consumption of *B. areolata* in all stages of people would cause non-carcinogenic risks; as for children (< 10 years old), the ingested *Argopecten irradians* and *Chlamys farreri* were at non-carcinogenic risks. As for children, adolescents, and adults, the bioaccumulation of Cd caused by shellfish consumption (*A. irradians, B. areolata, C. farreri*, and *Crassostrea ariakensis*) would lead to cancer risk during life-time, with Pb and iAs to be toxicity acceptable or negligible [96].

From the perspective of species, the concentration of Zn and Cu in the *C. ariakensis* was the highest, the concentration of Cd in *C. farreri* was the highest, and the concentration in the *Sinonovacula constricta* was relatively low. From the regional differences, Cd content in *C. farreri* of Dandong was the highest; the overall concentration of heavy metals in Qingdao was relatively low; Cu and Zn concentration in *C. ariakensis* and Cd concentration in *C. farreri* of Zhoushan were relatively high; Zn and Cu content in *C. ariakensis* of Shenzhen was the highest. The calculated daily intake-limit-results show that the feeding rate in the *C. farreri* only is 0.04 ~ 0.15 kg/d to reach the limit of Cd, and the feeding rate of Zn, Cu and Cd in the *C. ariakensis* is less than 1 kg/d can reach the limit value.

The results of the risk assessment showed that the weekly intake of heavy metals by eating shellfish did not exceed the provisional tolerable weekly intake set by Joint Expert Committee on Food Additives (JECFA*, *JECFA, 2010. Joint FAO/WHO Expert Committee on Food Additives, Summary and Conclusions by the JECFA.), and there was no non-carcinogenic risk to the human body. However, in terms of the long overdose of all sampling points of the *C. farreri* and *C. ariakensis* in Dandong, the accumulated Cd has a potential carcinogenic risk to the human body.

7. Persistent organic pollutants (POPs) in mangroves of China

Overuse of POPs like plastic bags pollutes mangrove stands and POPs are hardly decomposed in mangrove ecosystems and consequently degrade habitat for most living organisms in a mangrove stand. The value of mangrove environment is getting worse by accumulation of the POPs, therefore, we should know the effect of POPs on mangrove plants as well as ecosystem for improvement of rehabilitation strategy of degraded mangrove stands.

7.1 Microplastics

Microplastics (MPs) researches have been mainly investigating on food-web and bioconcentration in Japan [97]. For example, in Tokyo Bay, the bowel of several kinds of seabird, sardine, etc. contains huge amount of MP. In detail study on a kind of seabird (*Puffinus tenuirostris*), this bird cannot eat foods due to full with MPs in the bowel. Much worse, the accumulated MPs in their stomach gradually release toxic substances [98], such as PCB. Now, if we eat such polluted sardine, our health condition would not be injured. However, we cannot deny the harmful effects of PCB and related toxic substances in MPs.

MPs are now worldwide serious problem [97, 99]. MPs have a long life-span in ecosystem and become smaller in size of less than 5 mm over time, and deposit toward deep sea [9]. The existence form of MPs in south China was classified as fiber, film, and fine particle with several colors of original products [99]. At the 6 mangrove stands located along the coast of Southern China, the top 3 MPs were detected as health safety substance, including polypropylene (PP), polyethylene (PE), and polystyrene (PS). In terms of shape, color and size, MPs were mainly fibrous, white-transparent and 500 μm-5000 μm, respectively. MPs pollution in mangroves was significantly linked to surrounding socio-economic development. The TOC and silt content of mangrove sediments also affect the deposition of MPs [99]. Based on a comprehensive evaluation using the potential ecological risk factor, potential ecological risk, polymer risk index and pollution load index, MPs showed highest ecological risk in Futian mangrove of Shenzhen, China. These fundamental data on MPs occurring in mangroves of Southern China could support further studies of the ecological consequences of MPs on mangrove macro-fauna, shrimp, fish and even human.

7.2 Polybrominated diphenyl ethers (PBDEs)

Unfortunately, polluted condition with MPs of mangrove forest is getting worse in Shenzhen. As harmful MPs, PBDEs (polybrominated diphenyl ethers) have recently been detected. PBDEs are structurally similar to PCBs and other polyhalogenated compounds. Exposure to PBDEs would cause problems in the hormone system, liver and kidney morphology, neuro-behavioral and sexual development [100, 101]. The health risk of PBDEs and PCBs are increasing, and these chemical compounds have been shown to reduce human fertility to some extent [97]. The amount of PBDEs in a mangrove ecosystem increases with increasing amount of organic matters in soil [95, 102]. Concentration [unit: ng/g-dw] of PBDE-209 in mangrove stands of Hong Kong was 0.5 ~ 5.4 except for Mai Po mangrove (47.2–112.0) opposite to Futian district of Shenzhen [103]. These values were lower than those of Shenzhen (2.1–1987.6) [102].

In Shenzhen mangroves, the levels of PBDE-209 [unit: ng/g-dw] were 2.1 ~ 110.0 in mangrove sediment and 180 ~ 600 in the leaves. The highest value was detected as 3600 in bark of the avenue trees in Beijing [104]. We found that PBDE-209 was the dominant PBDE congener in all six mangroves in China, including Yunxiao, Futian, Zhanjiang, Fangchenggang, Dongzhaigang and Dongfang [5]. Futian mangrove in Shenzhen was seriously polluted by PBDEs (in particular PBDE-209), compared to the other 5 mangrove wetlands. Total organic matter acted as an effective factor in affecting spatial distribution and ecological risk of PBDEs in sediment of mangroves. In 6 mangroves, sediments may pose low/moderate risk of exposure to penta- and deca-BDE congeners for sediment-dwelling organisms, with penta- and deca-BDE congeners to be major drivers of ecological risk. Furthermore, we explored PBDEs contamination in 4 urban mangroves of Shenzhen, including Shajing mangrove (SJM), Xixiang mangrove (SJM), Futian mangrove (FTM) and Baguang mangrove (BGM) [102]. Regarding urban functional zoning, urban mangroves were featured with industry district (SJM and XXM), central business district (CBD) (FTM), and ecological preserve (BGM) [105–107]. Our result showed that the ranking order of PBDEs contamination in urban mangroves was BGM ≈ FTM < XXM < SJM.

Compositions of PBDEs were complex in SJM, XXM, and FTM, with surface runoff to be the main source apportionment of PBDEs. Thus, in urban mangroves with different urban functional zonings, PBDEs accumulation in mangrove sediment and their bioaccumulation in mangrove plants were different. In the future, much work should be done to decrease e the input of PBDEs into the urban mangrove, such as the inspection of the illegal waste recycling sites and promotion of sewage treatment capacity of PBDEs-related enterprises.

7.3 Other POPs

Levels of polycyclic aromatic hydrocarbons (PAHs: unit: [ng/g-dw]) in mangrove sediments of China ranged from 15 to 11,098 and decreased in the order of Hong Kong (56–11,098) > Fujian (171–1074) > Guangdong (15–726) > Hainan (31–63) > Guangxi (24) [11, 12, 108]. Higher levels of PAH s in Hong Kong mangrove might be attributed to the intense anthropogenic activities. Levels of PAHs in mangrove sediments of China (24–11,098) were far below effects range mean (ERM) (44,792), with levels of PAHs in Hong Kong to be lower than effects range low (ERL) (4022), indicating that PAHs in Hong Kong may pose little risk to biota in mangrove ecosystems [63, 108]. Li et al. (2014) explored PAH pollution in sediments of three mangrove swamps of Shenzhen, China, namely Futian, Baguang and Water-lands, and found that the mean concentrations of PAHs in Futian (4480) was higher than that in Baguang (1262) and Watersheds (2711) [109]. The higher levels of PAHs in Futian mangrove may be related to various anthropogenic activities, such as continuously discharges of domestic sewage from households and Fengtang River, effluents from industrial processes, construction of highways and heavy traffic [48].

In China including Hong Kong, Guangdong, Guangxi, Hainan and Fujian, levels of polychlorinated biphenyls (PCBs) in mangrove sediments ranged from 0.1 to 47 ng/g dry weight [110–113]. In general, PCB concentrations in mangrove sediments from Hong Kong, Shenzhen, and Zhuhai were relatively higher, indicating heavily PCBs-polluted mangrove sediments in the Pearl River Estuary to some extent [114]. The higher PCB levels in sediments from Pearl River Estuary could be linked to high density of electronic/electrical industries and electronic waste recycling activities [110].

Other organic pollutants in mangrove sediment were limited. Total petroleum hydrocarbons (TPHs) in sediments were reported to be 32–579 mg/kg-dw and a higher level was observed in the Pearl River Estuary, China [82, 115], which mainly derived from vehicle exhausts and incomplete combustion [82, 88]. Tam et al. (2008) reported that the levels of dichlorodiphenyltrichloroethanes (DDTs) and hexachlorcyclohexanes (HCHs) were 28 and 0.07 ng/g-dw in Leizhou Peninsula [116].

8. Education effort

8.1 General effort

Although Chinese ecological policy was proposed, ecological and environmental education should be made for conservation and increasing ecological services of mangrove forests [31, 98, 117]. In China, the environmental education mainly focused on the popular science and propaganda of mangrove reserve and park [97, 118–120]. Since there are multiple education stations in China, we show an example of Shenzhen because mangrove species are applied as the symbolic woody plants for the city. The City Hall shows SDGs (sustainable developmental goals) to the public with both ordinal (indoor type) museum as well as field museum (outdoor type). The former exhibits basic information of mangrove ecosystem by indoor exhibition. The latter mainly shows 2 parts; one is a practical method of how to rehabilitate mangrove stand at water front and the other is to conduct ecological research, including pollination biology, vegetation, etc.

8.2 Indoor and outdoor exhibition

Shenzhen shows all aspects of mangrove conservation and the latest advances in natural education at the city museums. The museum is unique in interactive exhibits, such as many educational quizzes about how to develop mangrove forests as well as to conserve the ecosystem. There are two field museums on the coast of Shenzhen: (1) one is a kind of park to walk in mangrove stand along with the interior experience of different species of forest stands, and (2) the other is to show the ecological rehabilitation of mangrove stands (**Figure 10**).

Figure 10A showed the rehabilitation of mangrove stands in Futian mangrove in Shenzhen. In order to improve ecological function of mangroves [121], the rehabilitation of Geiwai pond in mangrove ecosystem was conducted (**Figure 10B**). Among

Figure 10.
Example of mangrove ecosystem rehabilitation in south China. (A) Rehabilitation of mangrove stand; (B) Rehabilitation of Geiwai pond of mangrove ecosystem; (C) Typical example of mangrove ecosystem plantations by Prof. Changyi Lu of Xianmen University.

these trails, a distinguish exhibition for both tourists and education of mangrove park was established and popular trees were provided to the public near Xiamen, Fujian province, southeast China (**Figure 10C**). The star shaped mangrove restoration indicated that suitable mangrove species selection and planting design would create a beautiful landscape. This is a park showing a symbol of restoration success with mangrove.

8.3 Non-Government Organization in education effect of mangrove

The protection of mangrove in Shenzhen was closely related with large amounts of non-governmental organization (NGO) and volunteer groups. In 2017, the number of professional volunteers registered in Mangrove Conservation Foundation (MCF) exceeded 300, with 198 newly trained volunteer in one year, and 100,000 people participated in relevant activities in three years. In Shenzhen, China, the above-mentioned citizen acted as the volunteer labor group for Futian mangrove ecological park. These volunteers mainly come from enterprise, residence community and school, and took part in various environmental improvement activities,

Figure 11.
Activities carried out by nongovernment organizations. (A) Marine protection activity; (B) vein painting of popular science education; (C) display board of natural education. All photos were offered by RL Li and MW Chai.

including cleaning of invasive plants, collection of marine garbage, replantation of plant, and construction of ecological floating island, etc.

The implication of these activities increased volunteer number of mangrove protection in Shenzhen. Furthermore, there were also a certain number of volunteers in Overseas Chinese Town (OCT) wetland, Shenzhen Green Fund Association, Shenzhen Spring Environmental Protection Volunteer Association. Some activities related with mangrove education was implicated to improve protection awareness of mangrove protection (**Figure 11**).

9. Future perspective

Anthropogenic pollution in mangrove ecosystems has been intensively studied (including heavy metals and POPs, etc.) and consequently we can obtain many phenomena of current situation, such as sea level-rise [27, 122–124]. Based on the data of mangrove ecosystems in China, we should make further progress in increasing ecological services and forest rehabilitation. In the future, we believe that several aspects should be further explored to improve mangrove afforestation and restoration: (1) Ecological adaptation mechanism of mangrove species under various environmental stresses; (2) The development of mangrove plant breeding and colonization techniques; (3) The remediation of degraded mangrove ecosystem; (4) Digital technology research and development in mangrove ecological engineering.

Ecological exploitation of mangrove would create better ecological environment, economic and social benefits, being important for sustainable development of mangrove resource in the future. Several countermeasures are included to engage ecological exploitation of mangroves: coordinating development and alleviating the contradiction between protection and development; promoting diversified ecological development based on local conditions; improving the economic benefits of ecological development by scientific evaluation; improving relevant policies and plans while promoting regional cooperation and scientific research. We hope our data may contribute for improving restoration practices in the rapid economic development regions.

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Chapter 5

The Commercial Value of Mangrove-Based Pigments as Natural Dye for Batik Textiles

Delianis Pringgenies, Ali Ridlo, Lutfianna Fatma Dewi and Ali Djunaedi

Abstract

Mangrove, or bakau as it is known in Indonesia, is one of the vegetations commonly found along the shallow coasts, estuaries, deltas and protected coastal areas and are still influenced by rising tides. After the Aceh tsunami disaster, mangrove restoration was intensively conducted in coastal areas all over Indonesia and was made into a special conservation program by the government. Mangrove is distinguishable by its big, wooden stilt roots, sharpening tip in the form of supporting leaves. The roots of the mangrove tree are morphologically distinguishable into heart root which grows into the ground and the stilt root which appear to grabs onto the surface of the ground. Mangrove forests serve several important ecological roles: they act as filters which turns saline water into fresh water, buffer from seawater intrusion, prevent erosion and abrasion, hold sediments to form new habitats, feeding ground, nursery ground, and spawning ground for a number of aquatic wildlife. Mangrove forest also possess economical functions such as as source of income, industrial ingredients for the locals and as source of new mangrove seedlings. Mangunhardjo Village, Urban Community of Mangunhardjo, Mangkang Area, Kecamatan of Tugu, Semarang City, Indonesia was an area dotted with brackish water pond. However, the area had been suffering from the effects of climate change, being inundated by overflow of river and seawater intrusion (rob). These disasters caused decline in the productivity of the ponds in the area. In an effort to combat the adverse effect of environmental change in the area, the locals of Mangunhardjo village decided to shift their livelihood by restoring the surrounding mangrove forest. Mangrove conservation at Mangunhardjo Village was conducted through activities of the program such as mangrove planting, mangrove-based food production, and mangrove waste management by applications of bioactivator bacteria for mangrove composting and production of mangrove-based natural dye for batik fabric. Mangrove-based natural dye for batik fabric from *Rhizopora mucronata* mangrove waste is a quite promising product and increases people's income.

Keywords: batik, mangrove, natural dye, *Rhizopora mucronata*, waste

1. Introduction

One of the most valuable and potential natural resources in coastal areas of Indonesia is the mangrove forest. With a coastal line exceeding 80,000 km, Indonesia possesses 4.2 million ha total area of mangrove forest [1]. In 2014, the total coverage area of mangrove forest in Indonesia is 4,227,800 ha, which comprises approximately 25.79% global coverage area of mangrove forest [2]. However, mangrove forests in Indonesia continue to be threatened albeit relatively more protected as private sectors, NGOs, and environmental protection communities strive to preserve what is left.

There have been efforts to restore ecological, socio-cultural and socio-economical functions of mangrove forest, particularly in the northern coast of Java Island. One of most common restoration efforts is the replanting of mangrove trees.

Mangunhardjo Village, Urban Community of Mangunhardjo, Mangkang Area, Kecamatan of Tugu, Central Java Province, Indonesia was an area which mostly consisted of brackish water ponds. This area had been impacted by climate change, which caused yearly flood from the overflow of Beringin River and seawater intrusion (rob), reducing the production capacity of the brackish water ponds. The community in this area was affected by this condition, considering the brackish water ponds were the main source of income for many people in the area, as presented in **Figure 1**. To cope with this adversity, many people in the Urban Community of Mangunhardjo shifted their livelihood.

Most of the brackish water fish farmers became motorcycle taxi drivers, fragrant oil sellers, drinking water refill providers, fish-based food producers, mangrove tree seeders, etc. Today, what was once brackish water pond area has been turned into a mangrove forest restoration site. The existence of mangrove in the area has met the criteria of mangrove ecosystem. The ecosystem is protected from waves and currents as to support conservation of coastal areas in Semarang [3]. The shift in the socio-economic landscape of the community in Mangunhardjo Village came along with the progress of mangrove forest restoration. Once the restoration has shown viability, many in the community changed their focus on utilizing mangrove as a source of income. The restoration of the mangrove forest has had positive impact to the welfare of its surrounding community. In addition to enhancing the natural beauty and livability of the area and mitigating the negative impact of climate change, mangrove forest can provide a source of income to the surrounding community. Mangrove can provide economic benefit as the mangrove restoration project provide employment opportunity by sustainable planting and selling mangrove seedlings, producing and selling mangrove-based food, sourcing mangrove as basic materials for bioactivator in compost, and processing mangrove waste into natural textile dye.

Figure 1.
The site of Mangunhardjo Village, Urban Community of Mangunhardjo, Mangkang Area, Kecamatan of Tugu, Cental Java Province, Indonesia before mangrove forest restoration (a) and after mangrove forest restoration (b).

2. Mangrove tree planting

Due to the decrease in productivity of brackish water pond, the community of Mangunhardjo, Semarang, took part in mangrove forest restoration project. This activity involved almost everyone from all ages in the community. In addition to plating the mangrove used to alleviate ecological stress through enhancing biodiversity by conservation activities, the local community also nurse seedlings to be sold all over the country. Today, ecosystem of mangrove forest and its diverse plant and animal life strives in Mangunhardjo village. Healthy mangrove ecosystem provide shelter and feeding ground for various marine life, such as fish, prawn and crab, which in turn provides additional source of income for the surrounding community.

3. Mangrove-based food

Mangrove fruit can be processed into snacks and food, such as chips, syrup, brownies, klepon, sticks and other kind of snacks. The species used in making food are Lindur (*Bruquiera gymnorrhiza*), Api-api (*Avecennia sp*), and Pidada (*Sonneratia sp*), (*Rizhopora sp*) Lindur fruit is rich in carbohydrate, higher than that of rice. Mangrove fruit has tannin content, which gives it a bitter taste. To lower its tannin contents, the fruits are boiled or immersing overnight, before they are processed. Boiling or immersion has proven to reduce the tannin content of mangrove fruits by 40%. The fruits are also made into flour, to preserve its quality. Storing mangrove fruits as flours halts its metabolism and giving it a longer shelf life due to the lack of water, making it a viable ingredient for various food.

R Mangrove-based food made and marketed by women of the fishing community of Mangunhardjo village are chips, syrup, sticks, klepon, and cakes, as presented in **Figure 2**.

Figure 2.
Cookies made from Avecenia mangrove fruit.

4. Mangrove-based bacterial bioactivator for composting

Microorganisms associated with mangrove waste synthesize secondary metabolites similar to their host. These microbes are viable source of new compounds. Symbiont bacteria of mangrove waste are bacteria which thrive in association with mangrove waste. These associated bacteria contribute in the cycle of nutrition of its host and are decomposing agents for the waste. Compounds produced by symbiont bacteria has the potential to be used as precursors for the biosynthesis metabolism of immunity against pathogenic bacteria and other predators [4]. Microbes are the most numerous of all the organisms living on water, and as symbiotes of other organisms [5]. One way that bacteria contributes to its ecosystem is to act as a decomposer in breaking down organic materials such as dead leaves around mangrove plants. Due to bacterial activities, dead mangrove leaves are eventually broken down into nutrition. One of the processes in mangrove ecosystem which significantly contribute to the biodiversity in the water is decomposition, or specifically, the disintegration of mangrove leaves into nutrition. Disintegration is a step in the decomposition process, which in turn will produce important nutrients within the food chain, through the productivity of the surrounding waters [6]. Decomposition bacteria are groups of bacteria with the capability of decomposing other dead microorganisms into its basic building blocks, all of which will return to the environment. These decomposition bacteria are categorized into saprophytic organisms, due to its ability to break down organic compounds in nature. Saprophytic bacteria break down dead plants or animals and remains or waste of other organisms [7, 8]. Mangrove waste is a supply of organic materials to mangrove ecosystems, which maintains the carrying capacity of the surrounding area [9].

Microbes isolated from plants with bioactive compounds have been known to have similar compound to its host and, in some cases, even indicate greater activity than that of its host [10]. A study on symbiont microbes with bioactivator potential found four viable species, namely Pseudomonas sp., Flavobacterium sp., Acinetobacter sp., and Bacillus subtilis. The consortium of the 4 species can act as organic waste decomposer and restore the color and odor of fresh water [11]. The symbiont bacteria from mangrove waste have seen application in bioactivator products which has been used by the community in Urban Community of Tembalang, Semarang, Central Java to process organic waste into compost, as presented in **Figure 3** below.

Figure 3.
Liquid Bioactivator products from symbiont bacteria of mangrove waste, which are used in making compost.

5. Using mangrove waste as natural textile dye

The latest development in fashion industry sees a demand for breakthrough from designers and scholars to create textile materials and clothes that are creative, innovative and marketable. Batik, as one of the most sought after fashion products in Indonesia, are mostly made using synthetic dye. Synthetic dye has its advantages, namely its availability, range of colors and the practicality of its application. However, the use of synthetic dye pose health risk of consumers, and even greater threat to the environment. Due to its carcinogenic nature, the use of these dyes in fabric may trigger allergy reaction. The process by which these dyes is made also presents environmental hazards. Therefore, there is an opportunity to reintroduce natural dye as a safer, more environmentally friendly alternative. Batik clothes and fabric made using natural dye have high commercial value because of its artistry, unique colors and the sustainability by which they are made and sourced. The use of natural dye in batik also give impressions of ethnic-look and exclusiveness.

Rhizophora mucronata is one of the potential mangrove species to be used in the production of natural dye. Other than being an important species for the mangrove restoration project in Mangunhardjo village, Semarang, *R. mucronata* still sees limited utilization by the surrounding community. Yet, parts of mangrove have been known to be used as natural dye in several other areas in Indonesia such as Papua and Takisung. [12] mentioned that *R. mucronata* is a natural tanning agent commonly used in textile industry and can produce color variation depending on the mordant used. A number of studies also indicate the potency of *R. mucronata* as dye material. In Bontang, Borneo, fruit of *R. mucronata* is used as a material in dye production for the local industry [13]. One study also found that natural dye made from *R. mucronata* passed the quality test with a predicate of 'fine' [14]. Although color pigments of *R. mucronata* parts can be sourced as a material for natural dye, there are more color variation and and ways to retain colors that has yet to be tested.

Pigments of *R. mucronata* is a unique potential of this species of mangrove. The pigment content can become an asset through effective and efficient utilization, which can provide economic value to the community around mangrove ecosystem. Therefore, further studies on pigments of bark, propagules, and leaves of *R. mucronata* in relation to their application in batik as dye materials.

Batik has experience a rise in popularity among both the locals and foreigners in the last few decades. The increasing demand of batik products also creates increasing demand for and use of synthetic dye. This is due to the fact that synthetic dyes are marketed at a lower price point and have better color retention compared to natural dyes. However, as more and more consumers become more aware of environmental issues, fabrics with natural dyes becomes more popular in the market. Synthetic dye has been known to be carcinogenic, and the waste from its production poses danger for the environment. [15] mentioned that synthetic dye is mutagenic and non-degradable in nature. Orange II is one example of the most prevalent artificial dye in the industry. This artificial dye has been known to not easily broken down by natural means. The waste from production and use of synthetic dyes has also been known to contain high levels of heavy metals such as chromium, zinc, copper, etc. [15, 16] wrote that waste water from textile production activity was found to pose health hazard to the surrounding community in Palembang, due to its high content of corrosive chemicals, organic pollutants, and high levels of acidity in its waste. Pollutants from synthetic dye production and use contains high leves of heavy metals, and intermediate dyes which are mutagenic in nature [17]. Not only does this damage the environment, it also pose health hazard to the community.

Compared to stock of sythetic dyes, the availability of natural dyes is more limited since artificial dyes are mass produced and have better distribution chain whereas natural dye often see limited production and must be sourced directly from its native area. Yet, not all sythetic dyes in Indonesian market is produced within the country. *R. mucronata* with its application potential as a material for natural dye can be found all over Indonesia, yet there has been limited commercial exploitation for this use. Studies of *R. mucronata* parts to be used as dyes for batik fabric are expected to contribute to the novelty of *R. mucronata* as an alternative source for dye in batik textile industry.

6. The biology of *R. mucronata*

R. mucronata is a species prevalent in the Indo-Pacific region. In Indonesia, *R. mucronata* is known locally as "Bakau Hitam" (lit. Black Mangrove), "Bakau Korap", "Bakau Merah" (lit. Red Mangrove), "Angka Hitam", "Belukap", "Dongoh Korap", "Jankar", "Lenggayong", and "Lolaro". This mangrove often become the choice plant in mangrove restoration programs [18].

R. mucronata is classified into the genus Rhizophora. One distinguishing feature of this species is its broad leaves. There are two other species within the Rhizophora genus, namely *Rhizophora apiculata* andRhizophora stylosa along with two hybrids, namely Rhizophora lamarckii (a hybrid between *R. apiculata* and R. stylosa) and Rhizophora annamalayana (a hybrid between R.apiculata and *R. mucronata*) [19].

The tree of *R. mucronata* can reach a height of 30 meters. The trunk diameter can grow up to 70 cm with bark which is dark, mostly black and a horizontal crevice. Stilt roots and aerial roots grow on the lower branches of the tree. The stilt roots can be quite sizable and are woody. The stilt roots of *R. mucronata* are usually abortive, whereas the lateral roots can be quite numerous in one tree and extend from the tip of the branch as well as possessing numerous branches on itself, which are also known as stilt roots/hoop/pile-like which supports the tree. Aerial roots can sometimes be found in the lower branches. The trunk itself is enclosed cylindrical in form, with bark that are black or dark red, has a coarse, scaly texture, and with horizontal crevices formed around the bark [20].

The leaves of *R. mucronata* has layers with green stalks. The leaves can reach a length of 23 cm. They are typically elliptical with narrow tips. The propagules of *R. mucronata* have an egg-like shape. The color of the fruit varies from green to brownish. The base of the fruit has a coarse texture and typically monocots. When ripe, the cotyledon neck will turn yellow.

R. mucronata is a species with the highest tolerance for sandy environment, compared to other Rhizophora species. This species is commonly found in tidal area with sand substrates [21]. *R. mucronata* thrives in mud with fine, grainy soil and is believed to be one of the mangrove species capable of surviving during inundation by high tide [22].

7. Chemical composition of *Rhizophora mucronata*

Mangrove commonly contains compounds such as alkaloid, flavonoid, phenol, terpenoid, steroids, and saponins [23]. Proximate analysis of *R. mucronata* fruit by [24] found that there were 46.63% of water, 1.96% of fat, 0.41% of protein, 1.25% of ash and 22.29% of carbohydrate. [25] identified the phytochemical contents of *R. mucronata* bark, and found Positive results on phenolic compounds (including flavonoid and tannins), and believed that the tannins are drawn in the methanol extract with testing using FeCl3. In addition to phenolic group compounds, secondary metabolites such as terpenoids/steroids, alkaloid and saponins were also found in the bark of *R. mucronata*, only in this study the results were obtained by the use of multiple solvents (ethyl acetate and methanol) and varying reagents.

The leaves of *R. mucronata* was indicated as the most effective part to be used in extraction process [26]. It was found that the leaves of *R. mucronata* are rich in phenolic compounds, consisting of several flavonoid, phenolic acids, and tannin [27]. *R. mucronata* leaves contains dihydroflavonol with free 5-OH and 7-OH, with restored raffinose at 3-OH, caffeic acid, vanillic acid, p-hydroxybenzoate acid, and tannin, believed to be catechin tannin. [28] elaborated that the extract of *R. mucronata* leaves, both fresh and dried, and extracted using sterilized distilled water contains the following phytochemical constituents: alkaloid, carboxylic acid, coumarin, flavonoid, phenol, protein, amino acid, quinone, resin, saponin, steroids/phtyosterols, tannins, xanthoprotein.

8. The use of *Rhizophora mucronata*

In Madagascar, the wood of *R. mucronata* is extensively used in making boats and fishing nets for fish and shrimps, and is domestically used as a construction material for fences, housings and cooking fuel [29]. The indigenous people of Papua has also been using *R. mucronata* as materials for fence poles, walls and boats. In addition, fruits if *R. mucronata* has been used to treat diarrhea. Whereas in general, parts of the Rhizophora tree are brewed into alcoholic drinks in the Wondama Bay area [30]. In the field of biochemistry, bark from *R. mucronata* containing polysaccharides has been used as an in-vitro treatment for human immunodeficiency virus (HIV) [31].

[32] stated that *R. mucronata* is one of eight types of sources for natural dye used by the people of Papua. This species is used for several purposes such as a material for dye, food ingredients, and cosmetics [33]. *R. mucronata* bark from Takisung area has been used for dyeing batik cloth [34]. [35] wrote that *R. mucronata* bark, which has a natural brown pigment, is used as a textile dye because its tannin content reaches 30%. [36] successfully used the stem and leaf waste of *R. mucronata* as a natural dye for batik on cotton and silk fabrics.

9. Batik

Batik is a form of textile product that are generally used in the form of various crafts, tablecloths, sheets, and clothing. In 2009, UNESCO awarded Indonesian Batik as an Intangible Cultural Heritage of Humanity. The uniqueness of batik products are often found in their style, use, and design which are not only attractive to the local market, but also to the international market. In the period between January to June 2014, Batik became one of the commodity groups that had the highest export value in Central Java, compared to the other two commodities, namely textiles and textile goods. Textile and textile goods have the largest contribution of 36.84% of total export value or approximately US$189.01 million. This export value shows that textiles and textile products in Central Java have a huge potential as a contributor to the country's foreign exchange.

10. Textile dye

Color becomes visible to the eye when there is absorption of a portion of the color spectrum in the visible area by molecules. The molecular structure is responsible for the presence of compounds that absorb visible light, which will be interpreted as colors. Molecules in plants consist of chains of carbon, oxygen, and hydrogen as main compounds and a few additional heteroatoms such as nitrogen. Molecules that absorb visible light are filled by chains of alternating and single carbon bonds that are alternating or conjugated. The longer the double bond, the more vivid the colors will appear. This bond can absorb visible light in certain areas, which provides coloration to the compounds [37].

Textile dyes, based on the materials from which they are sourced, are classified into two namely Natural Dyes (ZPA) and Synthetic Dyes (ZPS). ZPA is a dye obtained from natural ingredients, which generally comes from the extracts of plants or animals. ZPS is artificial dyes or syntheses made by chemical reactions using the basic ingredients of charcoal, coal, or petroleum which are the result of aromatic hydrocarbon derivatives such as benzene, naphthalene, and anthracene [38].

The intensity of the color produced in natural dyes depends on the type of coloring matter. Coloring matter is the substance that determines the hue of natural dyes and is an organic compound. The classification of natural dyes based on coloring matter is divided into four groups namely mordant dyes, direct dyes, acid/base dyes, and laver dyes. Mordant (natural) dyes in the coloring process must be combined with a metal oxide complex to form an insoluble dye. Natural dyes in mordant dyes have good color resistance potential, for example Moridin dyes from Noni roots. Direct dyes are retained to the fabric fibers based on hydrogen bonds, making the color retention low, for example Curcumin from turmeric. Acid/base dyes consist of a combination of acid and base groups, such as flavonoid pigments. The last group is laver dye. These dyes must go through the process of reduction–oxidation (redox) in the fabric dyeing process. In addition, laver dyes are also known as the oldest dyes in the world because they have the best color retention among the three other classes of natural dyes. One example of laver dyes is Indigo from torn leaves [13]. Natural dyes that have been explored from plants and have been used in fabric coloring include sengon leaves (*Albizia falcataria*) as silk fabric dyes, mangosteen rind (*Garcinia mangostana*) as natural dyes on cotton fabrics, *Morinda citrifolia* bark on *Morinda citrifolia* cotton cloth, purple sweet potato (*Ipomea batatas*), etc. [39–42]. Extraction of natural dyes is mostly carried out using polar solvents such as distilled water, ethyl acetate, methanol, acetone and n-hexane [25, 37, 43].

11. Dye extract

In general, the results of extraction from leaves, bark, and propagules show brown color with different color density variations (**Figure 4**). The brown color indicates the presence of tannin [11]. Previous studies have found that high levels of tannin produce a dense color on tea leaves [44]. Several factors such as the extraction temperature below 100°C, the type of solvent (polar) used for extraction, particle size, and extraction time are things that need to be taken into account in producing quality tannins [45]. Tannins are found in the bark, fruit (propagules), and leaves of *R. mucronata* [46].

However, there is variation in tannin content in each part of the tree. The content of tannin *R. mucronata* has similarities with tannin derived from *Ceriops tagal* bark,

Figure 4.
Batik fabric coloring from mangrove waste extraction with lime, tunjung and alum fixations.

which is soluble in distilled water that has polar properties [47, 48]. The tannin content produced from extraction using distilled water did not differ significantly compared to other solvents with similar polarity.

12. FTIR analysis and UV-Vis spectrophotometry

UV Vis spectropometry to extracts of *R. mucronata* leaves, bark, and propagules extracted at 70°C shows the maximum absorbance located at a wavelength of 412 nm. This shows the existence of conjugated C=C and C=O bonds. The maximum absorbance value obtained at wavelengths between 300 and 550 nm indicates the presence of $\pi \rightarrow \pi$ * denoting conjugated C=C and n transitions $\rightarrow \pi$ * in the form of chromophore C=O [49]. Tannins are classified as natural polyphenol compounds which contain phenolic hydroxyl groups and carboxyl groups. In addition, there are also chromophore groups which generally give color to a compound. The C=C conjugated bonds and C=O are included in the chromophore group, thus supporting the notion that the brown color that arises from extraction is caused by the presence of tannin content.

Subsequent testing to see the absorption pattern using an infrared spectrophotometer. Test results on the three types of dye extracts on leaves, bark and propagules showed a similar absorption pattern. Absorption in the range of wave numbers 3500 to 3000 cm^{-1} and 2000 to 1500 cm^{-1} indicates the presence of C-H groups. The C-O group is also indicated although it must be further analyzed in the fingerprint area. The C-O group forms an aromatic compound, which is part of the tannin together with the O-H and -CH2 groups [50]. The solid-shaped extract of D_{70} shows a different absorption pattern. O-H, C-H, C=O ester, and C-O-C ether groups are indicated. The existence of these four types of functional groups shows that the flavonoid compound is indicated in D_{70} extract. This is supported by research conducted by [51] who found that the flavonoid compounds from the flavonone group had the OH functional group bound, aliphatic CH, C=O, C=C Aromatic, C-O and C-H aromatics. [52] revealed that flavonoids are building blocks of proanthocyanidin compounds which are condensed tannins. Flavan-3-ols polymer compounds consisting of (+)-catechin and (−)-epicathecin are the main constituents of the group of flavonoid compounds that fall into the category of condensed tannins. To support these findings, Total Phenol Content and Total Flavonoid Content were conducted.

13. Total phenol content and total flavonoid content

Determination of total phenol in D_{70} extract was carried out using the Folin–Ciocalteu reagent. This reagent is sensitive in reducing compounds such as polyphenols and in its reaction will show blue when measured by spectrophotometer [53]. The test results showed that the phenol content were 2.4950 mg GAE/g. The presence of phenol in the extract can be an indication of tannin. In general tannins are high molecular weight polyphenol compounds, which naturally form complexes with protein [54]. Testing of total flavonoids was also carried out and the results obtained were 0.6516 mg QE/g. Flavonoids are still included in polyphenol compounds and usually consist of flavones, flavonols, and condensed tannins, which are secondary metabolites of plants [53, 54].

14. Fabric with mangrove-based dye

Fabric dyeing using natural dyes of *R. mucronata* was done by immersing dry, white cotton fabric with the dye and then air-drying them. This step was repeated three times. When immersing the fabric into the dye solution, the fabric undergoes swelling so that the pores of the fabric fibers will open and the dye can be absorbed into the fiber together with the dye solution. Dyes that have been absorbed into the fiber will be bound by reactive groups on cellulose fibers in the form of hydroxyl groups (OH) and form hydrogen bonds. The finished dyed fabric was then aerated with protection from sun exposure. After the cloth dries, the cloth is then immersed in alum color-fixating agent ($KAl(SO4)2.12H_2O$). When dyeing, the dye is absorbed into the fabric fibers. But in general there are substances on the fabric surface that block the process, so fixation agents such as alum are needed to help the absorption of dyes on the fabric and increase color retention by binding the dye molecules to the fibers of the fabric. The reaction between the fabric which has been dyed and fixated by alum (KAl(SO4)2.12H2O) does not produce complex salts but compounds which are ionically bonded [55].

The colors produced by the three types of dyes from *R. mucronata* after fixation with alum through qualitative observations based on [56] were shades of tawny/tenné brown. The tawny brown digital code according to [57] is AE6938. Tawny brown can be described as a light brown hue with a combination of brown and orange The tawny brown color that was obtained after fixation with alum was not much different from the color before the addition of alum. This is in accordance with the nature of alum which gives out hue according to its original color [58].

15. Color retention test

The results of the color retention test of dyed fabrics from parts of the *R. mucronata* through extraction with temperature variations and fixation using alum showed permanent color properties. The value of Gray Scale and Staining Scale in the color retention test against fabric rubbing showed almost the same results, namely in the category 4 (fine) and 4–5 (fine). In the soap washing test, the average results showed 3–4 (adequate) to 4 (fine). Leaf extracts heated at 70°C (D_{70}) and bark extract heated at the same temperature (K_{70}) consistently showed a staining scale value of 4 showing the ‘fine’ category at three replications of the test. In general, all test results met the minimal SNI standards of 3.

Tannin commonly used as dyes are found in *Ceriops tagal* mangrove bark and can produce a brownish red color [48]. The leaves have 15% less tannin content.

Types of tannins in *Ceriops tagal* and *R. mucronata* are tannins condensed with procyanidin types. Tannin extraction from plants is strongly influenced by the composition of the solvent used [59]. The optimal solvent will be able to produce tannins in large quantities. In addition to the dyes obtained, the color retention of the fabric also depends on the fixation agent. Staining quality test results that showed the category of 'adequate' and 'fine due to the use of alum fixation, creating strong molecular bond which in turn contributes to good color retention. According to [59], the strength of the bond that occurs between fabric fibers and dyes determines the color retention during the washing process. Dyes strongly retained in the fabric fibers will create better, more vibrant colors after being washed.

16. Conclusions

Mangroves can be used as natural dyes on batik cloth, because of their high availability and positive impact on the household economy of the local community. *Rhizophora mucronata*, a mangrove species commonly found in the coastal areas of Semarang, is used in conservation efforts and beneficial in the field of fisheries. The existence of this species of mangrove forests can improve the catch and welfare of the local fishing community.

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Chapter 6

Mangrove Ecosystem Restoration after Oil Spill: Bioremediation, Phytoremediation, Biofibers and Phycoremediation

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Abstract

Environmental accidents involving spills of oil and its derivatives in mangroves present themselves as difficult problems to be solved in the short term, as for example in the construction of emergency strategies to combat the arrival of oil stains and fragments. Petroleum its derivatives and the residues generated in this chain, have a complex mixture of hydrocarbons and are considered dangerous substances. This mixture is difficult to degrade and can cause multiple problems in the ecosystem. Our developed biofiber barrier removes oil more than five times in relation to its mass in a simple way and in a short time. However when the spilled oil reaches the mangroves, other biotechnologies were developed and applied such as phytoremediation (87% efficiency), the use of microalgae (94% efficiency) and the use of fungi and bacteria (70% efficiency). This chapter will present biotechnologies developed, patented and applied in cases of oil spills in tropical mangrove of Brazil. These generated biotechnologies have been applied together with civil society in tropical ecosystems that were hit by the Venezuelan oil spill in 2019. The use of advanced molecular biology (studies of genomics, transcriptome, proteomics and metabolomics) in the biotechnologies presented has shown a promising path to faster, viable economically and ecologically correct mangrove restoration.

Keywords: petroleum, bioeconomy, biodegradation, recovery of degraded areas, urban wastewater treatment

1. Introduction

The control of losses during the production, transport and disposal of oil is fundamental in preventing environmental accidents, in guaranteeing the safety of the community and in the preservation of natural resources [1]. Process losses, such as leaks and ruptures, generate a double cost for companies and environmental pollution [2]. First, the cost of repairing the image, as a damaged image can trigger the closing of contracts with other companies and a reduction in sales. The second cost is to repair the environmental damage caused to people and environmental resources. It is important to note that if the company does not meet the legal criteria, it may still have additional costs with the request for licenses not previously requested. Hence, the need to establish an action plan for the prevention and containment of environmental accidents, that is, to think of all strategies from the containment of the problem to the repair or recovery of the affected area.

The first action to be considered before the arrival of the spot is what is the measure or set of containment measures that will precede the arrival of the spot on the coast. Especially because at first the objective is to prevent the stain from spreading and reaching the coastline, and to carry out this action, the support of the government, fire department, NGOs, scientists, companies and other professionals is necessary, depending on the severity of the problem [1]. Recently, the coast of northeastern Brazil was the victim of a natural disaster, during this period (2019–2020) some scholars sought answers, such as the origin of oil, how to contain and treat it [3].

Biosorbents are efficient in combating environmental accidents, since the bioproducts generated can act as adsorbents and co-products of added value and can adsorb contaminants [4, 5]. They thus allow the reduction of the arrival of the oil slick in the mangroves, in addition to assisting in phytoremediation through the adsorption of hydrocarbons. Coconut and sisal fibers, thermally and chemically pretreated [6–8], have high adsorption efficiency of aromatic hydrocarbons, such as anthracene and methylene blue [9, 10].

In biotechnological processes, it is common to use microorganisms to generate bioproducts of interest in the industry, such as drugs, beverages and fertilizers, as well as in the treatment of contaminated sediments and soils [11]. Rhizospheric microorganisms, also present in plants, can be applied in the bioremediation of areas contaminated by oil spills [12]. It is important to note that plants have abilities such as phytoextraction, phytostabilization, photodegradation and phytostabilization, which assist in the action of rhizospheric microorganisms. In phytostimulation, for example, the plant releases enzymes, metabolites and nutrients, which influence rhizodegradation and plant growth, given that there are bacteria that promote plant growth [12].

Phytoremediation also has the advantage of acting in the control of carbon dioxide emissions, which is a product of the biodegradation of hydrocarbons generated in the bioprocess [13]. It is also important to highlight the application of microalgae (phytoremediation) in the biofixation of carbon dioxide generated during the photosynthesis process [14]. In this way, phytoremediation is aligned with the Paris Protocol, the 17 UN SDGs and also with the circular economy, since the biomass generated can be reused directly in industrial processes.

2. Biotechnologies developed and applied in the restoration of oil-impacted mangroves

2.1 Phytoremediation with mangrove plants

The mangrove is strongly impacted by environmental accidents, due to the richness of biodiversity and abundance of resources, which are used by riverside communities as a source of subsistence [15]. Nowadays, one of the main problems associated with the mangrove ecosystem is environmental accidents, resulting from failures in the process, during the transportation, production, storage and disposal of oil [16].

The presence of heavy metals in petroleum-contaminated areas also interferes in the rehabilitation of the mangrove ecosystem [17–20]. It is important to point out that certain metals, such as Al, Fe, Pb, Cr, Cu, Zn and Ni influence the biodegradation process of petroleum, which may make it impossible or reduce the efficiency of the implemented remediation strategy. [19] performed an integrated evaluation of the metals Al, Fe, Pb, Cr, Cu, Zn and Ni with the physical–chemical parameters (pH, temperature, dissolved oxygen and salinities), in order to assess how these factors contributed to the response variable, that is, in the percentage of removal of total hydrocarbons from oil, by phytoremediation and bioremediation. Pearson's correlation indicated the strength and direction of the linear relationship between the variables, and the principal component analysis (PCA) was applied to explain the events that were not fully clarified by Pearson's correlation.

The experiment was carried out for three months in a greenhouse near the mangrove, where samples of sediment and residual oil were collected. The tidal regime was simulated daily in each unit, in order to provide models for the remediation conditions closest to a marshy ecosystem. Altogether, 72 seedlings were selected and cultivated, 36 of which were *Avicennia schaueriana* and 36 were *Rizophora mangle* [18, 19].

Seedlings of mangrove plants were collected at low tide, taking into account their height (average of 3 months), defining a standard sample. [19] found after fifteen days of application, that intrinsic bioremediation showed greater efficiency in relation to phytoremediation, which required a longer period to reach maximum efficiency. As [20] this result was expected, since the plants have a longer response time to the pollutant, which varies according to the species and the conditions of the natural system studied or simulated in the laboratory. It is also important to highlight the peculiarity of the mangrove sediment, which has low or no oxygen availability, medium salinity and low diversity of microorganisms in relation to other environmental compartments. These factors can provide greater or lesser biodegradation of toxic compounds. However, the impact of petroleum on mangroves also depends on the types of pollutants, concentration, toxicity, distribution and the retention time [18]. In many cases, the sediment can behave as a reservoir of pollutants such as heavy metals from the marine or terrestrial environment and, thus, the toxicity of the contamination is greater and the degree of difficulty in removing the organic compounds derived from oil becomes more complex [15].

After three months, [19] proved that phytoremediation showed a removal of compounds in the sediments from 33.0 to 4.0 μg / g initially, while the intrinsic bioremediation decreased from 33.0 to 9.0 μg/g (**Figure 1**). Thus, phytoremediation was able to remove the sediment about 20% more than intrinsic bioremediation.

A higher efficiency of phytoremediation, in relation to the removal of the intrinsic bioremediation of petroleum hydrocarbons was observed. The presence of metals did not influence directly on Bioremediation, except for Cu, which may have moderately inhibited greater efficiency in the process (**Table 1**). However, Ni and Al seem to have been absorbed by mangrove plants, while they were removed from the hydrocarbons, which may have favored more the growth of microorganisms in the rhizosphere, besides the stimulation by the allelopathic compounds. Finally, it was emphasized that the implementation of the Phytoremediation model in areas impacted by oil activities can be very important, since it is an inexpensive, environmentally friendly and socially correct technique. Moreover, this process may also contribute to reduce global warming through carbon.

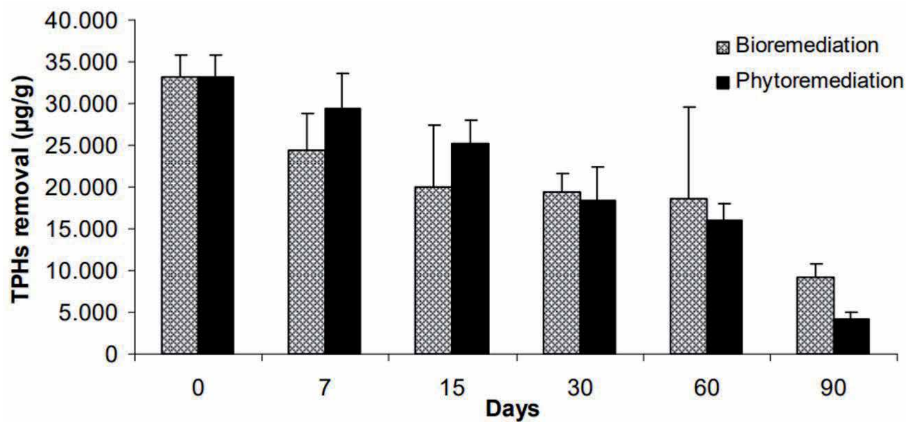

Figure 1.
Temporal removal of total petroleum hydrocarbons (TPHs) during the application of intrinsic bioremediation and phytoremediation in mangrove sediments.

2.2 Bioreactors

The mangrove is one of the coastal ecosystems impacted by socioeconomic and environmental activities, which directly or indirectly affect the distribution of hydrocarbons derived from oil [21]. Marine sediment is one of the main matrices for the deposition of organic contaminants in mangroves, as the biogeochemical characteristics contribute to the accumulation of these compounds and associated with environmental legislation limit the local application of biotechnologies [22]. Thus, studies in bioreactors are great strategies for studying bioprocesses for treating sediments contaminated by oil, without inflicting the requirements established by Brazilian environmental legislation [19–24].

To address this issue, [24] evaluated the efficiency of the bioreactor in the biodegradation kinetics of Total Petroleum Hydrocarbons (TPHs) in the Campos basin present in mangrove sediment. To this end, [24] monitored over 187 days the variation of the physical–chemical and biological characteristics in the sediment and in the circulation water in the bioreactor, used in the simulation of high and low tides.

The methodological steps were carried out in two phases. In the first phase, only bioremediation was tested in the bioreactor, in phase 2, bioremediation plus phytoremediation was tested. The kinetics of oil hydrocarbon biodegradation was evaluated using the [25] model (Eq. (1)), previously selected by [24] in a systematic review. The experimental design was composed of two treatments, the control (sediment without oil) and the contaminated (sediment with oil), both in triplicate, totaling six simulation units, with 6 mini reservoirs/simulation unit.

$$\text{Substrate consumption speed} = \mu\text{máx}.S\left(S0 - X0 - S\right)/\left(Ks + S\right) \tag{1}$$

In Eq. (1), KS represents the concentration of half saturation, the S was the concentration in time t (final bioprocess time), µmáx was maximum growth rate and the S0 the concentration in time t0 (initial bioprocess time).

The method 3051A (extraction in microwaves) was used for the determination of HTP and HPA in sediment [26]. Subsequently, the extracts were injected in a gas-operated chromatograph (VARIAN brand, model CP3800), with DB 5 capillary column and flame ionization detector (CG / FID) for the determination of total petroleum hydrocarbons. HPAs were detected by gas chromatography (Mark

VARIAN) coupled to a mass spectrometer (GC / MS). In the water samples the extraction method applied was that of U.S. EPA 3510C (liquid–liquid extraction) [27]. Subsequently, the extract was concentrated with the aid of a rotovaporator, model R-215 and, finally, transferred to vials and sent for reading in the gaseous chromatographs. HTP reading was performed on the CP3800 gas chromatograph, with a DB 5 capillary column and flame ionization detector (CG/FID), and HPA determination on the gas chromatograph (VARIAN) coupled to a mass spectrometer (GC/MS). The colony forming units were counted through the micro droplet technique [28] and the culture medium used was Nutrient Agar.

The maximum and specific growth rates of microorganisms were similar in the simulation units in the contaminated treatment, but the speeds obtained were different between the units. In the contaminated treatment the value of the maximum rate in the simulation units ranged from 0.10 day −1 to 0.14 day −1, the temperature ranged from 25° C to 30° C and the pH ranged from 6.5 to 8,5 in the simulation units, a suitable range for biodegradation of petroleum hydrocarbons [29].

The mangrove ecosystem is influenced by the variation of the tides, and to simulate this process in the bioreactor, water from the São Paulo river estuary (class 1 saline water) was used [30].

The catabolism and anabolism reactions that occur during the biodegradation of compounds are influenced by abiotic and biotic factors that interact in biological systems, both natural and simulated. Understanding how these factors influence the response of microorganisms is of fundamental importance in phytoremediation and bioremediation studies.

The uses of predictive models bring satisfactory results for understanding interactions during phytoremediation and bioremediation processes. Therefore, to understand how these variables influence or contributed to the response of microorganisms, [24] generated a generalized linear model, which did not evaluate the contribution of independent variables in the variable response, and also did a Pearson correlation analysis to verify how variables correlated with each other.

In all contaminated treatment simulation units, estuary water significantly influenced the growth of microorganism cells in the sediment. Water pH and salinity had a positive contribution to the number of colony forming units, the number of microbial cells increased with increasing pH and salinity of water used in the bioreactor ($p < 0.05$). Total nitrogen, as well as total organic carbon and total hydrocarbon concentration of petroleum significantly decreased in the sediment with the increase of colony forming units (p value <0.05). We also observed a reduction in the number of colonies with increasing temperature (**Table 2**). Therefore, we believe that microbial cell growth is associated with total nitrogen consumption and total oil hydrocarbon catabolism. Probably, this total nitrogen reduction in the mangrove sediment is available to detect fixed bacteria as rhizospheric roots, such as those that were probably stimulated with the activation of enzymes and metabolites by plant roots.

Correlation analysis of the variables indicated that there was a negative correlation between the number of colony forming units and the dissolved oxygen concentration[1] (**Tables 1** and **3**). This correlation is expected since the mangrove sediment is anoxic, so we believe that the bacteria present in this sediment are facultative anaerobic) [32].

The temperature had a positive correlation with dissolved oxygen concentration and salinity (**Table 2**). Therefore, we believe that increasing the temperature in

[1] The correlation test evaluated the interaction of the independent variables with the response variable, and the pvalue was used to assess the degree of significance of this interaction, so the $p <0.05$ indicates that the null hypothesis was rejected, and the result was significant [31].

	pH	Eh	T	Sal	DO	Cu	Zn	Pb	Cr	Ni	Fe	Al	TOM	TOC	TN	P	TPH
pH	1																
Eh	−0.92	1															
T	-0.23	0.18	1														
Sal	-0.8	0.58	0.31	1													
DO	-0.31	-0.07	0.1	0.74	1												
Cu	-0.21	-0.09	0.04	0.73	0.9	1											
Zn	-0.04	0.03	0.93	0.27	0.09	0.17	1										
Pb	-0.39	0.28	0.76	0.71	0.46	0.57	0.85	1									
Cr	-0.17	0.23	0.88	0.32	-0.02	0.11	0.97	0.86	1								
Ni	-0.01	0.08	0.64	0.29	0.03	0.3	0.87	0.84	0.92	1							
Fe	-0.46	0.32	0.79	0.65	0.5	0.39	0.72	0.84	0.7	0.54	1						
Al	0.48	-0.34	0.43	-0.3	-0.22	-0.14	0.59	0.33	0.57	0.6	0.4	1					
TOM	-0.47	0.22	0.05	0.85	0.86	0.89	0.13	0.6	0.14	0.27	0.57	-0.05	1				
TOC	0.5	-0.23	-0.71	-0.82	-0.73	-0.68	-0.67	-0.87	-0.6	-0.5	0-0.82	0	-0.65	1			
TN	0.67	-0.38	-0.5	-0.91	-0.83	-0.68	-0.39	-0.72	-0.35	-0.23	-0.83	0.13	-0.79	0.92	1		
P	-0.52	0.24	0.43	0.91	0.86	0.87	0.46	0.83	0.44	0.46	0.76	-0.02	0.9	-0.91	-0.93	1	
TPH	0,52	-0.16	-0.24	-0.85	0.91	-0.83	-0.18	-0.54	-0.09	-0.07	-0.49	0.44	-0.74	0.84	0.87	0.86	1

Table 1.
Pearson correlation in intrinsic bioremediation.

Variables	Estimate	Std. Error	z value	Pr (>|z)
Intercept	72987.51	727.12	100.38	<2e-16
TOC (sediment)	-757.15	22.96	-32.97	<2e-16
TPH (sediment)	-0.01	0.00	-370.31	<2e-16
NT (sediment)	-107861.61	1138.39	-94.75	<2e-16
DO (Water)	6855.73	31.41	218.26	<2e-16
P (Water)	-31438.05	126.42	-248.69	<2e-16
P (sediment)	631.38	3.11	202.94	<2e-16
pH (water)	11954.19	63.08	189.50	<2e-16
Salinity (water)	440.45	2.58	170.48	<2e-16
Temperature (water)	-6374.67	30.03	-212.24	<2e-16

Table 2.
Contribution of water and sediment biogeochemical variables in the growth of colony forming units in simulation units.

bioreactors generates higher evaporation rate in the system, increased salinity and reduced number of colonies forming units. The reduction of colony forming units causes increased availability of dissolved oxygen in the water used to simulate tidal variations.

One of the factors that may indicate the degradation of petroleum hydrocarbons is the increase in the number of microorganism cells. [22] identified that a number of *Bacillus subtilis* bacteria cells were using hydrocarbon biodegradation from the petroleum bioremediation experiment. Analyzing a growth curve of unit 1, it was possible to observe the microorganisms reached in the stationary phase in the final stage of the experiment, from the 153 days of experiment.

In unit 2, the stationary phase of growth of microorganisms was not observed. However, just as in unit 1 there was variation of exponential death phase in the ranges from 42 to 62 days (death phase), 62 to 99 days (exponential), 99 to 118 days (death), 118 to 153 days (exponential) and 153 to 187 days (death). The same was observed for unit 3, which was also not detected in the stationary phase, but there was exponential phase variation in the 42 to 99 days (death), 99 to 118 days (exponential), and 118 to 153 (death) intervals. And 153 to 187 (exponential) (**Table 4**).

The unit 2 in the second phase showed an efficiency of 85.93% in the biodegradation of low molecular weight Aromatic Polycyclic Hydrocarbons compared to the first phase of the bioprocess experiment (49.18%) (**Table 4**) [11].

The three simulation units presented greater removal of hydrocarbon from the sediment in phase 2 of the bioprocess experiment. Thus, we believe that oil contaminated sediment remediation was efficient with bioprocess joining. And, In relation to biodegradation of total petroleum hydrocarbons, unit 2 stood out with the percentage of biodegradation of petroleum from 81,25% and GCR from 0,04 mg.kg-1.day-1 (**Table 5**).

It is important to note that in the first phase of the unit 3 of bioprocess experiment the concentration of low molecular weight hydrocarbons increased in the sediment (**Table 4**). Probably, the increase of low molecular weight HPAs was the result of catabolism of high molecular weight HPAs.

The substrate consumption velocity differed significantly between units, with a confidence level of 5%. There was no interaction of velocity with time and unit. However, at certain time intervals (153 until 187 days and 62 until 99 days) there was similarity in velocities.

Variables	Intercept (CFU)	TOC	TPH	NT	DO	P (water)	P (sediment)	pH	Salinity	Temperature
Intercept (CFU)	1.00									
TOC	0.57	1.00								
TPH	-0.42	-0.02	1.00							
NT	-0.07	-0.36	0.15	1.00						
OD	-0.54	-0.26	0.48	-0.12	1.00					
$P_{(water)}$	0.12	0.36	0.64	0.08	0.26	1.00				
P (sediment)	-0.18	-0.40	-0.49	-0.44	-0.02	-0.53	1.00			
pH	-0.65	-0.26	0.06	0.20	-0.06	-0.35	-0.15	1.00		
Salinity	0.24	0.03	-0.19	-0.31	0.06	0.07	0.39	-0.58	1.00	
Temperature	-0.06	-0.19	0.29	-0.24	0.54	0.33	0.40	-0.71	0.54	1.00

[1]*pvalor < 0.05.*

Table 3.
Correlation between the variables of the generalized linear model and the CFU response variable.

UNIT	% of biodegradation of PHA of low molecular weight	
	Step 1- Bioremediation	Step 2- Bioremediation + Phytoremediation
1	76,38	82,16
2	49,18	85,93
3	55,28 of increase	83,63

Table 4.
Percentage of low molecular weight aromatic polycyclic hydrocarbon (PHA) removal from mangrove sediment.

SIMULATION UNITS	GCR (ppb.day-1)	GCR (mg.kg-1. day-1)	% BIOD.
UNIT 1	10,82	0,01	46,05
NIT 2	40,14	0,04	81,25
UNIT 3	22,14	0,02	64,95
	24,37 ± 14,79	0,02 ± 0,01	64,08 ± 17,61

Table 5.
GCR in the simulation units.

2.3 Phycoremediation with marine microalgae

The produced water is one of the effluents generated after oil extraction. It is estimated that the production of water produced/oil can reach approximately 3: 1 (v/v) of barrels/day [31]. Organic compounds from produced water such as polycyclic aromatic hydrocarbons (PAHs) are classified as highly hazardous pollutants mangrove ecosystems because they are compounds recalcitrant, carcinogenic, teratogenic and mutagenic. When PAHs come into contact with plants and animals, toxic effects are alarming by oxidative stresses, genetic mutations and biomagnification.

Mangrove swamps are coastal ecosystems of great ecological importance to tropical countries. These environments return biomass and nutrients to the sea and act as ecologically nurseries of marine organisms. However, according to the Environmental Sensitivity Index for Coastal Areas published by NOAA, the mangrove habitat is classified as a tropical habitat sensitive to oil spills due to the difficulties of implementing a contingency plan [33].

Therefore, it is necessary to use biotechnologies that increase the efficiency in removing PAHs before being released into water bodies. The use of microalgae-based biotechnologies is characterized as an self-sustaining treatment, since these microscopic beings are photosynthesizes and can be mixotrophic, that is, they perform photosynthesis using sunlight as an energy source and biofixation of CO_2 for their own development, but are also able to absorb organic carbons from polycyclic aromatic hydrocarbons as a potential source of energy [34, 35]. Thus, the objective of this research is to evaluate the potential of the removal of polycyclic aromatic hydrocarbons (PAH's) for the treatment of produced water using a photobioreactor system with the marine microalgae species *Nannochloropsis oculata*.

To assess the potential, the removal of polycyclic aromatic hydrocarbons (PAHs) by the photobioreactor system with marine microalgae an experiment was carried out with gradients of different concentrations, for 28 days in the laboratory. The samples produced water were provided by the company Petróleo Brasileiro S.A. (Petrobras). The saline water samples, for dilution of concentrations, were collected at the pier of Porto da Barra whose bounding coordinates were: 13°00′14.12”S and

38°32′01.81"O. The marine microalgae species *Nannochloropsis oculata* was acquired from the Culture Collection of Algae at The University of Texas at Austin (UTEX).

A set of photobioreactors with different gradients of produced water concentration diluted in saline water was assembled, establishing five gradients was called: Photobioreactor with 25%, 50%, 75% 100% (v/v) of produced water and photobioreactor with Conway medium (control). The monitoring of the removal of PAHs chosen in this research was planned in five intervals of different times: consider the 1st day, 7th day, 14th day, 21st day, 28th day. The evaluation of the removal of PHAs was made from the Liquid–liquid extraction was performed in the laboratory [36]. All samples extracted were transferred for injection into the gas chromatograph coupled with mass spectrometer (GC–MS).

The monitoring of microalgae growth was determined through cellular density (cell number ml^{-1}) from the correlation curve (Eq. (2)) between cell count using a Neubauer camera [37] and spectrophotometer absorbance (Agilent Cary 60 UV–Vis) using 680 nm wavelength. The experiment was carried out in triplicate and one-way analysis of variance (ANOVA) with a significance level of $p < 0.05$ was used for statistical analysis. The analyses were conducted using BioEstat 5.3 software.

$$n^{\circ}\frac{Cel}{ml} = (3E+07)\,x\,OD680nm + (8E+06)\;\; \mathrm{R}^2 = 0{,}9231 \qquad (2)$$

The first five days corresponded to the microalgae acclimatization process to the new cultivation medium (**Figure 2**). After these days of experiment, the growth of microalgae *Nannochloropsis oculata* increased by 25% in all photobioreactors, presenting resistance to organic contaminants until reaching cell stabilization from the 15th day. The results show that its higher growth was presented on the 19th day and in Conway cultivation medium with a concentration of 6.50×10^7 cells ml^{-1}, followed by cultivation in water produced at 25% presenting final result 5.24×10^7 cells ml^{-1} and the cultivation in water produced at 50% with final concentration of 4.09×10^7 cells ml^{-1}.

Considering 75% produced water its highest growth was presented on the 17th day with about 2.77×10^7 cells ml^{-1} subsequently begins its decay. 100% produced water presented lower growth of the marine microalgae where it remained constant during the experiment, with about $1.17\ 10^7$ cells ml^{-1}. Constant growth may have been influenced by ions present in the desemulsifiers inserted in the produced water, where they are introduced directly before the water was collected in the well.

The ions of the demulsifying, when at high concentrations, have the ability to neutralize the cellular surface by inhibiting the multiplication of them, being reported the same results in crops above 50% of water produced in experiments developed by [34].

Although microalgae growth is reduced when the water concentrations produced in the medium increase, an increase in efficiency in the removal of total PAHs by microalgae was also increased when the water concentrations produced are also increased, there was a reduction of PAH in low molecular weight compounds and those of high molecular weight in all produced water concentrations, and the largest reduction was observed in 100% produced water, presenting about 3.016 μg L^{-1} reducing to 152.22 μg L^{-1} of light compounds. This reduction represents about 94% efficiently (**Table 6**).

Removal of PAHs in water using microalgae can occur through two pathways: by intracellular bioaccumulation or biodegradation [38]. Biodegradation of polycyclic aromatic compounds by marine microalgae occurs under mixotrophic conditions, with compounds oxidized by oxireductose enzymes, in addition, can

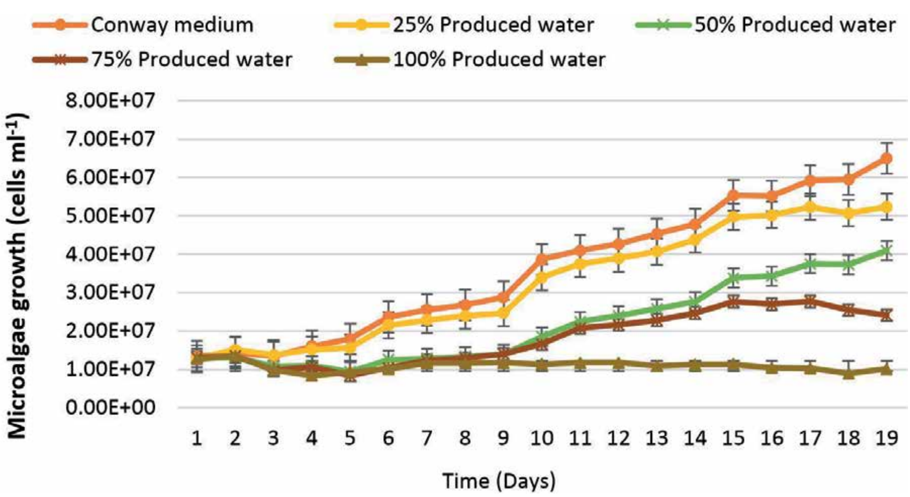

Figure 2.
Effect of different water concentrations produced in the growth of the Nannochloropsis oculata *microalgae measured in cells mL^{-1}. Concentrations: Conway medium, 25% produced water, 50% produced water, 75% produced water and 100% water produced. Data are presented mean value ± margin of error, n = 3.*

form hydroxylated intermediate fractions, justifying the increase in intermediate fractions in the medium [39].

Microalgae are presented as a profitable biotechnology for the efficient removal of PAHs, being exploited as a sustainable source in the treatment of different types of effluents and can be reused for the generation of biofuels, enabling its multi-restorative effects to prevent PAHs from reaching sensitive ecosystems such as mangroves.

2.4 Biofibers

Biotechnologies such as the use of biosorbents and phytoremediation can be applied in situ if there are specialists who know the technique and the ecosystems affected. Adsorbent containment barriers are alternative technology used as a response to spills to contain and recover oil, preventing stains from spreading affecting sensitive areas, as mangroves [40]. Currently the main sorbent materials used in the commercialized barriers are synthetic, however these materials are expensive, are not biodegradable, which makes it difficult to use [7]. In this scenario, some strategies are studied to make the use of sorbents economically viable, through the implementation of natural fibers. The main advantages of natural fibers are low cost, low abrasiveness, not toxic, low density, as well as ecological and social aspects, due to better recyclability and biodegradability [41, 42]. The coconut and sisal fibers, thermally and chemically pre-treated, have high efficiency of oil adsorption in marine and sweet waters, and can be applied from the construction of a containment bar [43–45]. These fibers can also be applied directly to coastal surfaces (beach sediments, mangrove sediments, exposed rocks) and with little contact time and in a simple way is able to remove oil. The use of biofibers should be encouraged, as it allows the reuse of oil adsorbed in the industry for various purposes. This biotechnology is directly aligned with the circular economy [40, 42].

The crushed and sieved coconut fibers were stirred in NaOH solution (5% w /v) at room temperature (approximately 25°C) for 1 hour for mercerization. Then, a wash was carried out with distilled water until a constant pH to ensure the removal of all residual solvent in the fiber [43]. This same procedure was used for acetylation

Concentration of polycyclic aromatic hydrocarbons (μg L^{-1})									
	Initial concentration			Final concentration			Total composition of PAHs		
	LMW (2 - 4 rings)	**IMW (4 rings)**	**HMW (5 - 6 rings**	**LMW (2 - 4 rings)**	**IMW (4 rings)**	**LMW (5 - 6 rings**	**Initial**	**Final**	**Removal efficiency**
Conway medium	102.8 ±4.92	8.26± 0.35	5.84± 0.31	94± 4.91	9.99± 0.77	1.34± 0.02	116.9±4.78	105.33± 2.98	10%
25% produced water	687.84 ±19.23	14.09± 1.13	8.3± 0.98	92.44± 4.90	13.84± 1.02	2.32± 0.13	710.23± 4.88	108.6± 2.57	85%
50% produced water	1537.25± 41.48	13.52± 0.47	5.38± 0.71	127.38± 13.84	9.08± 0.71	1.87± 0.01	1556.15± 4.61	138.33± 2.06	91%
75% produced water	1823.72±166.45	13.29± 0.57	5.02± 0.12	131.79± 8.74	14.56± 0.91	5.43± 0.01	1842.03± 4.86	151.78± 1.05	92%
100% produced water	3016.43± 93.75	13.59± 0.89	7.38± 0.49	152.22± 1.91	35.73± 4.05	6.89± 0.02	3037.4± 2.40	194.84± 4.56	94%

Low Molecular Weight (LMW), Intermediate Molecular Weight (IMW) and Hight Molecular Weight (HMW). Data shown as the mean ± SD, n = 3.

Table 6.
Removal efficiency of polycyclic aromatic hydrocarbons in relation to the molecular compounds present in the five photobioreactors with different gradients concentrations of water produced diluted in saline water.

and treatment with Protic Ionic Liquids (PIL). In acetylation, mercerized fibers were immersed in a solution of acetic anhydride and glacial acetic acid (1.5:1.0 by mass) with 12 drops of sulfuric acid at 80°C for 3 hours. For the treatment with PIL, a sample of coconut fiber was added in 2-hydroxyidoethylammonium acetate [2-HEA] [Ac] at 80°C for 2 hours [44]. These fibers (in natura, pretreated by mercerization followed by acetylation and with PIL) were characterized from the morphology by the Scanning Electron Microscope (SEM).

After the pre-treatment procedures, the fibers were weighed (0.5 g) and conditioned in mini barriers made from TNT (non-woven fabric) to continue the sorption and kinetics tests. The tests were performed in a thermostatic bath, with reciprocal movements of approximately 126 cycles/minute and temperature of 25°C (average temperature of the marine environment). The kinetic experiment was conducted in beakers with 95 mL of saline water and 5 mL of oil from the Campos Basin with the mini-barriers in contact with the oil slick for 120 minutes, in which samples were taken, in triplicate, in the time intervals of 5, 20, 40, 60, 90 and 120 min [7]. In the sorption equilibrium experiment, the oil concentration was varied for the construction of the isotherms [45]. After testing, the samples were cold dried in the lyophilize and weighed. The sorption capacity of the fibers was determined through Eq. (3), where S is the adsorption capacity (sorbate g/g of sorbent), S_0 (g) is the initial mass of the fiber and S_f (g) is the final mass of the fiber after adsorption [6, 7]. The tests were performed by the barriers with in natura and pre-treated fibers.

$$S = \left(S_f - S_o\right) / S_o \tag{3}$$

Through SEM analysis, it was possible to observe a large irregularity and pores on the surface of fibers in natura (**Figure 3a**). After the treatments, the mercerized/acetylated fiber increased the rough area of the cross section, in comparison with the fiber in natura (**Figure 3b**). The fiber with PIL, on the other hand, had a higher number of pores (**Figure 3c**), resulting from the cleaning by treatment with this organic solvent. Thus, chemically treated fibers have more space available for adsorption through the pores and the roughened surface compared to fibers in natura.

The kinetic results of the adsorption of the barriers with coconut fibers are shown in **Figure 4**. In all fibers studied (in natura, mercerized/acetylated and with PIL) the kinetic behavior was very similar. There was a marked sorption up to 5 minutes and then the sorption remained practically constant. This happens because the initial number of pores and available surface in the fibers are occupied over time, reducing the availability and consequently the sorption capacity [6, 7, 42, 45–47]. From these results, it can be concluded that the time of 5 minutes has more significant efficiency in adsorption, requiring a minimum contact time between the

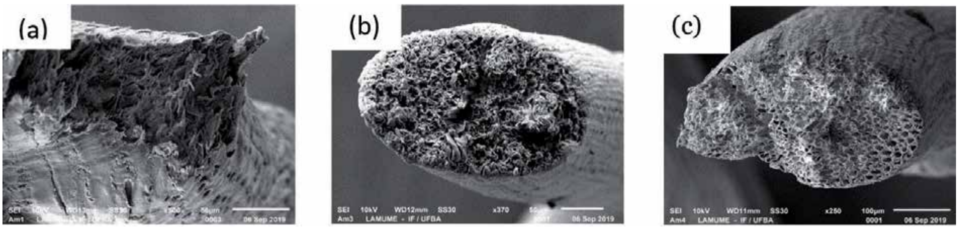

Figure 3.
SEM coconut fiber (a) in natura (b) treated with mercerization/acetylation (c) treated with PIL.

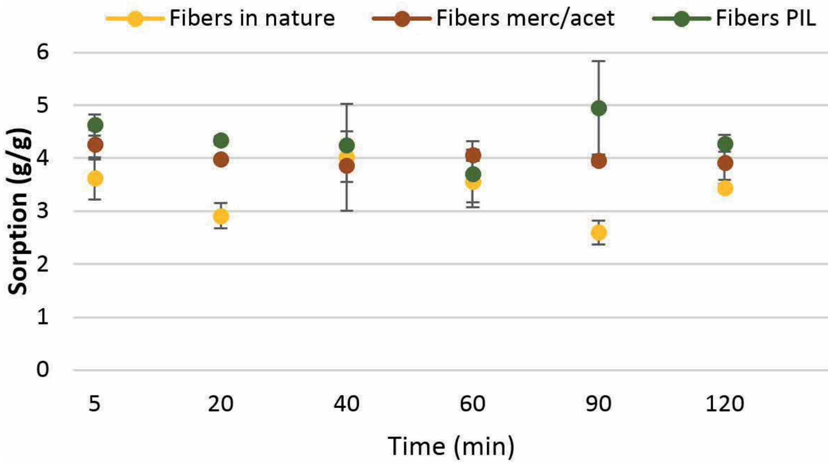

Figure 4.
Comparison of the kinetic behavior of sorption among all coconut fibers.

adsorbent material and the adsorbate to removal of crude oil in the marine environment, in addition to the contact technology operator time with toxic oil.

The equilibrium sorption was 4.00 g / g for fresh coconut fiber, 4.27 g / g for mercerized / acetylated fiber and 5.37 g/g for PIL fiber. Therefore, the fiber with PIL adsorbed 20.5% more than the mercerized/acetylated coconut fiber and 25.5% more than the fresh fiber. (b).

The result of the higher sorption of the treated coconut fibers can be explained by the chemical, structural and morphological modification presented in relation to the natural fibers through the characterizations. The greater quantity and density of pores resulting from the removal of chemical constituents, such as lignin and hemicellulose, waxes and impurities, made the pores of coconut fibers clear and consequently increased the surface area for interaction with oil.

3. Conclusions

Our study with phytoremediation in mangroves, showed that it is possible to accelerate the process of removing oil hydrocarbons in sediments when using the mechanisms of plants, their rhizosphere and the associated microorganisms. Phytoremediation is the most suitable technique for mangrove areas, since sediments have low oxygen solubility and have granulometric characteristics that increase the residence time of persistent organic pollutants such as PAHs. Based on the results found, it can be said that the barriers with chemically treated fibers are more efficient than in natura to be used in the containment and cleaning of oil spilled in marine environments so that it does not affect sensitive areas such as mangroves. The barrier composed of the fiber treated with PIL obtained greater oil sorption, followed by the fiber treated by mercerization-acetylation and finally the fiber in natura. These fiber barriers that were produced by our group can be used during emergency combat of oil stains in estuarine waters, preventing oil from reaching the sediment. They can also be used as sponges to clean oil already adhered to the surface of plants and mangrove sediments, preventing the infiltration of hydrocarbons. In this study it was identified that the *Nannochloropsis oculata* marine microalgae used for the removal of polycyclic aromatic hydrocarbons in produced water showed greater efficiency in the produced water with 94% removal, demonstrating that this marine microalgae is able to contribute to the degradation of organic pollutants and to prevent PAHs from reaching sensitive ecosystems such as mangroves. Microalgae photobioreactors can be used in the treatment of effluents from the oil industry that are released into the mangrove. In addition, the use of microalgae biorefineries has already been used to remedy river waters, and may be an option during the emergency combat of oil spills in mangrove estuarine waters. A sequential application of bioremediation and adequacy contributed positively to the biodegradation of petroleum hydrocarbons. There were improvements in the quality of the sediment, due to the variation of the physical–chemical characteristics provided by the action of rhizosmic microorganisms, stimulated by enzymes released by the plants, during the oil hydrocarbon metabolism. This process was also noticeable in the growth curve of microorganisms and in the variation in the speed of consumption of petroleum hydrocarbons. The studies that our group has been carrying out for more than 10 years show that there is not a single biotechnology that can restore oil-impacted mangroves. Each biotechnology presented here has its particular contribution in removing pollutants in the various environmental matrices of the ecosystem. Recently our group has advanced in the studies of advanced molecular biology (studies of genomics, transcriptome, proteomics and metabolomics) for the improvement of bioprocesses in a faster restoration and with economic viability (bioeconomy).

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Section 3

Conservation and Management

Chapter 7

Stieglers Gorge Dam Construction: Potential Impacts and Possible Mangrove Restoration Options in the Rufiji Delta, Tanzania

Claude Gasper Mung'ong'o

Abstract

The varied importance of mangroves has long been recognized. And so have been the threats to their existence, leading to various actions taken locally by local communities, national governments, and through international agreements for the protection and integration of human livelihood needs in a manner that balances conservation goals and goals of socio-economic development. In Tanzania the mangrove conservation ethos began during the German colonization of Tanganyika and has been persistent in the age of high globalization. In an effort to deepen our understanding of the dynamics of global, national and local nature conservation, this chapter documents the various strategies and approaches used in mangrove restoration elsewhere in the world generally, and then specifically in the Rufiji Delta. The chapter further unpacks the contrasting socio-political interests behind the efforts to conserve mangroves worldwide and in Tanzania. It does so by looking at three competing narratives, i.e. the mainstream perspective, the neo-liberal perspective, and the local cultural perspective, acting at a number of nested scales from the local grassroots to the national and the global scales.

Keywords: ecosystem goods, ecosystem services, Africa, coastal community, conservation management, socioeconomic

1. Introduction

1.1 Framing the problem

Mangroves have provided critical services to humans and the ecosystems. They have done this well and their ecological, economic, cultural and esthetic importance values have long been recognized. It was not until recently in the Anthropocene when the threats to their existence have been magnified with losses of the habitat of more than 50% reported in some parts of the globe due to their commoditization [1–5]. It is thus that the mangrove conservation ethos has particularly been persistent now than ever before in human history [6].

In an attempt to deepen our understanding of the dynamics of nature conservation reinforced by dominant discourses of the 1990s, neo-liberalism and ecological modernization, this chapter documents the strategies and approaches used in mangrove restoration in Tanzania, in general, and specifically in the Rufiji Delta. The chapter further unpacks the contrasting interests behind the efforts to conserve mangroves worldwide. This is done by looking at three competing moral narratives operating at nested scales from the grassroots to achieve conservation with social justice through the national, regional to the global and back again [7–9]. The three narratives interrogated here are the mainstream ecological conservation narrative, the neo-liberal economic narrative and the local cultural narrative at the grassroots [10] as discussed later in this chapter.

1.2 Methodology

Data collection for this study involved a desk-based literature search during September–November, 2019. Published and gray literature and secondary sources were purposively sampled using key words in the Google search engine. Key words such as mangroves, restoration, commoditization, ecosystem goods and services, Rufiji Delta, et cetera, were used to create a document set for known mangrove countries in the world.

A qualitative content analysis approach was then used to analyze each of the relevant research categories. Through a directed approach each document was reviewed to identify and collate evidence for each of the research themes and the level at which they operated. Three levels were identified: namely, local factors that operate at the community, village and household level; national factors that operate at the state level; and international factors that operate beyond the level of the state.

Content analysis was then followed by discourse and narrative analyses that have long been a major part of political ecology. While discourse analysis was an epistemological exercise, narrative analysis was important for understanding how environmental knowledge of specific events was communicated [11]. These narratives were deemed important for policymakers as they would make arguments for controlling the actions of certain, often unknowing groups; to achieve desired environmental outcomes. The rest of this chapter is structured according to the results of these latter analyses.

2. Results and discussion

2.1 Defining the mangrove ecosystem

The word "mangrove" refers to trees, families of the plant, and the ecosystem that has adapted to flourish in tidal zones in tropical and sub-tropical regions. Mangroves have been defined variously by many people; but they all agreed that mangroves are salt-tolerant evergreen forests found at sheltered coastlines, shallow-water lagoons, estuaries, rivers or deltas in intertidal areas around the world [12, 13].

They comprise around 73 species covering an area of over 150,000 km^2 spread in 123 countries [1]. (See also **Figure 1**). Over two-thirds of the mangroves exist in just 12 countries, with Indonesia accounting for over 20% of the global mangrove area. With about 8% of the total mangrove estate, Brazil has the largest contiguous mangrove forest cover. In tropical estuaries of Indonesia and Brazil and deltas like the Rufiji, there grows some of the largest mangrove trees in the world, reaching heights of 30 m or more, with extensive roots penetrating into soft mud deposits. Mangrove trees growing in the sediments of a carbonated shoreline and in arid,

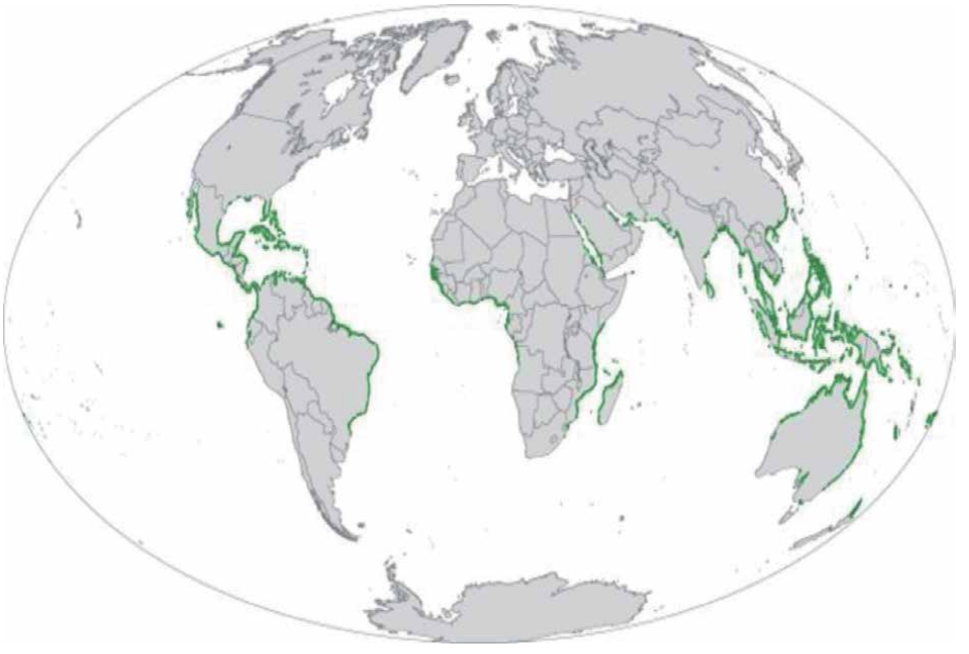

Figure 1.
*Mangroves are common along tropical and subtropical coastlines around the world, and among the most biologically important systems on earth [12]. **Source:** NASA earth observatory as described by Twilley and Rovai [14].*

very salty regions along the Red Sea are so much smaller that they look like stunted "ornamental trees in public parks" [15].

Mangrove forests in mainland Tanzania are categorized as State Forest Reserves by the Forest Act of 2002 [16]. They occur along almost the entire coastline in continuous or fragmented stands [17]. Recent estimates by the National Forest Resources Monitoring and Assessment (NAFORMA) indicate that mangroves cover approximately 158,100 ha, which is about 0.3% of the total forest area in the country [18].

Despite the commercial value of mangroves, "blue" carbon ecosystems are globally being lost twice as fast as tropical rainforests [19]. They are threatened by changing climate, natural impacts such as hurricanes, and human impacts such as deforestation and alterations in freshwater management regimes. Approximately 35% of mangrove trees were lost in this way during the last two decades of the 20th century [20].

Ngongolo *et al* [21] note, for example, that by 2000 the total estimate for mangroves was 137,760 km^2, representing a decline from 198,000 km^2 of mangroves in 1980, and 157,630 km^2 in 1990. These losses represent about 2.0% per year between 1980 and 1990, and 0.7% per year for the period 1990–2000. Hence, the anticipated task of mangrove restoration is immense.

2.2 Mangrove's ecosystem services

Ecosystem services are the benefits that people get from ecosystems such as mangroves [21, 22]. Forests moderate the amount and type of water we get from a river. It also decreases both the erosion and run-off of a place. They also provide food security as far as the variety of biodiversity they contain and general economic development. The goods and services they provide have the capacity to bring resilience among smallholder farmers, through diversification of incomes and livelihoods such as fishing.

Ecosystem services are necessary for people's livelihoods and wellbeing. They include provisioning, regulating, and cultural services that directly affect people, and supporting services needed to maintain other services (**Figure 2**). This is from the provisioning of food and water, to disease regulation and maintenance of general conditions of the natural environment. Biodiversity is behind every ecosystem services.

The concept of ecosystem services has been used in diverse ways by different interests to justify different kinds of interventions that at times might be totally opposed. The concept has historically been depicted as a one-way flow of services from ecosystems to people. Jeffers *et al.* [21] argue, however, that this conceptualization is inaccurate. It neglects the reality that humans have often also contributed to the maintenance and enhancement of ecosystems, as evidenced in many traditional and indigenous societies.

Secondly, the ecosystem services idea has mainly been used to justify forest conservation in ways open to critique for its neo-liberalization of nature [25, 26] or disempowerment of communities in some developing countries such as Madagascar. On the other hand, the discourse of ecosystem services has also served the liberating agendas of traditional populations and family farm lobbies in places like the Brazilian Amazon, where the ecosystem services concept has been mobilized by diverse actor interests in real-life situations that have led "to complex, regionally particular and fundamentally political outcomes" [27].

Irrespective of the range of species and forest types, the manifold ecological role of mangrove ecosystems is, economically and socially, highly significant. The international discourse on mangroves hypothesizes that they play an important part in shaping the physical coastline by trapping sediments and stabilizing the coast.

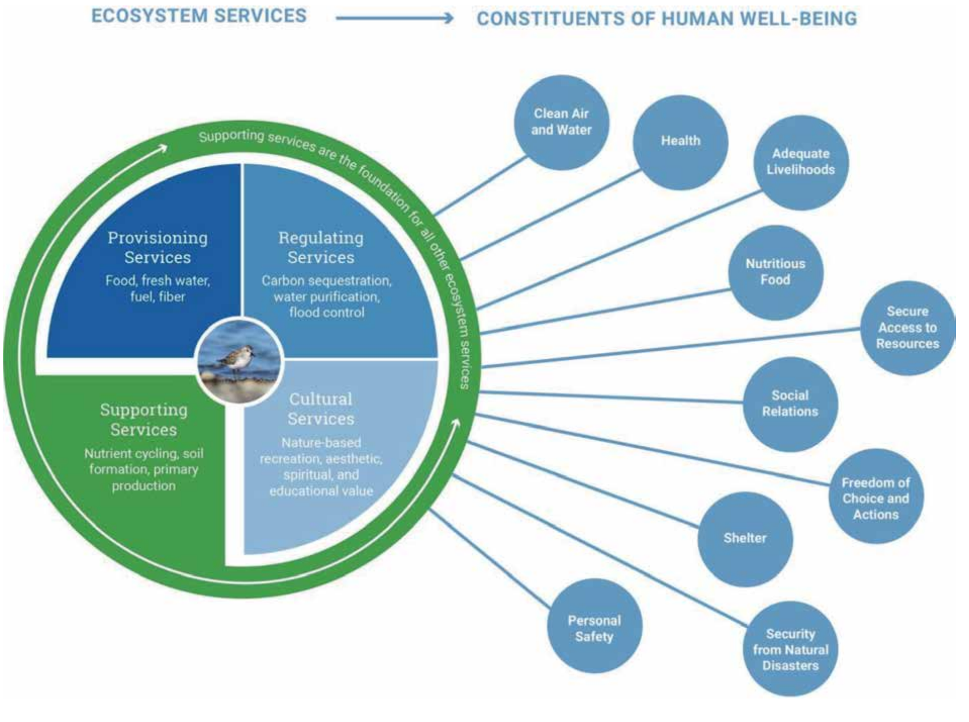

Figure 2.
*Healthy ecosystems benefit human well-being. Humans have often also contributed to the maintenance and enhancement of ecosystems in a reciprocal fashion [23]. **Source:** Adopted and modified from Chapin* et al. *[24].*

Moreover, the mangroves are highly productive ecosystem that can store carbon in sediment for long period; therefore, they have the potential of providing an efficient CO2 sink [11].

Mangrove plantation provides the possibility of forestation for the Clean Development Mechanism (CDM) project worldwide. Recent studies revealed that mangrove restoration can continue to combat climate change after 25–30 years [28]. Anthropogenic interventions decrease the capacity of ecosystems to provide goods and services as discussed above.

2.3 The mangrove estate of the Rufiji Delta

Located between latitudes 7°50′ and 8°03′ S and longitudes 39°15′ and 32°17′E, the Rufiji Delta is about 200 km south of Dar-es-Salaam (**Figure 3**). The lower Rufiji valley starts upstream from Stiegler's Gorge, some 180 km from the Indian Ocean, and into the Selous Game Reserve. Below the gorge the river fans out into an outer plain with numerous lakes before entering its lower floodplain. This part of the floodplain gradually widens until the river branches out and forms the 23 km wide and 65 km long cobra like hood of the delta [30].

Before reaching the Mafia Channel in the East, the river passes through 20 islands and 31 villages, and supports the largest contiguous block of mangrove

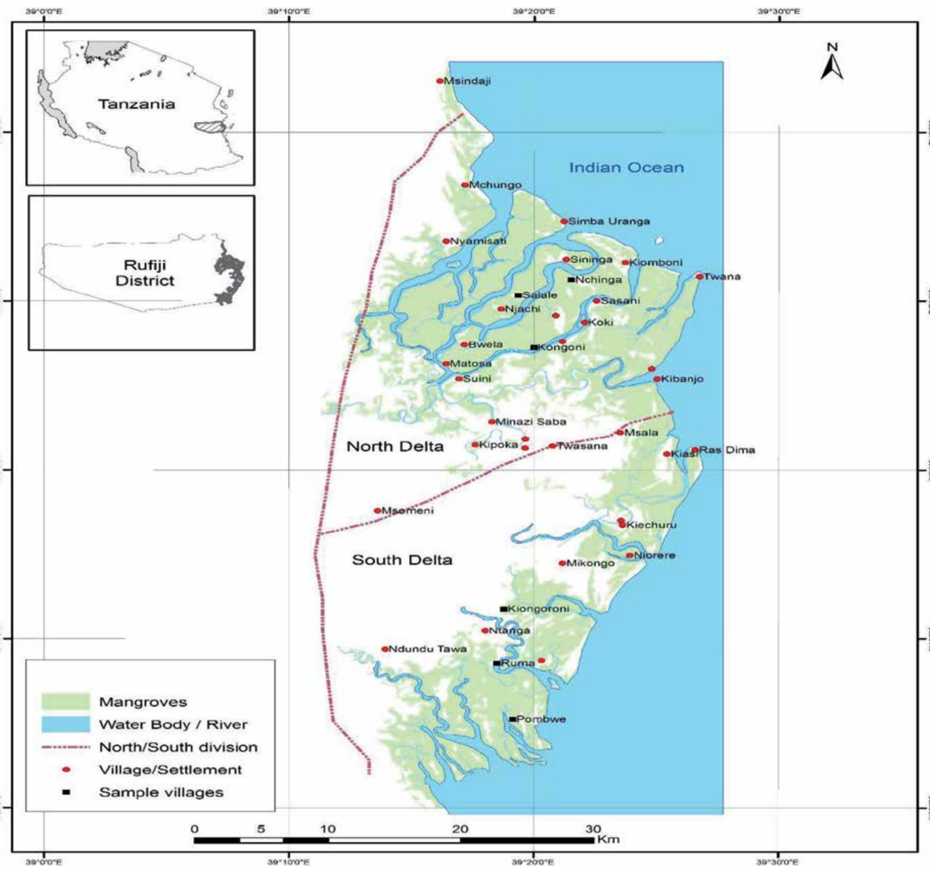

Figure 3.
*Location of the delta area in Rufiji District, Tanzania. The crescent shaped Rufiji Delta has extensive, estuarine mangrove forests that constitute almost half of Tanzania's mangrove forests (**Source:** Adopted from Mwansasu [29]).*

forest (53,255 ha) in East Africa. Eight mangrove species are reported to occur and are well represented in the delta, i.e. *Avicennia marina, Sonneratia alba, Ceriops tagal, Lumnitzera racemosa, Bruguiera gymnorrhiza, Rhizophora mucronata, Xylocarpus granatum* and *Heritiera littoralis* [31]. Two particular species, *Xylocarpus molluccensis* and *Pemphis acidula,* are missing in the delta. These are characteristically rare in the region due to a limited geomorphological niche [17].

In the delta mangroves are cleared mostly for rice farming and timber to feed urban Tanzania, including Zanzibar, and some parts of the United Arab Emirates. Areas dominated by *H. littoralis* are more favored for rice farming while *C. tagal, R. mucronata* and *B. gymnorrhiza* are heavily cut for poles. *X. granatum,* and more recently *S. alba,* are logged for timber [32].

Rufiji River is also endowed with the greatest fish potential along Tanzania's coastline, supporting about 80% of all prawn fisheries in the country [33, 34]. With a mean annual flow of approximately 800 m3/, Rufiji is one of the largest rivers in Africa and drains 20% of mainland Tanzania through three major tributaries, the Great Ruaha, the Kilombero and the Luwegu. Together, the rivers provide approximately 18%, 62% and 15% of Rufiji's annual flow, respectively [35].

The basin is targeted for major socio-economic development over the next two decades as part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). Its water resources are central to the development plans. If the plans go on as arranged targets are met, irrigation water demand will increase by 7 billion m^3/per year. 2.4 giga watts of new hydropower are expected to be produced from the controversial Stigler's Gorge. Many of these developments will be in the most valued landscapes and ecosystems of Kilombero and Lower Rufiji sub-basins [36].

Coastal sedimentation and siltation of coastal waters due to agricultural expansion on the highlands has always been a blessing rather than a curse. Of primary threat will probably be reduced stream and peak water flows due to the proposed river impoundment for the hydroelectricity power (HEP) station, with the associated trapping of sediments in the proposed dam [37]. This is further expected to have significant consequences with respect to increased salt water intrusion and diminished nutrient availability for agriculture and altered natural vegetation in the floodplain and the delta.

The delta is also an internationally recognized wetland protected under the Ramsar Convention and a system of UNESCO's World Heritage Sites upstream [38]. These aquatic systems have historically provided valuable ecosystem services, including the *mlau* agriculture performed by the Warufiji as discussed elsewhere by Ochieng [30], Duvail and Hamerlynck [35], and others.

2.4 Mangrove restoration initiatives/options

The characteristics of ecosystems, such as species composition, tree cover or growth conditions, modulate the type and magnitude of ecosystem services that can flow to societies. Mangrove restoration is an important strategy for reversing plant decline and rebuilding the ecosystem services lost due to deforestation and degradation. Mangrove restoration has usually been in the form of replants of single species, and has mostly been for silvicultural purposes. More recently replants have, however, also been undertaken to re-create the lost ecosystem functions [17]. The Indian Ocean region, for example, saw the rapid expansion of government and NGO-funded mangrove replants after the 2004 Indian Ocean tsunami to maximize the coastal protection function provided by mangroves.

Large-scale planting projects have, nevertheless, had mixed success. Many causes have contributed to the low success of plantation interventions, including:

i) biological causes such as pest infestations, ii) unsuitable physical locations, and iii) the socio-economic aspects, as elaborated in Section 3.3 below.

In addition, knowledge of the ecological processes has been added in some projects to increase restoration success. One such approach has been the Ecological Mangrove Restoration (EMR), a community based restoration practice that used several ecological principles to support natural decolonization [39]. This approach shifts the emphasis from seedling planting to prior physical site preparation. For example, the hydrology and topography of a site can be restored to allow natural regeneration of selected mangrove species [40].

2.5 Mangroves in the mainstream development narrative

Nested within mainstream values and definitions of development in Tanzania, several assumptions tend to have guided a policy narrative that has supported mangrove forest conservation in the country:

1. assumptions of inefficiency in local resource use and management regimes [28];

2. inadequate perceptions about the socio-economic benefits of local aquaculture production system, and

3. the central government may be seeing mangrove restoration from the angle of ecological services, while local people view mangrove forests as part of their culture and source of livelihoods.

For example, local aquaculture production systems are considered by regional and district officials to be economically inefficient and incongruent with broader national economic development goals for wetlands [21]. Such assumptions and perceptions are even captured in formal policy documents [41].

In contrast, traditional use of common property mangrove resources is not accorded the same economic value in mainstream discourse despite the numerous benefits provided to local communities [42, 43]. Such conceptions of local inefficiencies and the economic productivity of external aquaculture and carbon sequestration for REDD+ situate well within the broader value sets and definitions of "development" and encourage neo-liberal narratives in developing countries like Tanzania [44, 45].

Moreover, in the case of Rufiji study area, values supportive of common property ecosystems held by indigenous groups have been usurped by an influx of different interest groups, including international environmental NGOs with their political agendas and economic modes of production [44, 46, 47].

The practice of mangrove restoration is based on restoration ecology, which aims to help the recovery of resilience and capacity of ecosystems to adapt to degradation and other damage. Since environmental impacts are ongoing, successful restoration of an ecosystem implies not merely to recreate its former condition, but to strengthen its capacity to adapt to change over time [48]. One of these capacities is the management aspects of mangrove conservation.

After the acknowledgement that strict protection of mangroves did not work in Tanzania, experiments have recently been unfolding in the Rufiji Delta and elsewhere in the country. Three different models of community engagement have been tried in the delta with varying degrees of success [49] as discussed below.

3. Managing mangroves by restoration and reserves

Declines in the extent of mangrove forest cover have a long history in the Rufiji Delta [29, 32]. The Rufiji mangrove forest was the first to be declared a forest reserve in Tanzania during the German colonial period in 1898 [45]. The delicate socio-ecological balance was, however, upset during the course of successive German, British, and the national governments.

The British colonial government adopted and expanded a strict protection approach in the 1920s and 1930s [49]. The Forest Ordinance of 1957 allowed for the creation of forest reserves by government decree after considering "any objections" by interested parties to this de jure transfer of rights from local communities to the state. The independent state expanded mangrove forest reserves in the 1960s and has repeatedly used its authority over mangrove forests to exert control over the Rufiji Delta communities and resources. In 1987, for instance, the current Tanzania Forest Service (formerly Forestry and Beekeeping Division) declared a ban on the cutting of all mangroves in the northern Rufiji Delta, with forest officers posted to the area to enforce this ban [12].

By creating 'forest reserves' for the exclusive use of the government, local communities were effectively excluded from using these socially, culturally, and economically important resources. Meanwhile, various large-scale extractive projects were proposed for the delta, including commercial shrimp harvesting [12]. Elsewhere in the Coast Region and the country a devolution of resource management to local government, in combination with improved road access and the opening-up of the Tanzanian economy, led to increasingly unsustainable use of other forests in general.

Evidence from literature shows that traditional government agencies have not been effective in protecting forest ecosystems, including mangrove forests. Constraints of capacity and the economic position of many district agencies have resulted in few controls on the scale and intensity of mangrove conservation in the delta, despite an increasingly well-established legal framework for forest conservation [29, 32].

Tanzania was the first country in Africa to develop a mangrove management plan [49]. Although it was never implemented, the 1991 National Mangrove Management Plan crafted by the TFS was the first attempt at halting mangrove conversion alongside monitoring and regulating the use of the resource. Strict mangrove protection entailed actively excluding people living in and around mangroves from accessing and using mangroves for their survival, while the government controlled the harvest and export of mangrove products, particularly timber and building poles [13].

Tanzania's protectionist policies generally achieved limited and short term success in some locations around the country, with general failure in most mangrove areas of the country. At the local level, to the mid-1990s local residents had, from the colonial period, actively resisted state-led protection of forests, including mangroves [49].

As a result, efforts by the government to continue with strict protection approaches, such as establishment of new marine parks in the late 1990s and mangrove forest reserves continued to face serious implementation challenges, including resistance from coastal residents who complained that these forest reserves and marine parks marginalized them from their main livelihoods [46].

Lack of an appropriate institutional framework for the allocation of management rights and responsibilities between the local government and the national state, as well as weak government enforcement capacity at the national level [33, 51] have been the main culprits of this failure. It was because of these weaknesses, for example, that Wang *et al.* [43] and Mwansasu [29] noted the ambiguous features of the forest reserve in the Delta - that there were legally established village settlements within it which relied on mangroves and the associated marine environment for a range of ecosystem goods and services. Population estimates by then indicated that over 49,000 people lived in and around the delta, directly engaging in rice farming, mangrove cutting for poles and timber, and fishing [32].

This was possible partly because of political influence at the national and local levels. Mshale *et al.* [49] point out that politicians at various levels in the Rufiji Delta had been issuing statements that encouraged unsustainable use of mangrove forests and mangrove clearance for paddy rice farming to gain residents' political support, particularly during election times. Such statements sent confusing messages to the populace. While elective politicians often promoted mangrove clearance when this was pertinent to increase votes, the civil service maintained a strict protectionist approach. Often, the rural poor who depended on mangroves for their subsistence continued to be characterized by the state institutions as culprits of the degradation of the resource [17, 52].

The 1990s can be dubbed the age of policy shifts. Many natural resource management policies were changed during this period. Since then, the approach to mangrove protection changed, with new efforts being more and more directed toward collaborative management of the trees with local communities. This paradigm shift later led to the emergence of what I call "community appeasement forest management" that was seen as an appropriate alternative to state control with its ambiguous institutional arrangement for ensuring management of forest resources, including mangroves. The turn toward community appeasement forest management was motivated by a number of reasons, including conflicts over forest use between local residents and outsiders seeking to use the forests, and political interests at the national and sub-national levels as discussed above [49].

I would argue in this context that mangrove restoration, including replanting, has in fact also been an attempt at community appeasement rather than a forest management practice adopted to regenerate areas that have been seriously degraded. Mangrove restoration has thus been conducted in various parts of the country by the Mangrove Management Programme, as well as in Tanga and Mbweni by local coastal management efforts. In the Rufiji Delta WWF's Rufiji-Mafia-Kilwa Seascape (RUMAKI) programme has invested substantial donor resources since 2005 to help communities in the delta, as well as in Mafia and Kilwa Districts, to secure long-term mangrove co-management rights [8, 53, 54].

The philosophy behind this supposedly "new approach" has arguably been to show local stakeholders that the restoration projects and the protected areas were in fact theirs, providing a range of benefits such as access to carbon financing schemes, eco-tourism revenue and sustainable sale of commercially valuable timber and non-timber products. It has been the carrot side of the Equation [44, 45]. Three different models of community engagement have, therefore, been tried – with varying degrees of success as discussed below.

4. Three models of community engagement

4.1 Individual taungya farming with permits

This is a TFS system whereby individuals are given permits to farm forest plots with the aim of clearing them of weeds. Farmers apply for renewable one-year licenses allowing them to continue farming rice in exchange for facilitating the natural regeneration of mangrove trees on their plots. Once the trees reach a certain height, their shade renders rice paddies less productive, and farmers must move elsewhere to repeat the process.

This scheme has not fared well though. Farmers have found it one-sided – imposing a lot of conservation responsibility on the farmers in exchange for meager returns. It has also been creating insecurity. People know that once the mangroves have re-grown farmers will be kicked out, so there is a perverse incentive for farmers to intentionally prevent mangrove recovery.

The written contracts have also been problematic. Many people in the delta are illiterate, and they fear anything that is written and requires to be signed. People feel like they are getting tricked. As one respondent in a focus group discussion remarked: "*perhaps there is something written there that we don't understand…*?" During the introduction phase of one of these projects many communities refused to sign these contracts due to such apprehensions [12]. After so many years of mistrust and harsh policies, people (especially pastoralists and "squatters" around protected areas) do not always trust government's intentions [49].

4.2 Group rehabilitation

This is another rehabilitation strategy that has been tried for the mangroves in the Rufiji Delta, with the support of the UNDP and UNEP. Local collectives of 15–30 men and women were assigned an area of mangrove forest to rehabilitate, and were paid for each day they used replanting or weeding the young trees. Under this arrangement, small-scale mangrove replanting was undertaken between 2009 and 2010 as a community project by 100–200 community members from 10 villages over about 70 ha of former mangrove habitat, of which around 45 ha were abandoned rice farming plots [12].

Communities initially embraced the project, but as one project official confessed sometime later, some villagers complained about favoritism, saying they felt excluded from the scheme (Mshale, pers. comm.) Even though TFS were emphatic that the project would be expanded to ensure benefits were shared by as many people as possible, the program could not manage to give people a sense of ownership over the forest. As the official later noted:

> *"These people are providing casual labour, but they don't have any other rights over the areas that they are replanting. So the moment you stop paying them, they won't be able to come and work for you."* (Mshale, pers. comm.)

Hence, the future of the program itself was uncertain because it relied heavily upon donor support. Once the funds dried up, the system could not be sustained. And because these schemes also failed to confer long-term management rights or responsibilities on community members, those involved were not incentivized to ensure the trees' survival and in many cases people returned to farming the areas once the scheme failed.

4.3 Community co-management of mangrove resources, including Joint Forest Management

Community participation as a neo-liberal approach to natural resources management in Tanzania has become the most important approach within the forestry sector following its inclusion in the National Forest Policy of 1998, Land Act of 1999 and the Forest Act of 2002. Nevertheless, the efficacy of the move to designate responsibility of forest management to local communities remains unclear [51, 55].

Building interest in poverty reduction to enhance sustainable resource management and strengthen the rights of communities to access and manage mangrove forests to improve livelihoods and resource conditions is one thing. But, whether this has translated into actual poverty reduction in practice is another thing altogether. So, the dilemma persists in poor countries like Tanzania on account of building a strong synergy of community participation and poverty reduction, *at least in theory* (emphasis added) [56].

The most promising approach, according to CIFOR research, has been the Joint Forest Management (JFM) scheme being tried in the Rufiji Delta as part of the Participatory Forest Management program [49]. By the time of this study TFS had negotiated with individual communities in four (4) Rufiji villages to draw up plans for sharing the costs and benefits of managing the mangrove forest. Though the state retains ultimate ownership of the mangroves, the scheme transfers some decision-making power to the local people.

By the time of the Mshale *et al* [49] study, the communities had embraced the scheme. The JFM system appeared to provide broader rights and benefits than the other two mechanisms. It meant that community members' actions such as harvesting timber, poles, charcoal, firewood and other products were no longer criminalized. What is needed is proper management and making sure that the benefits and costs are equitably and fairly distributed among community members.

In particular, it needs ensuring women's meaningful participation in decision-making in a culture where women are traditionally meant to stay silent during group meetings. That could need providing a separate space for women to debate ideas among themselves, before bringing their concerns to the wider community. However, implementation efforts and tangible evaluation of progress continues to lag behind conceptual development [57].

The proposed mechanism for REDD+ offers significant potential for conserving forests to reduce negative impacts of climate change. Tanzania has been one of nine pilot countries for the United Nations REDD Program, receiving significant funding from the Norwegian, Finnish and German governments. The country is also a participant in the World Bank's Forest Carbon Partnership Facility. In combination, these interventions aim to mitigate GHG emissions, provide an income to rural communities and conserve biodiversity for the market [58].

As already noted above the mangrove plantation is expected to be one of the options of afforestation in the Clean Development Mechanism (CDM) project through its ability to accumulate sequestered carbon below-ground [58]. However, it is the economics of the initiative that is of interest to us here. The establishment of the UN-REDD Program in Tanzania, for example, illustrates the challenges that face many developing countries. As noted by Burgess *et al.* [59], the challenges have included inadequate baseline forestry data sets needed to calculate reference emission levels.

It has also involved inadequate government capacity and insufficient experience of implementing REDD+ type measures at operational levels. In addition, for REDD+ to succeed, current users of forest resources must adopt new practices, including the equitable sharing of benefits that accrue from REDD+ implementation. This challenge is compounded by failure of conservation (as a form of land use) to compete effectively with alternative land uses [60].

For example, it is reported that the annual global economic value of ecosystem services is estimated to be between US$200,000 - US $900,000 per hectare [12]. The value of commercial mangrove timber products and poles in the Rufiji mangrove delta and flood plain in Tanzania is around $771,789 per year, fuel wood extraction $156,000 per year and honey extraction $9000 per year [19]. Most of the latter benefits go straight into the communities' household economy but stand to be foregone under global conservation.

Büscher *et al* [59] provide an interesting thesis on this phenomenon. They note that in the spirit of "ecological modernization", modern environmental problems and related crises are in fact themselves increasingly becoming conceptualized as opportunities for capitalist expansion rather than vehicles of poverty reduction. In a study that measured the impact of a national community-based conservation and poverty reduction initiative in Tanzania, it was found that from 2007 to 2015, the impacts of Wildlife Management Areas (WMAs) on wealth of the local communities were small and variable, with no clear evidence of widespread poverty reduction [61].

On the other hand, another study using five (5) years of photographic data capture-recapture found greater densities of livestock and lower densities of wildlife inside a WMA. After the management changes, the study documented significantly higher densities of wild ungulate species and lower densities of domestic ungulates in the WMA [62]. Giraffes' survival and population growth rate were both found to have increased in response to the management changes, indicating that the WMAs were effectively providing habitat and protection for wild ungulates while generally excluding domestic livestock [62].

4.4 Mangroves in the neo-liberal perspective

Neo-liberal conservation takes many forms, but more significant it reframes conservation in terms of market mechanisms [63]. Neo-liberal conservation is being defined as the decentralization of environmental governance, or a shift in responsibility for formal resource management from state to local institutions and new forms of commoditization and commercialization of nature that emerge in these contexts in order to fund conservation efforts. Advocates of market-based conservation argue that such markets will increase conservation funding and increase environmental-friendly businesses. People say it will promote participatory conservation and protect native property rights. Others say it promotes environmental consciousness, thus enhancing more effective and efficient conservation [64, 65].

Ever since the first Earth Summit in 1992 which was perceived to be a potential regulatory constraint on the operation of business, corporate interests have struggled to draw the sting out of the regulatory measures that the Summit recommended. States are said to have out-maneuvered NGOs around the Convention on Biological Diversity (CBD) to produce a convention which prioritized generating profit from genetic resources over protecting the environment [63]. Business interests have thus enjoyed access to prime slots during Conferences to the Parties of the CBD. Crucial to all these developments has been the formation of a transnational capitalist class fostering alliances and giving business interests the space and support they require [66].

It has been observed that much as conservation NGOs need the capital and legitimacy businesses provide, it has been the corporate interest which has reached out to conservation groups [63]. Corporate interests are seeking to make money out of new opportunities in mangrove restoration and conservation. They are looking for new profits in ecological modernization rather than biodiversity conservation. Although the gains for biodiversity are less clear within conservation organizations, the result of their embrace by commercial interests is that there has been a "near universal conflation of nature and capital [which] has established itself as a dominant view" (*ibid* [67]. See also [25].

Costanza *et al.* [68] assessed the economic value of 17 ecosystem services for 16 different habitats. They found out that the value of the whole biosphere was approximately US$16–54 trillion per year or US$33 trillion per year on average. They note that those figures may probably be higher today. Hence, they insist that drastic measures need to be taken if we are to prevent further widespread and irreversible loss of these ecosystems and *sustain their ability to generate new profit avenues worldwide* [64] (emphasis added). See also [69, 70].

However, market-based conservation has also been observed to lead to primitive accumulation, accumulation by dispossession and green grabbing [64]. All these processes have been proved to have negative impacts on local people's access to natural resources, food security, human rights, and the environment. Mariki [64] reports, for example, that some WMAs in Tanzania have disappointed the local people as people were persuaded to demarcate their land for conservation, take management responsibility and benefit from the resources through tourism. Instead in WMAs like Enduimet the central government has retained the power of strategic decision making over the WMA and only minimal benefits have been realized by the local communities.

4.5 Mangroves from a local cultural perspective

> *With a grim look on her face, Maimuna (Maimuna Ramadhani, 39-year old lady, Mchungu village) laments over the dwindling number of fish in the area for which she blames the destruction of mangroves. "The trees are harvested without replanting and now even when there is a high tide, it floods our homes," she says. "Why don't you do something about it?" we ask. "Because it is not my place to do so," she says.* (Mshale, pers. comm.)

Formal sources specifically linking people and mangroves, in particular their management and tenure regimes are lacking. However, basing on knowledge on linguistic analyses of some of the ancestors' myths and other oral traditions, coupled with the written narratives by European explorers, mangroves seem to the colonizers to have long been wastelands [13]. Nevertheless, to a majority of the local people, the mangrove landscapes were communal territories, inhabited, managed into multiple use systems, governed by access and use rights and controlled by local customs [64].

A second point that can also be surmised from these histories is the diversity of the human establishments in the mangroves and the highly varied forms of customary tenure with their "simple" knowledge of resources, the presence of spirits and supernatural creatures, with which the populations had to negotiate [13].

South of the Rufiji Delta, the island of Kilwa establishes a remarkable evidence of an urban and commercial civilization built in the mangroves dating from 9th to the 16th centuries. The historian Sheriff [71] reports of palaces and mosques, testifying of a glorious past of the sultanate, until the arrival of the Portuguese, who destroyed the estate in 1505 and monopolized the trade of gold, textile, spices, ivory and slaves.

The colonial institutions, then the independent State competed to destroy the former order in the form of traditional institutions [13]. They also tried to marginalize the traditional users. The tragedy of the commons observed elsewhere by Hardin [72] became their explanatory theory. But observers such as McCay and Acheson [73] see a new struggle brewing up by the present generation that is trying to grapple with in the Rufiji Delta and elsewhere in the country.

In general, however, the main image of mangrove swamps, the one that emerges from the narratives of European voyagers and missionaries in the 17th century, echoed throughout the 18th and 19th centuries in the writings of colonial agents, is one of a hostile and impenetrable environment [13]. For hygienic and productivity aims, mangrove swamps were reclaimed under the control of colonizers, who finally became their landlords.

Thus the first enclosures of mangroves were both public and colonial and aimed at converting mangrove swamps into rice fields. The following more recent enclosures (especially from the years 1970s) joins what certain authors qualified as "green imperialism" and aim at making it world heritages through conservation [13]. Nevertheless, the effectiveness of such protection has been highly variable, with several protected areas failing to halt mangrove decline because they were poorly designed or lacked enforcement.

In Tanzania there were greater mangrove gains between 2009 and 2015 than in other years [40]. This is probably due to conservation projects initiated in the delta in late 1990s and implemented by WWF-Tanzania, the TFS Agency and the Rufiji District Authority aimed to restore the deforested areas [17]. The projects are now promoting Payment for Ecosystem Services (PES) as the most rational approach to environmental management. PES uses the language of economics to convince potentially resistant policymakers, corporate actors and domestic populations, particularly in developing countries, to farther ecological goals such as biodiversity conservation.

Thus, environmental nongovernmental organizations (ENGOs), academics and international organizations alike spend considerable effort trying to "translate" the worthiness of the environment into the mutually intelligible language of neoliberal economics, in order to convince policymakers and economic actors of the validity of the conservation actions [9, 74].

Nevertheless, a study on the outcomes of CDM projects in Argentina a few years ago did not give such a hopeful picture at all. The study demonstrated that under the current Argentina's energy policy framework, the income by the selling of CERs covered less than 6% of the incremental costs for renewable energy projects [75]. A sensitivity analysis to evaluate the impact of CDM in the coverage of incremental costs for renewable energy based on the prices of both the energy in the local market and the CER demonstrated that the best conditions would only cover 15% of those costs. The contribution of CDM to technology transfer in Argentina was minor considering that 45% of the projects qualified as type III where technological learning and capacity building were limited at the level of operation and maintenance of a foreign technology [75].

In another research on REDD+ implementation in two case study villages in Tanzania, Scheba [65] argued that the emergence and nature of market-based conservation are complex and more shaped by structural challenges than is commonly acknowledged. The research identified three important challenges:

1. the politics surrounding the establishment of community-based forest management;

2. the mismatch between formal governance institutions and actual practices on the ground; and

3. the fickleness of income from carbon sales and alternative livelihood opportunities [65].

The challenges were conceptualized not only as teething problems. The results questioned the very fundamental assumptions of market-based conservation. Moreover, adopting neo-liberal approaches like PES may cause problems for the effective management of nature at the local level, and by extension, the implementation of the environmental regimes themselves. According to Scheba [65], market-based instruments share a common objective of re-framing landscapes as providers of "ecosystem services" and rural communities as latent eco-entrepreneurs, who can cultivate and sell the services as commodities for profit. "Selling nature to save it" is promoted as the best philosophy of achieving sustainable rural livelihoods in the face of mounting environmental crises and persistent poverty.

In fact, some authors (e.g. [67]) even think the commoditization of nature is part of broader project of neo-liberal globalization and encompasses a number of scientific and political techniques meant to bring non-market and non-economic materials, processes and things, including those that are considered part of natural ecosystems and are objects of traditional conservation, into the logics of economics and markets [65, 76–78].

Many indigenous peoples are concerned about the ways in which carbon markets commodify nature [79]. A market-based view prioritizes cost-effective strategies and the commoditization of ecological services, thereby utilizing the same economic tools and logic of capitalism that is also the underlying cause of the climate change problem. It is thus that some observers emphasize that market-based conservation is more complex, contested in practice, with mixed outcomes than is implied in the mainstream narrative [65]. It produces both benefits and risks. It produces benefits in the form of nature protection, political inclusion, and economic opportunities, while risks include physical displacement, loss of livelihoods, increased human–wildlife conflicts, and unequal distribution of benefits to some local community groups.

5. Concluding remarks

Since the late 2010 mangroves have become an important focus of market-based carbon-oriented nature conservation. A lot of work by different conservation organizations has been focused on framing or branding mangroves as particularly charismatic and valuable, but vulnerable, ecosystems. Beyond carbon, conserved mangroves and other coastal ecosystems are framed as untapped resources for ecosystem services, including coastal protection, fisheries, water purification, and conservation of marine and coastal biodiversity.

However, what the neo-liberal approach describes as "effective management" has not always been compatible with effective management of resources. For practical and ethical reasons, practitioners need to be critical of any assumption that neo-liberal economics is always an appropriate framework upon which to base local environmental management. Initiatives like REDD+ just represent the latest in a long line of efforts to tap global markets for conservation finance.

It is thus that current difficulties in the REDD+ mechanism are essentially symptomatic of inherent deficiencies in the market-based conservation in general. The fundamental problem is that conservation markets are intended to counter the conventional extractive markets, which generate profit by externalizing environmental costs.

Conservation markets seek to reverse this by internalizing these costs within the payments they provide to forest managers. Yet to function as market mechanisms, *payments must provide at least as much revenue as the extractive markets they replace* (emphasis added), covering not only opportunity costs of extraction but also the social and environmental costs that this extraction externalizes.

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Chapter 8

Conservation Management of Planted Mangroves through Evaluating Ecosystem Services in Baros Village Bantul Regency, Indonesia

Djumanto

Abstract

Planting mangrove trees on sandy land in Baros village into forest conservation has many ecological, economic, social, and tourism benefits for the surrounding community. The mangrove conservation in Baros village is artificial conservation managed by the men and women Baros youth. The coastal area of Baros village is often affected by tidal flooding, which causes losses to agriculture, fisheries, and livestock. In the early 2000s, an NGO assisted at research sites in mangrove restoration in a mangrove restoration area in the lagoon of Baros village to prevent abrasion and sea intrusion and protect agricultural areas. Restored mangroves can grow well to bring ecological, biological, economic, and social benefits. The local government of Bantul has designated the Baros mangrove forest as a reserve of a coastal park conservation area. The existence of the tree is beneficial ecological, biological, economic, and social. The Baros village youth group made various efforts to increase mangrove trees' area so that their benefits were sustainable. Managers and the village government and tour guides are expected to accommodate the existence of culture and local wisdom. Also, increasing community participation, fisheries, agriculture, and animal husbandry activities can provide socio-economic benefits for the community and the wider community's welfare.

Keywords: community, diversity, ecotourism, youth group, Yogyakarta

1. Introduction

Yogyakarta is one of the fourth most considerable cities in Indonesia by population, located in the southern part of the Java island. It became the capital of the Republic of Indonesia in January 1946–August 1950. It became a Special Province of Yogyakarta because of its enormous role in the founding of the Republic of Indonesia. It is a province that has many nicknames, namely as a student city, cultural city, tourist city, culinary city, artist city, batik city, palace-city, traditional market city, warm city, bakpia city, and so on.

Yogyakarta has a variety of tourist and cultural attractions that are very interesting to be visited and enjoyed by local and foreign tourists. Tourist attractions in Yogyakarta are quite complete, ranging from ecotourism, natural attractions such as beaches and mountains, historical tourism, religious tourism, shopping tourism, culinary tourism, and cultural tourism. Therefore, Yogyakarta ranks second as a tourist destination after Bali Island. Besides having full tourism potential, it also has several beautiful and challenging natural environments. One of them is the Merapi-Kaliurang lava tour, the off-road jeep Merapi lava tour, which is also an attraction for tourists to visit and try it. Some of these attractions include an excellent warm air climate, stunning views of the sandbanks, a culture that is still profoundly engraved with its people, and the friendliness of its citizens [1].

Bantul is a regency city located on the southern side of the Special Province of Yogyakarta. It has a 16.8 km long beach, which is very interesting as a tourist spot and various other activities. One of the tourist attractions is the sandbank or dune along the south coast with a width of 1–2 km. Residents partly use the dune area as a sultan ground for agriculture, animal husbandry, fisheries, tourist areas, and conservation areas. Local people also plant with evergreen shrimp trees (*Casuarina equisetifolia*) for a protector of crops and shade for visitors or tourists. Also, some areas of the southern coast of Bantul serve as turtle landing areas for laying eggs. Species of turtles that often land are hawksbill turtles (*Eretmochelys imbricata*), curved turtles (*Lepidochelys olivacea*), green turtles (*Chelonia mydas*) and leatherback turtles (*Dermochelys coriacea*). They use Pelangi Beach Depok, Samas Beach, Goa Cemara Beach, and Baru Pandansimo Beach as landing points for laying eggs. Furthermore, some people who are members of nongovernmental organizations carry out turtle conservation by saving and hatching to be released into the sea after they are old enough [2].

Bantul beach also has a natural attraction with the presence of mangrove forest conservation areas in the village of Baros. Administratively, the mangrove forest located in Baros village, Kretek sub-district, Bantul regency. The Baros Mangrove Conservation Area situated between Depok beach and Samas Beach in Yogyakarta. The mangrove forest is a conservation area that was initiated by the family of Baros young women (KP2B) since 2003. The Baros coastal area is planted with several types of mangroves, *namely Avicennia lanata, Avicennia officinalis, Nypa fruticans, Rhizophora mucronata, Rhizophora stylosa*, and *Sonneratia caseolaris*. The plants are used for area conservation due to natural disasters, such as coastal abrasion, crop failure, drought, intrusion, tsunami threats, and high salt levels that make crops wither. Natural hazards that routinely hit Baros beach have made people aware of cheap and durable natural protection. The position of Baros beach, which is at the mouth of the Opak river, causes various types of waste to be stranded on the beach, for example, wood debris. The community processes wood debris waste into high-value decoration. Besides, the Baros youth family collaborated with NGOs of Relung initiatives to carried out mangrove planting and various other coastal plants. With the existence of environmental conservation activities in Baros Beach, Baros's youth family has increasingly gained the community's trust in managing the environment of the Baros village sustainably [3].

Baros mangrove conservation ecosystem is a dynamic area that has biotic and abiotic resources. Biodiversity consists of birds, land animals, terrestrial plants, mangroves, aquatic biota, while abiotic natural source includes lagoons, sandy beaches, river mouths. The area behind the mangrove is for agriculture, animal husbandry, and fisheries. Various components interact and are interdependent with each other, which has great potential in supporting the community's economy, so it must be managed optimally and sustainably [3]. The Baros mangrove conservation area can have a positive impact on the surrounding community, including the following: (a) improve the economy of the surrounding community. (b) They are protecting rice fields from abrasion. (c) Protecting crops from the brunt of sea salt. (d) Opening job opportunities and new business opportunities. (e) Increasing public awareness to protect and preserve the environment, (f) Providing social, economic, and physical comfort. (g) Foster a sense of ownership of mangroves for community members. And (h) open networks with government, NGOs, universities, communities, and stakeholders to manage mangroves.

The conservation mangrove area of Baros is an artificial natural tourism area that has very diverse natural resource potentials, but its management is not yet optimal. It is necessary to study their resource potential, the obstacles faced by managers, and opportunities for their development. This paper aims to identify the benefits of the existence of mangroves, and opportunities to increase their profits and sustainable management strategies while still considering their natural protective and coastal functions. Besides, it is as a reference for policymakers. It can add insight into the importance of mangrove forests as a natural tourist attraction as a place of learning to foster public awareness of the sustainability of mangroves.

This paper was written based on field observations, interviews with the KP2B management, and Baros village officials, research results, and based on literature studies from various sources. Data or information from resource persons is analyzed descriptively to get an understanding of the level of mangrove utilization for the Baros village community and the role of the society in maintaining the sustainability of coastal ecosystems, as well as providing input for Baros mangrove conservation managers.

2. The benefits of Baros mangrove ecosystem

The mangrove forest ecosystem in Baros is an essential natural resource located on the southern coast of the Baros village and the west side of the Opak river estuary. The ecosystem has four main functions, namely, physical, biological, economic, and social services. The physical service is as a windbreak, filtering pollutants coming from upstream rivers and the sea, anchoring waves and rising tides, flood protection, waste repellent, and preventing seawater intrusion to land. The biological function is as a place for the parent and larvae of aquatic biota that is to spawn (spawning ground), nursery ground, and as a place to find food (feeding ground) for fish and other marine biotas. The direct economic function is as a producer of wood for building materials and industrial raw materials, food and medicines, animal feed sources, a place for grazing and raising poultry. The indirect economic function is for tourist attractions, places of education, research, its existence can protect crops. Also, mangroves become primary producers, forming stable micro-ecosystems between marine and terrestrial ecosystems. The social function is the existence of mangroves capable of bridging the formation of social groups of Baros youth families, breeder groups, farmer groups, marketing women's groups [4]. The existence of mangroves on the Baros coast can provide ecosystem services directly and indirectly. For example, direct services filter out dust and salt vapors, provide oxygen, provide shade for visitors, and protect beaches. For example, indirect ecosystem services preserve agricultural, livestock, and fisheries areas, and prevent seawater intrusion.

The existence of mangroves is a characteristic of the coastal area, however the Opak estuary and the Bantul coast until 2003 were in the form of a very dry and unproductive dune. Furthermore, starting in 2003, some university students in Yogyakarta, NGOs, and the local community planted several species of mangrove trees. Since then, the mangrove area has slowly increased. Mangrove tree seedlings transported from the city of Cilacap, which was 170 km from Bantul. The Species of mangrove seedlings planted were *Rhizophora* sp., *Bruguera* sp., *Nypa* sp., *Soneratia* sp.

The Regent of Bantul in 2014 issued Decree No. 284 of 2014 concerning the Reserve of Conservation Areas for Coastal Parks in Bantul Regency [5]. The Baros mangrove forest area is designated as a conservation area with a total area of 132 hectares divided into three zones, namely the core zone (10 ha), transition zone (94 ha), and buffer zone (28 ha). The Baros mangrove forest's current area is still less than 10 hectares, so a gradual expansion is needed. The development of the mangrove forest area is carried out by planting mangrove seedlings that are propagated in locations or transported from other cities (**Figure 1**).

2.1 The physical existence benefits

The existence of mangroves on the Baros beach will provide many benefits to the surrounding ecosystem directly or indirectly. The direct benefits of the mangrove

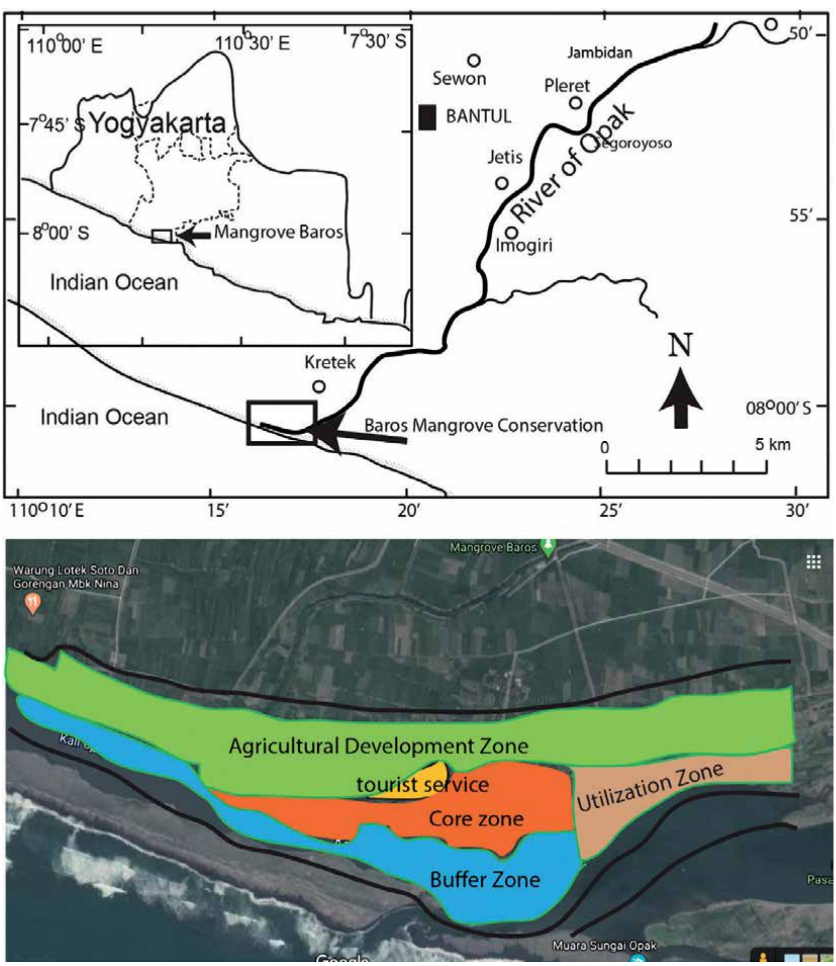

Figure 1.
The map shows the reserving area of coastal garden conservation area in Bantul regency. The zone consists of a 10-ha core zone, a 28-ha buffer zone, and transition 94-ha zone.

ecosystem as a habitat, as a protection, and source of raw materials. Indirect benefits provide a fresh ecosystem, provide food, absorb carbon, and provide nutrients for aquatic organisms.

2.1.1 Mangrove as a habitat

Baros mangrove ecosystem becomes a habitat for various species of native or migratory birds, living temporarily or permanently. Mangroves provide space for birds to breed and maintain their chicks. Species of birds found before mangroves are only a few species, for example, Blekog Sawah (*Ardeola speciosa*), rice field finches (*Lonchura punctulata*), finches (*Pycnonotus aurigaster*), etc. Blekog sawah comes during the growing season, while rice field finches come just before the rice harvest. After the mangrove area planted, various types of birds stopped by permanently or in-migration. Every rice planting season, several species of birds will migrate alternately [5].

The presence of birds in the Baros mangrove area can be an indicator of functional space. The number of bird species increases due to the availability of material to make nests, and there is no disruption to birds. Water birds are the dominant bird species in the mangrove area because mangroves provide habitat for feeding, breeding, and growing chicks. The species of birds that found are Java bondol (*Lonchura leucogastroides*), Peking bondol (*Lonchura punctulata*), and beach trinil (*Trunga hypoleucos*). The bird is active in mangrove trees of *Avicennia alba* and *Rhizophora apiculata*. The number of bird species in the Baros mangrove found as many as 21 families consisting of 48 species [5].

2.1.2 Mangroves as coastal protection

The existence of mangroves can protect the coastline, crops, and groundwater. (1) A robust mangrove root system helps to form a natural barrier against storm surges and floods [6], trapping river and terrestrial sediments [7], thus protecting coastline areas and slowing erosion. (2) The presence of mangrove plants can reduce and affect airflow. The sea breeze that blows hard will decrease its speed after passing mangrove plants. Strong winds that blow directly can break the branches and leaves of vegetable crops. Also, high salt levels contained in the sea breeze will be absorbed by mangrove leaves so that the salt content also reduced [8]. Mangrove plants are resistant to salt, while crops are very vulnerable. Sea breeze with high salt content can kill crops. Salt carried by the sea breeze will stick to vegetables. Salt is absorbing water so that salt attached to plants will absorb plant water, which can cause plants to wither. (3) The existence of mangroves can withstand the flow of seawater through a healthy root system so that saltwater does not intrude on agricultural land. The farm area behind the mangrove is protected and can be used for farming. Farmers can plant crops only once per year before there are mangroves, but now thanks to mangroves, agriculture can be done 2–3 times per year [4].

2.1.3 Mangrove as source of raw materials

Coastal communities use plants in mangrove ecosystems for various purposes, namely as medicinal materials, firewood, animal feed, building materials, decoration materials. (1) Daruju or Mountain Thistle (*Acanthus montanus*) is a bush that grows in the Baros mangrove ecosystem (**Figure 2**). This plant has a unique shape, large-toothed leaf edges, and sharp edges. The leaves are shiny green and slightly yellowish. People use daruju seeds for stomach worming and cough

Figure 2.
(A) The community uses the leaves and seeds of daruju (Acanthus montanus) as a traditional and herbal medicine for several types of diseases. (B) The daruju that grows on the edge of the lagoon to form thickets as a hiding place for fish larvae.

medicines. Also, shrimp farmers use daruju leaves to treat white disease in their shrimp. (2) Baros residents easily find a lot of dry wood scattered on the beach. The wood comes from the headwaters or the sea carried by the waves. Timber from the headwaters of the river is for firewood, while wood from the sea becomes driftwood. Driftwood is wood that has long been adrift in the sea. Driftwood has a definite, dry, lightweight, and unique shape, so it is suitable for decoration raw materials. They separate wood into driftwood and firewood. Good quality driftwood is used as raw material for handicrafts, while low quality is used as firewood. Conservation area managers forbid anyone from collecting mangroves for firewood. Firewood and driftwood are sold to collectors, making it a household income. (3) Mangrove leaves and grass contain a lot of protein so that it can be used as animal feed ingredients. *Avicennia* sp. can be used for animal feed. In addition, grass that grows around mangroves is also collected as animal feed. Cattle farmers often have difficulty in getting forage feed, especially in the dry season. The presence of grass in the Baros mangrove ecosystem can be an alternative source of animal feed. In Baros, there is a group of breeders with around 35 cows, some of which have green grasslands in the form of grass from the Baros mangrove area. (4) Mangrove wood has a waterproof and robust character, so it is suitable for building materials or ship materials. Large mangrove stems can be used as household building materials. Mangroves that are already high enough can be used as blocks for housing construction [9].

2.1.4 Providing fresh air

Mangrove in Baros is in excellent condition with the color of fresh green leaves, and no damaged mangroves are found. The distance between trees is less than two meters, which is classified as dense and has a high enough biomass potential. A healthy tree has healthy chlorophyll so that during photosynthesis, it can produce a lot of oxygen. Mangrove forests can produce oxygen (O_2), which is essential for life. The existence of mangrove forests in Baros becomes so important and attracts people to visit [9]. Every month there are around 700–1000 people visit the Baros mangrove forest to feel healthy ecosystems and fresh air.

2.1.5 Providing food

Mangrove ecosystems can support food security by providing food that is an aquatic biota that lives in the mangrove ecosystem, and food that is processed using mangrove plant parts. Mangroves can produce substantial amounts of organic material as food. The use of mangroves as a food source can improve family nutrition.

The existence of mangroves becomes very important in the life cycle of various types of fish, shrimp, shellfish, mollusks, and other aquatic organisms. Many kinds of shrimps and crabs that have economic value utilize mangroves as nurseries. Many species live in mangroves or visit temporarily in young stadia using mangroves to find food. The existence of good mangrove forests will support the life and production of marine biota that can be used as a source of food for the community [5].

2.1.6 Absorption carbon

During photosynthesis, mangroves absorb CO_2 gas from the atmosphere and convert it into organic carbon, then stored as carbon biomass in roots, stems, and leaves. The amount of CO_2 used by mangroves has a positive relationship with the total amount of biomass. CO_2 gas that is absorbed is getting more significant when the mangrove plants are getting denser. The results of photosynthesis are used for horizontal and vertical growth. The larger the diameter of the tree, the higher the CO_2 gas absorbed by the tree to be converted into organic material. Mangrove forests store more carbon than most tropical rain forests [10].

2.1.7 Providing nutrients

Mangrove provides organic material and nutrients through the production of litter. Litter production is an important part of the transfer of organic matter from vegetation to the soil. The nutrients produced from litter are essential in the growth of mangroves and as a source of detritus for estuary ecosystems in supporting the lives of various aquatic organisms. Mangrove litter productivity is a source for fishery's productivity in estuaries and contributors of nutrients to the surrounding waters. It makes mangroves play an important role as a nutrient cycle chain for aquatic organisms. Mangrove plants are a potential food source, in various forms, for all the biota that live in the mangrove ecosystem. The basic component of the food chain in the mangrove ecosystem comes from mangrove plants that fall into the litter. Mangrove leaves provide many benefits to the surrounding organisms. Mangrove leaves contribute 81% of the total litter production, while the rest comes from twigs and plant reproductive organs [11]. As much as 5% of the total leaf production is consumed directly by herbivorous organisms, while 95% enters the aquatic environment as detritus. Mangrove dominated by Rhizophora sp. with a high density can produce an average of a litter of 4.05 g/m^2/day. Nutrient potential production from litter produced is C = 0.35, N = 0.009 and P = 0.0008 g/m^2/day [12].

2.2 Biological function

One of the essential functions of mangrove forests is biological functions, namely, their ability to support life around them. The biological function that is carried out by the Baros mangrove forest is as a spawning ground, nursery ground, and feeding ground for aquatic biota, as a natural habitat and to provide food. Some fish species that migrate or settle in the mangrove ecosystem may spawn, care for their offspring, take refuge, or find prey [13].

Species of fish inhabitants of the Baros mangrove ecosystem based on their ability to adapt to salinity are grouped into three, namely the original inhabitants of freshwater, brackish water, and marine species. The number of fish species found in the mangrove ecosystem is 36 species consisting of 3 brackish water species, 11 freshwater species, and 22 marine species [12].

2.2.1 Spawning ground

The Baros mangrove ecosystem experiences changes in salinity that occur every day. Extreme changes in physical parameters affect the number of fish species that can adapt to brackish water. Brackish water species are species that all stages of life exist in brackish waters. Brackish water species are the least amount compared to seawater or freshwater species. This species uses brackish or mangrove water ecosystems to breed, care for, and raise their offspring [3]. This species is most vulnerable to extreme physical and chemical changes in brackish waters. Efforts to improve mangrove ecosystems can save the survival of brackish water species. Brackish water species found in the Baros ecosystem are *Acentrogobius caninus*, *Ambassis interrupta* and *Glossogobius giuris*.

2.2.2 Nursery ground

Freshwater and marine fish species found in the mangrove ecosystem are mostly in the larval stage. Eggs that hatch into larvae spawned in the sea or upstream of the river are carried by currents to reach the mangrove ecosystem by utilizing tidal or river flow. The waters of the mangrove ecosystem provide habitat for larvae protection. Besides, the mangrove ecosystem is very fertile so that it can provide food for aquatic biota larvae stage. The proportion of larvae of marine species is more than that of freshwater species. The Baros mangrove ecosystem is essential as a nursery ground for most economically important marine fish, such as snapper, mugil, and sardine [3].

2.2.3 Feeding ground

The number of species and individual fish in the juvenile stage is higher than in the young fish stage. Omnivorous and detritivores groups dominate fish in the immature stage. Mangroves, as first-rate producers, can produce large amounts of detritus from leaves and twigs. Mangrove ecosystems can provide organic nutrients that fertilize brackish water, the more mangrove trees, the higher leaf litter production. The number of leaves that fall will produce more detritus. The more leaf waste is produced, the more food is available. Mangrove ecosystems and health conditions affect the capacity of young fish to feed in mangroves. The healthier mangrove ecosystems, the more able to accommodate fish biomass [3].

Season and water conditions affect the abundance of juveniles in mangrove ecosystems. The number of biomass and young fish species is found more in the rainy season. The amount of available nutrients is more abundant in the rainy season. Likewise, most fish species spawn in the rainy season. The abundance of juvenile fish is also affected by the lunar cycle. In the full moon and new moon, the juvenile number is less.

2.3 Economic function

Baros mangrove ecosystem has an economic function or economic value. The commercial service is the role value of mangrove forests in creating employment for the community, so they have income. Economic value shows the role of conservation of mangrove resources in producing activities that can be valued. Economic value includes the amount of utilization and nonvalue utilization of resources. Utilization value consists of the direct amount of use, the indirect cost of use, and the value of choice. Nonutilization value includes the value of existence.

Direct use value is the value obtained from the production of goods that is resulting from the direct utilization of resources. The direct use value includes the use of wood and the capture of fishery commodities in the mangrove area. Indirect use-value is the value assigned to the benefit of resources in the environment. Indirect use values, for example, the cost of mangrove areas as a barrier to seawater intrusion, and the amount of a wall as waves, or other environmental benefits felt by the local community. The choice value is the benefit value of a resource that is stored or maintained for future use. The choice value is the value of the biodiversity of mangrove flora and fauna. The existence value is the value given by the community to resources for the various benefits [4].

The total economic benefit value of the Baros mangrove area is $ 14,846 US ha/year. The direct economic benefits value of $ 1738 US ha/year, and the indirect economic benefits value of $ 11,615 US ha/year. The optional benefits value about $ 15 ha/year. The existence value for $ 1478 US ha/year. The highest percentage of economic benefit value is the indirect benefit of the mangrove area at 78.2% [4].

2.4 Social function

Social service is the role of mangrove forests to improve the welfare of life or improve the social welfare problems of local communities. The social function of the Baros mangrove is closely related to the formation of the family of Baros young women (KP2B) in the 80s. KP2B members are all Baros villagers who are in first grade of high school. KP2B, in collaboration with NGO Relung in 2003, initiated the planting of mangrove trees in Baros Village. The purpose of planting mangrove trees is to protect the village from the threat of abrasion, intrusion, and tsunami and to protect plants from blowing sea breezes high in salt, which causes crops to wither.

The family of Baros young women empowers citizens to play an active role in improving their welfare by forming five working groups. Workgroup activities are related to mangrove conservation. The working groups formed are Avicennia working group, Mino Tirtohargo, Andini Lestari-Karya Manunggal, Mangrove Farmer Group Association—Women Farmer Group, and Processing and Marketing Group.

Each working group conducts a business that supports mangrove sustainability. They are namely (1) Avicennia working group does business in the field of processing marine driftwood waste. (2) The Mino Tirtohargo working group conducts fishing activities. (3) Andini Lestari-Karya Manunggal working group conducts business in cattle and duck farming. (4) A joint working group of farmers—women farmer groups carrying out agricultural activities. (5) The processing and marketing working group carries out learning activities and consumption services in the form of traditional food. The actions of each working group are as follows.

Avicennia's working group activity is an effort to process driftwood waste into handicrafts with artistic value. This effort is motivated by concerns about the amount of garbage in the Baros mangrove area. Garbage often covers or breaks young mangroves, thus disrupting mangrove conservation efforts. Driftwood is wood waste that has long been oscillated in the sea and then stranded in mangroves or beaches. Processing driftwood waste is an effort to reduce garbage and to increase income. Driftwood waste processed into handicrafts with high artistic value. The final product processed driftwood is a type of craft items in the form of wall displays, wall clocks, decorative lamps, tissue boxes, miniature Christmas trees.

The Mino Tirtohargo working group carried restocking of mangrove crab and fishing. The crabs find food, grow and breed in the mangrove area. Mangrove crabs can grow well and reproduce in areas with mangrove areas. Stocking crabs can increase the stock and catch of fishermen. Before doing restocking, fishermen get small crabs in the dry season only. After restocking and mangrove have grown well, fishermen can get crab catch every day. Restocking is also carried out by universities to increase fish stocks and fishermen's catches. The fish stocked is milkfish (*Chanos chanos*) in the year of 2014 at the amount of 20,000 individuals. Milkfish restocking aims to increase fish stocks as fish consumption catch and fishermen income. Milkfish restocking is done by considering that the Baros mangrove area is a suitable habitat for milkfish. Milkfish restocking can balance the population structure of the mangrove ecosystem.

The Andini Lestari working group conducts a cattle breeding business using group cages. The location of cattle farms is in an integrated livestock utilization zone adjacent to the agricultural land and the Baros mangrove area. Andini Lestari's working group has 35 units of cages with three types of cows, namely Simetal, Lemusin, and Java, which are managed in an integrated manner. Cattle are fed grass obtained in the Baros mangrove conservation area, to increase household income.

Manunggal working group works in the field of raising ducks using a cage. It is located in the ranch area to the north of the Baros mangrove forest. Breeders herd ducks during the day in the mangroves, so the ducks get natural food and nutrients. Ducks are herded into cages in the afternoon, so ducks lay eggs at night in pet cages. The eggs are then processed into high-quality salted eggs.

Working groups of Farmers and Women Farmers are active in agriculture. They grow agricultural commodities, which include vegetables, shallots, and rice. Each type of agrarian product has a different treatment and planting period, for example, vegetables 40–50 days, onions 50–60 days, and rice 90–110 days. Rice farming activities are carried out in groups such as plowing soil, planting rice seeds, cleaning weeds, and harvesting rice. The location of agricultural land is in an integrated agrarian zone. This location is behind the mangrove, so it is protected from the sea breeze [3]. The existence of mangroves can protect integrated agricultural areas from exposure to sea breezes and tidal floods.

The Processing and Marketing working group consists of mothers who provide lessons on traditional cooking and guest consumption services. The types of traditional cuisine taught are typical village dishes, namely Cucur, Adrem, Rempeyek Udang, Nasi Wiwit. Baros traditional food is served to support mangrove ecotourism activities. The process of making traditional food is part of the mangrove ecotourism material. Traditional cuisine guides are mothers of traditional cake craft craftsmen.

3. Problems encountered

Baros mangrove forest managers face several obstacles to maintain environmental and forest health. The management of the KP2B organization often faces many obstacles in managing conservation areas, but the most prominent is the management of waste and the quality of human resources. Constraints or problems in managing mangrove conservation areas are mostly from outside, and a small portion is from local locations. Some limitations and solutions are explained below.

3.1 Garbage disturbance

3.1.1 Rubbish characteristics

The Baros Mangrove Conservation Area is in the lagoon of the Opak river and south of the village of Baros. The headwaters of the Opak river are located on the slopes of Mount Merapi, stretching from north to south. This river has a flow length of about 65 km and an area of flow of about ±1398.18 km^2. The river flows through the city with a population density of around 1194 people/km^2, carrying garbage from settlements and agriculture, consisting of various types and shapes. The volume of waste that has accumulated in the Opak river estuary is increasing, making it a scourge for mangrove conservation area managers [14].

Garbage piles at the Opak river mouth come from residents along the riverbank and residents in the village of Baros. Garbage contribution from residents along the riverbanks is estimated at 1800 kg/day or 180 m^3/day, whereas the contribution of rubbish from Baros villagers is estimated at 1000 kg/day or 100 m^3/day. Total garbage accumulation in the river mouth is expected to reach 2800 kg/day or 280 m^3/day. Types of waste consist of plastic, rubber, Styrofoam, cans, wood, glass, cloth. The most dominant type of waste is plastic, then timber, and the least is cloth [15].

Garbage scattered along the coast of Baros originates from upstream rivers and debris carried by seawater. The volume of waste increases when river water overflows during high rainfall. Every rainy season arrives, household rubbish that settles at the bottom of the river then flows with the river flows toward the beach. Waste that flows directly into the sea will eventually be pushed by the waves back to the beach so that, in the end, the beach is full of rubbish. Every high rainfall and abundant river flow, the waste carried from the river to the sea will increase.

3.1.2 Garbage management

The main problem in dealing with garbage is to change the paradigm, behavior, and public awareness. The community views waste as something that is useless and has no value. Society considers waste as everything that is thrown away, rejected, ignored, unwanted material, or worthless. This mindset must be straightened out so that it considers garbage as a valuable object. Those who are involved in the work of utilizing waste are slogan "in your opinion, the things you have disposed of are rubbish, but for us, these items are a blessing for life." We must see waste as raw material or material that has economic value. Abundant waste can be processed into objects that have artistic value or sale value. Communities must be able to manage waste by recycling, reusing, purifying, or purifying [16].

Garbage that scattered along the coast of Baros consisting of organic and inorganic materials. Types of organic waste, such as used wood for household furniture, can be recycled into valuable items. It is improving by changing used materials into useful new articles and of economic value. Recycling can reduce the volume of waste, minimize the use of new materials, reduce the cost of producing goods, increase household income, and create new jobs. Recycling begins with the activity of sorting waste, grouping similar goods, processing into new products. The rest of the recycled material can be used for firewood so that all organic waste is used up. Production goods can be sold to tourists as souvenirs, furniture stores, or exported.

The most inorganic waste is plastic used food envelopes, beverages, and household needs. Plastic has many advantages compared to other materials, for example, cheap, durable, lightweight, resilient, strong, so that dependence on plastic is very high. Each person, on average, discards plastic as waste as much as 0.45 kg/day, while waste production is as much as 0.9 kg/day. Plastic waste reaches 20–25% of all types of inorganic waste. Plastic waste mostly causes the death of young mangroves by covering leaves or breaking stems. Also, seedling cannot grow if the space is occupied by plastic or other rubbish. Plastic waste management is done by reusing, recycling, and making other products. Reusing plastic waste, for example, used plastic bottles for sowing mangrove seeds, gallon bottles for vertical cultivation of vegetable crops. Plastic waste that is completely unused, it can be melted down to make new products, such as flower pots or other products [9].

3.2 Human resources quality

Human resources play an essential role in the successful management of the Baros mangrove conservation area. Conservation area managers need someone who has the determination and love for the environment, innovative and creative. Love of a healthy environment will make someone persistent in saving plants as the lungs of the world. The population of Baros village who completed education to graduate from high school was 42%, while those who graduated from college were 8.8% [4]. The learning average of Baros residents is junior high school graduates, so they are classified as common knowledge. Although the average learning level is moderate, they have high innovation and creativity. Skilled human resources are needed to realize the creation of an independent and sustainable mangrove conservation area. Creative human resources are required to face various challenges in managing mangrove areas.

A manager is a group of people consisting of the head of the Baros youth group, village heads, hamlet heads, and elders to manage the Baros mangrove conservation area. Compact managers can take advantage of mangrove forests optimally and sustainably. Mangrove managers need skilled human resources capable of creating healthy mangrove conservation areas. Improving the quality of HR education is very influential in the successful management of natural resources. Some ways to improve the quality of human resources can be through formal and informal learning. Also, human resource development can be achieved through skills training, certification, or competency testing. Residents can certify as managers of marine and fisheries conservation areas. National standardization professional bodies carry out certification and competency tests for those who need them for free.

4. Mangrove management strategies

The Bantul Regency Government has designated the Baros mangrove forest area as a coastal park conservation area. Conservation areas with reserve status indicate a minimum level of management. The government has not allocated funds to carry out activities and has not formed an organizational management unit following the provisions. Bantul has a mangrove forest conservation area of 132 ha, which is managed by the zoning system. The area of each zone is a 10-ha core zone, a restricted use zone of 28 ha, and the other zone is 94 ha. The next step is to make a management plan for the Coastal Park-Conservation Area in Bantul Regency [17]. The area management plan must be implemented to accommodate the interests of many parties while maintaining the minimum negative impact.

The development of conservation areas is directed to ecotourism activities based on mangrove conservation. Mangrove conservation is managed by continuing to plant mangroves until the plant covers all core zones. However, mangrove planting must consider the representation of mangrove plant species to produce high biodiversity of mangroves. High diversity and plant density can increase the heterogeneity of animals and aquatic biotics. At present, there are 25 species of mangrove plants, 48 species of birds, and 36 species of fish [4]. Mangroves that need to be propagated are red pedada (*Sonneratia caseolaris*) and perepat (*Sonneratia alba*). These plants quick increase, local plants, so they are adaptable, have many biological and ecological benefits. However, the local community has not been able to seed, and the success rate of plants is low. Conservation area managers as well researchers must collaborate with the government and other parties to increase the diversity of mangrove species via restoration.

The next step is to empower all levels of society to be actively involved in supporting the success of ecotourism. Farmers cultivate various types of plants under local conditions as an attraction. Farmers do livestock activities according to the rules, so it is interesting to be visited and carried out by visitors. Production of traditional food preparations is carried out following health standards, and produces attractive products, and is characteristic of the village of Baros [16].

The next step regulates the zonation of mangrove areas so that the available land use is following its purpose. The goal is that there is harmony between the mangrove area and other designation areas, such as agricultural, livestock, and fishery areas. The existence of mangroves can protect agrarian crops from tidal flooding, seawater intrusion, and a strong sea breeze. Also, mangroves are home to various species of birds that can help farmers cope with pest attacks. Conversely, agricultural activities can support the lives of birds by providing prey hunting grounds [18]. Managers need to invite experts to provide education to local communities about the life of birdlife, fish biota, and mangrove ecology, to create harmony in the mangrove ecosystem with its environment.

Sustainable mangrove management strategies by carrying out ecotourism activities that integrated with other businesses under their designation. Ecological tourism activities that combine various attractions by involving different sectors, namely forestry, agriculture, fisheries, and animal husbandry. The forestry sector presents a scene of observing the diversity of mangroves, the ecological role of mangroves as a buffer for the environment, the variety of bird species. Various attractions can be carried out in the core zone, for example, observing bird behavior, planting mangroves, arranging mangroves, and researching the diversity of aquatic biota. In the field of agriculture, it can present the attraction of farming activities in the utilization zone as well as the observation and introduction of crops. The fisheries sector can show the attractiveness of raising fish in ponds, spawning, breeding, harvesting fish. Fisheries activities in the utilization zone can provide fish restocking, crab restocking, and fishing activities. Animal husbandry activities can present attractions offering livestock activities, for example, feeding, harvesting livestock products [2].

Managers need to do promotions so that the number of tours increases. However, an increase in tourists must be followed by an increase in services. It is necessary to conduct a study of the capacity of tourist visits to achieve maximum capacity and satisfaction. Mangrove managers can collaborate with a competent institution to survey tourist carrying capacity. The results of the study can provide information on the time and number of visits, set the types of attractions, and information on facilities for tourists and tourism service managers. The results of the carrying capacity study were disseminated to stakeholders to get responses.

One of the critical jobs that must be done for conservation area managers is to collaborate with stakeholders that can have a positive impact. Besides, good governance can have a positive effect on management performance and increase revenue and generate economic activity in conservation areas and people's purchasing power. Guidance to the community so that an increase in income will have an impact on raising public awareness in supporting the preservation of regional resources.

5. Conclusions

Mangrove forests can directly act as coastal protection, storm barriers, strengthen coastal areas for sea wave disturbance, and control coastal erosion. Mangrove restoration measures can build resilience in coastal communities, reduce storm disruption, tidal flooding, and high wave disturbances, and protect surrounding agricultural, livestock, and fishery areas. Mangrove conservation areas can provide welfare and provide new jobs for the surrounding community, as a source of food, food, medicinal materials, and habitat for terrestrial and aquatic animals. Healthy mangrove areas can provide ecosystem services that can generate economic activities for the community and stakeholders.

The management strategy of Mangrove Baros is by implementing ecotourism, integrated with other companies that are mutually beneficial, arrangement of the tourist area so that it can attract visitors by providing tracks to explore the mangrove area, provision of complete public facilities, transportation, health, and safety facilities, and the addition of various attractions that are interactive with visitors. The attractions are adjusted to the interests of visitors.

Conservation managers need to accommodate research and development interests related to the area to support management activities. The use of conservation area resources considers all benefits and does not harm the inhabitants. Agricultural activities, fisheries, and livestock in conservation areas are managed to the maximum to provide socioeconomic benefits to the community. Collaboration with partners is crucial to create economic activities and increase stakeholder income.

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Conflict of interest

The authors declare no conflict of interest.

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Mangroves serve as one of the nature-based solutions for coastal communities. We are now almost at the tipping point where we can restore mangroves ecologically to mitigate climate change and enhance other important ecosystem services under the United Nations Decade on Ecosystem Restoration. *Mangrove Ecosystem Restoration* focuses on mangrove ecosystem restoration, the ecosystem services mangroves provide, and how to manage and conserve mangroves. The three sections include eight chapters that cover such topics as evaluating mangrove degradation, forest recovery through seedling recruitment, natural regeneration of mangroves, advanced molecular biology for restoring mangroves, and more.

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