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Review

Challenges and Strategies for Sustainable Mangrove Management in Indonesia: A Review

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Abstract: Mangroves are an important ecosystem that provides valuable social, economic, and environmental services. Indonesia has placed mangroves on its national priority agenda in an important effort to sustainably manage this ecosystem and achieve national climate commitments. However, mangrove management is faced with complex challenges encompassing social, ecological, and economic issues. In order to achieve the government's commitments and targets regarding mangrove restoration and conservation, an in-depth study on and critical review of mangrove management in Indonesia was conducted herein. This work aimed to provide a comprehensive analysis of the challenges and strategic recommendations for sustainable mangrove management in Indonesia. SWOT analysis was carried out to understand the strengths, weaknesses, opportunities, and threats related to mangrove management in Indonesia. To address these gaps, we reviewed the existing policies, current rehabilitation practices, environmental challenges, and research and technology implementations in the field. We found that strategies on mangrove ecosystem protection, such as improving the function and value of mangrove forests, integrating mangrove ecosystem management, strengthening political commitments and law enforcement, involving all stakeholders (especially coastal communities), and advancing research and innovations, are crucial for sustainable mangrove management and to support the national blue carbon agenda.

Keywords: mangroves; sustainable management; climate change; blue carbon; mangrove policy; restoration; rehabilitation

1. Introduction

Mangroves are a unique ecosystem: an interface between terrestrial and marine environments characterized by a high salinity concentration, high temperatures, strong winds and tides, muddy sediments, and anaerobic soils [1]. This type of ecosystem is one of the environmentally and economically valuable ecosystems for many tropical and subtropical countries [2,3] and provides social functions to coastal communities [4].

The role of mangrove forests includes protection against storms and tsunamis [5–7], the regulation of water systems, habitat provision for various fish and other animals, and a source of biodiversity and wood and non-timber forest products [8,9]. Mangrove forest ecosystems are also a source of nutrition and have an aesthetic value for ecotourism activities. Another important function is their role in climate change mitigation activities, where mangroves can store and sequester significantly more carbon than terrestrial forests in tropical and temperate regions [10].

Indonesia has 3.3 million hectares of "mega diversity" mangrove forests across the archipelago, consisting of 2.2 million ha within forest areas and 1.3 million ha outside forest areas [11,12]. The diversity and distribution of mangroves across the archipelago are immense: Java (166 species), Sumatra (157 species), Kalimantan (150 species), Papua (142 species), Sulawesi (135 species), Maluku (133 species), and the Lesser Sunda Islands (120 species) [13]. Despite the significant values of mangroves and their richness, it is estimated that around 637,000 ha or 10–33% of mangrove areas have been degraded and converted over recent decades [13–16], mostly caused by coastal development, such as aquaculture, logging, mining, reclamation, and pollution [13,15,16]. The highest mangrove deforestation occurred during 1987–1998, resulting in a drastic decline in the area covered by mangroves [17].

In response to huge mangrove loss, several regulations regarding mangrove conservation and management were enacted in Indonesia. The Law No. 5 of 1990 on the Conservation of Biological Natural Resources and their Ecosystems has become the basis of the concept of mangrove conservation in Indonesia. According to Law No. 27/2007, which was amended into Law no. 1/2014, on the Management of Coastal Zone and Small Islands, Indonesia allowed logging practices in mangrove areas that adhere to the sustainability of coastal ecological functions. The issuance of this policy was followed up with Presidential Decree No. 73 of 2012 on the National Strategy for Mangrove Ecosystem Management, which regulates the norms, standards, principles, criteria, and indicators of mangrove forest management. The government also issued Presidential Decree No. 73/2015 on the Implementation of the Management of Coastal Areas and Small Islands at the National Level with the aim of managing national coastal areas and small islands in a harmonious, synergistic, integrated, and sustainable way [18].

There are two key sectors that play important role in mangrove management in Indonesia, i.e., the forestry and fisheries and marine sector. The forestry sector has the authority to manage all state mangrove forests, whereas mangroves outside forest areas fall under the authority of the fisheries and marine sector. Therefore, the existing mangrove management policies are generally influenced by the interests and authorities of these two sectors, which are sometimes contradictive and overlapping. The complex social and economic conditions in mangrove areas, along with unclear boundaries between different authorities, have created an overlap in the implementation of laws and responsibilities among the governing institutions.

To sustainably manage mangrove ecosystems and improve coastal community welfare, effective policy implementation must be supported by various action plans or strategies that are prepared based on strategic issues in the concept of sustainable development [13,19–21]. However, there are major challenges in mangrove management that should be addressed by specific strategies and require programs as a measuring tool for achieving the goals of sustainable mangrove management. In this study, we aimed to conduct a comprehensive analysis of the complex constraints faced when managing mangrove ecosystems and to provide strategic recommendations for sustainable mangrove management in Indonesia.

We tried to fill the gaps between existing policies and implementations at the field level that are significant for constructive mangrove management and for supporting Indonesia's blue carbon agenda.

2. Mangrove Governance and Policy

Learning from the previous development of mangrove management policies in Indonesia, most drivers of mangrove forest loss could be effectively managed by policy interventions [21]. Mangrove management policies and regulations having been issued for almost a century (Table 1); however, they have not been optimally implemented in the field, and mangrove degradation still occurs with little or no compliance with existing laws and regulations [22–26]. Violations of the laws and regulations still exist due to the poor law enforcement and discordant policies. In addition, unclear policy objectives between government institutions have often worsened the situation [15,21,27,28], resulting in contradictive management decisions. The main challenge lies in the coordination and communication of related stakeholders, both those with authority and those affected by the policy.

Table 1. Government policies on mangrove forest management in Indonesia *.

No.	Policies/Regulations	Ministry Support	Guidelines for Mangrove Conservation	Policy Impact
1	Law No 5/1990 on the Conservation of Natural Resources and their Ecosystems	1. Ministry of Environment and Forestry 2. Ministry of Marine and Fisheries	The basis for implementing area and species conservation in Indonesia	1. Build public awareness and knowledge regarding environmental damage, especially mangrove ecosystem areas, as well as legal products and law enforcement 2. Sustainability of the mangrove rehabilitation program in coastal areas with mangroves/mangroves that have been degraded/deforested 3. Determination of mangrove ecosystem areas that do not overlap with general use areas
2	Law No. 41/1999 on Forestry, revised in Law No. 19/2004	Ministry of Environment and Forestry	Management of mangrove ecosystems in forest areas, such as regulations on the prohibition of logging and forest encroachment (Article 50)	
3	Law No. 23/2014 on the Regional Government	District and Provincial Government	Significant authority given to regional heads in the management of natural resources, and the environment is linked to the existence of mangroves as coastal borders with the status of local protected areas	
4	Law No. 26/2007 on Spatial Planning	1. Ministry of Public Works 2. Regional level conducted by BAPPEDA	Does not specifically regulate mangroves, but binds/regulates coastal boundaries and status as local protected areas	
5	Law No. 27/2007 on Sustainable Management of Coastal Areas and Small Islands juncto Law No. 1/ 2014	Ministry of Marine and Fisheries	Sustainable management of coastal areas and small islands	
6	Law No. 32/2009 on Environmental Protection and Management	Ministry of Environment and Forestry	Arrangements for activities that have the potential to change the landscape (including mangrove conservation)	
7	Government Regulation No. 26/2008 on National Spatial Planning		Timber use violations of mangroves and activity bans that can change, reduce the area, and/or pollute the mangrove ecosystem in the mangrove zoning system	

Table 1. *Cont.*

8	Presidential Decree No. 73/2012 on The National Strategy of Mangrove Ecosystem Management	1. Ministry of Environment and Forestry 2. Ministry of Marine and Fisheries	Conservation activities and ecosystem rehabilitation of mangroves in protected and cultivation areas, as well as improvement of the public well-being
9	Presidential Decree No. 73/2015 on the Implementation of Coordination for the Management of Coastal Regions and Small Islands at the National level	Coordinating Ministry of Marine and Fisheries	Sustainable management of coastal areas and small islands
10	Coordinating Ministry of Economy Regulation No. 4/2017 on the Policy, Strategy, Programs, and Performance Indicators of National Mangrove Ecosystem Management	1. Ministry of Environment and Forestry 2. Ministry of Marine and Fisheries	Recovery target of 3.49 million ha of mangroves by 2045

* The policies are focused on management, protection, conservation of biological resources, and disaster mitigation.

Given the many institutions involved in mangrove management, effective and legitimate regulations are needed and can be used as benchmarks for action in mangrove management. The synchronization of land and sea policies for determining mangrove management areas of different authorities is very important to avoid ambiguity for site-level managers and ineffective responsibilities for protecting mangrove forests.

In addition, clarity of policy content, both conceptual and technical, is an important requirement for the effectiveness of implementing a policy. The implementation of regulations in the management of mangrove resources is still weak [29], especially in terms of strengthening local-level institutions. Technical regulations are important to facilitate the implementation of national policies at the provincial level and to avoid different policy interpretations. Therefore, it is necessary to clarify policies, especially on mangrove reforestation for the marine and fisheries sector, considering that the sector's interest in increasing fishery production is very high [15].

Another challenge relates to the triggers of mangrove deforestation and degradation, which are intricate and often related to regional development strategies. Mangrove forest management efforts should consider related stakeholders with various interests (social, economic, and ecological interests) [30]. In many cases, these interests are contradictive. Although several policy initiatives have been developed by offering social and economic incentives to increase community participation in mangrove management, these efforts have faced problems related to an uncertain tenure, land encroachment, elite captures, and unfair benefit sharing. In addition, the involvement of local communities in natural resource management also encounters other challenges, such as a limited capacity, different goals, and limited time needed by the community to develop and maintain sustainable natural resource management [31–33].

Despite some of the challenges faced in mangrove management, an increased understanding of the importance of natural resources to sustain the economy at both the national and local levels, coupled with periodic political and economic crises in many developing countries, has encouraged the development of a new approach to mangrove management. A cross-sectoral and multi-stakeholder participatory approach has become the core strategy in mangrove management in many countries. Brazil, Ghana, and Mexico are some of the countries that have succeeded in developing the co-management of mangroves [34–36]. Co-management requires that key stakeholders, particularly resource-users themselves, play significant roles and responsibilities in the management process. Subsequently, in some countries, the legal framework for some forest tenures has changed from state-based to community-based, such as in Vietnam, the Philippines, and Ecuador [37]. There is ample evidence showing that coastal communities (including indigenous groups) have local wisdom in mangrove management and conservation practices that are integrated into their social structure. In general, where communities are empowered and given legal rights and authority to manage their own forests, community-based management has proven to be effective in rationalizing the use of mangrove goods and services, as in several places in Asia and Africa [37,38].

3. Community Participation in Mangrove Management

Communities play a key role in determining the success of sustainable forest management [38–40]. The dependence of coastal communities on these ecosystems can encourage them to restore and conserve them using their local knowledge [4,41–44]. The willingness to participate in an activity also has correlation with education level and income; those who have a higher education level and a more stable income become more easily involved and can serve as key community actors in mangrove restoration and protection activities [39,45–47].

From a socioeconomic perspective, sustainable mangrove management is full of challenges due to (a) different understandings of the value and benefit of mangrove ecosystems and the urgency of rehabilitation efforts; (b) local involvement not being optimal; (c) the majority of the families living next to the mangrove ecosystem being classified as low-income families; (d) sustainable mangrove ecosystem utilization not yet having been developed; and (e) a high rate of population growth and economic needs having triggered land use and land cover change.

Problems in understanding the ecological value of mangroves may create the conception that the damage or loss of mangrove resources is not always perceived as a loss. Community participation in mangrove management has become difficult to achieve, whereas, in contrast, the participation is easier to ensure when the benefits to be received can be felt immediately, locally, and are real [40,41]. Therefore, information about the benefits/values of mangrove forests, both direct and indirect, needs to be widely disseminated to increase people's awareness of the ecological role of mangrove forests [42]. A specific strategy is also needed, such as offering several incentive scheme options, to increase community willingness to be involved in mangrove management.

Law enforcement and compliance are other challenges in inducing community participation. Unclear sanctions/penalty mechanisms lead to low levels of compliance [43]. Local willingness to participate in mangrove management depends on (1) effective law enforcement; (2) accountable and transparent financial management; (3) fair profit sharing; (4) fair distribution rights and obligations; (5) co-financing from the government or projects; (6) annual income level; (7) and whether one's livelihood depends directly on mangroves. Eventually, the provision of incentives should not only drive local communities to replant new mangroves, but they should also maintain newly planted and old mangroves [32].

The form of the community's involvement in mangrove management varies depending on the regional conditions and the typology of the community. One example of mangrove management that considers community participation in mangroves is widely known as community-based mangrove management (CBMM). CBMM is currently needed to ensure the success of mangrove resources [44,45] and is considered an important factor in minimizing disturbance while assuring the sustainable use of mangrove resources. Communities are also involved in mangrove rehabilitation projects, e.g., providing mangrove seedlings, working in mangrove nurseries, and conducting mangrove plantings.

4. Incentives for Mangrove Ecosystem Services

The provision of incentives for mangrove conservation, as well as dissemination and facilitation to develop environmentally friendly mangrove utilization in coastal communities, is needed to increase the public acceptance of policy implementation and community engagement in mangrove management. The forms of incentive programs offered include the provision of capital, production inputs, training for capacity building, facilitation to market access, and funding [32,43]. The incentive programs requires partnerships and cooperation among the institutions at the site level to support product marketing from up- to downstream [48].

One of the incentive schemes that have succeeded in encouraging community participation in mangrove rehabilitation was initiated by Wetlands International Indonesia through the "Bio-right" scheme, with a success story in Pesantren Village, Pemalang Regency, Indonesia [29]. Bio-right is an incentive scheme that provides a funding mechanism to participating communities. This scheme is an attempt to accommodate the importance of increasing the economic benefits of mangroves while promoting conservation and restoration actions. In the Bio-right scheme, if community-based conservation efforts indicate satisfying results (evaluated based on the survival rate of mangrove plantations or other parameters, according to the contract agreed between the initiator and the community who obtains the microcredit), then the credit will be converted into grants [49].

Another incentive scheme to instigate community participation in mangrove management was developed through the payment for environment service (PES) scheme [21]. The environmental services derived from mangroves are distinguished by ecological functions and economic goods and services. For example, *Avicennia marina* species are able to bind the heavy metals Pb and Copper (Cu), absorb salt, and are resistant to salinity; thus, they can be used as a phytoremediation agent to improve environmental and water quality [50,51]. The environmental services generated from mangrove ecosystems in Southeast Asia are valued at USD 4200 ha^{-1} year^{-1} [52]. If associated with the mangrove area in Indonesia in 2021, which was 3.3 Mha, then the total value that can be generated from the environmental services of the mangrove ecosystem is estimated to be USD 13,860,000,000. The intrinsic economic service value has an impact on the preservation of mangrove ecosystem biodiversity, leading to the encouragement of more intensive rehabilitation activities.

The economic benefits of mangrove ecosystems contribute to the welfare of society and the State. Research in West Kalimantan [53] has shown that the highest estimated value of mangrove protected forests is approximately IDR 27,386,581,500 year^{-1} (77.75%), while the annual indirect, direct, and optional value benefits are IDR 3,869,442,410 (10.98%), IDR 2,929,650,000 (8.32%), and IDR 1,037,800,210 (2.95%), respectively. Community understanding of the ecological benefit (74%) and economic value (74%) of protected forests is relatively high. Another study showed that household income from natural mangrove ecosystem resources in four villages in Central Java, Indonesia, ranges from USD 1202 to 2189 year^{-1} household^{-1} [54], whereas, in the coastal area of Lampung, Indonesia, it ranges from IDR 12,000,000 to 24,000,000 year^{-1} household^{-1} [45]. These values indicate the existing contribution of the income from mangrove ecosystems to coastal communities, but, to determine whether this income is sufficient or not, it must be compared to the regional minimum wage (RMW) of each region.

5. Environmental Challenges

Understanding the biophysical process and other drivers that control mangrove survival is crucial for mangrove rehabilitation. Based upon the Ministerial Regulation Forestry No. P.70/Menhut-II/2008, mangrove rehabilitation is considered successful if the survival rate is 70% or more. A number of studies have reported that failure of mangrove rehabilitation could be caused by environmental constraints, such as tides/abrasion [55], species intolerance to salinity and tidal inundation [55,56] and pests and diseases [55,57]. Propagule supply and wave and tidal flooding are important factors to be considered in mangrove rehabilitation [58]. When the site is lacking in propagule supply, planting the right species in the right habitat is the alternative solution to alleviate mangrove reforestation failures. The establishment of mangrove plantation should consist of the processes that involve selection, site preparation, planting, maintenance, monitoring, and evaluation [59]. Permanent or permeable structural water breaks are also needed if the planting is undertaken in areas with high waves.

The symbiotic relationship between mangrove vegetation and various types of fauna occurs in various forms, both beneficial and destructive. Therefore, controlling pests and diseases is crucial. One type of pest that attacks mangrove plants in Indonesia is crabs from the Crustaceae family, especially from the karma type (*Episesarma* spp.) and wideng crabs [60]. Apart from crustaceans or crabs, several animals that become pests for mangrove plants are pagoda bagworms (*Pagodiella* spp.), bagworms (*Acanthopsyche* sp.), stem borer beetles (*Xanthochroa* sp.), tick leaves (*Prociphilus tessellatus*), barnacles (*Balanus amphitrite*), snails (*Gastropoda* sp.), and shell-less snails (*Vaginula bleekeri*) [61]. Pocket caterpillars are a pest that attack beneath the leaf surface, creating holes. A population explosion of bagworms causes bare leaves at the seedling and sapling levels. The seedling level is the most vulnerable stage to pest attacks. Bagworms attack the shoots [61] and damage the roots, leading to the disruption of the regeneration of mangrove plants [62–64]. Disruption in the vegetation regeneration process can result in the loss of genetic material and a decreasing biodiversity [65].

Marine pollution, such as anthropogenic marine debris (AMD), can also cause damage to mangrove ecosystems. AMD in the form of plastics, cloths, polystyrene, metal, glass, paper, rubber, and leather has been reported to disrupt the productivity of mangroves in Indonesia [66]. It is estimated that Indonesia's marine plastic debris is the second largest production of marine pollution in the world, which is around 0.57–0.6 Mt year^{-1}. A preliminary value of plastic debris accumulation on beaches has been estimated to be 113.58 ± 83.88 g m^{-2} a month [67], or equivalent to 0.40 Mt year^{-1} [68]. AMD can be found especially in big cities on the main islands of Java, Bali, Kalimantan, Sumatra, and Sulawesi [69]. The Indonesian government has targeted a national action plan to minimize marine plastic debris by 70% between 2018 and 2025, with a long-term ambition to achieve near-zero plastic pollution in Indonesia by 2040 [70]. This effort needs synergistic coordination between the central and local governments on strengthening law enforcement and real actions at the field level to deal with hazardous AMD, as well as international cooperation [71,72].

6. Technology Development and Implementation

Research development, technology transfer, and information systems are very important in supporting the success of mangrove forest management in Indonesia. According to the Ministry of Environment and Forestry, the mangrove rehabilitation activity carried out during 2015–2019 (Supplementary Table S1) is incomparable to the rates of mangrove deforestation. However, if the current commitment from the Indonesia government to restore 600,000 ha of degraded mangrove area is reached, it would constitute an important milestone.

Several technologies and advances that are currently being developed to support sustainable mangrove management, rehabilitation, and conservation are outlined below.

6.1. Seed Technology and Genetic Aspects of Mangrove Management

The availability of high-quality seeds in sufficient quantities plays a significant role in the success of mangrove forest rehabilitation [73,74]. To ensure the sustained existence of mangrove plants as genetic material sources, the application of a genetic-based technique to assess the structure and diversity among and within populations is essential. Propagule dispersal—whether by water or through animals—is a key ecological factor for identifying the distribution of mangrove patterns of genetic diversity and populations [75–78]. This allows the occurrence of crosses between individuals with distant relatives and broadens the genetic diversity of the population. The wide genetic distance between populations is a crucial factor for breeding mangrove species [79].

When the seed sources are not enough, producing mangrove seedlings in a nursery is one of the potential efforts to meet the need of large quantities of mangrove planting stock for rehabilitation purposes. Nursery-produced seedlings of the species *Ceriops* spp., *Avicennia* spp., *Bruguiera* spp., and *Rhizophora* spp. have higher survival rates following planting activity (60–80%) compared to the direct planting of their propagule in the field (20–30%) [73,79].

Understanding the phenology of mangrove species is needed to support forest restoration. The success of mangrove forest restoration is also influenced by the existence of pioneer mangrove species [80] because these pioneer species are able to withstand conditions of hydrodynamic pressure and changes in sediment. Previous studies have shown that *Avicennia alba* and *Sonneratia alba* are pioneer species, especially for Southeast Asia and Australia [80,81]. Both have a good growth ability in the seedling phase, despite hydrodynamic changes, and have a fairly wide seed dispersal ability due to their seed characteristics [81–83]. A study of mangrove phenology in Unggas Island, West Sumatra, Indonesia [84], revealed that the flowering and fruiting seasons of *R. apiculata*, *R. mucronata*, and *R. stylosa* occur throughout the year, with the peak season in September to December, July to December, and October to December, respectively. The time spans from the first stage of flowering to the ripening of propagules for the above three species are 22.06, 18.85, and 21.70 months, respectively.

Studies related to the genetics of mangrove species, especially the molecular aspects, in Indonesia are still very limited. An initial study of mangroves along the coastlines of Java Island was performed by using isozyme markers [85]. The results showed that, along the northern coast of Java, the populations of *Sonneratia alba* had higher similarity with each other than those of the southern coast. It was concluded that gene flow and genetic exchange might be affected by isolation due to the distance, sea current direction, and their connectivity [86]. Another study conducted in the Krakatoa area found a lack of genetic variation in *A. marina* in severely contaminated habitats, which are quite significant compared to moderately and non-contaminated habitats [87].

Morphological and inter-simple sequence repeat (ISSR)-based marker research conducted on *Avicennia* in Java showed that the existing mangrove grouping is based on the similarity of characteristics, not on the origin of the plant [88]. Sequence-related amplified polymorphism (SRAP) markers in the Banggai Islands showed a low genetic diversity of *R. apiculata,* thus exhibiting a greater risk of extinction, especially on small islands [89]. However, the breeding strategy is very important in supporting the successful development of mangrove rehabilitation. Breeders are challenged to explore the potential of mangroves, especially in mangrove species that produce non-timber forest products (food and medicine) [90].

6.2. Integrated Mangrove Sowing System (IMSS) using Unmanned Aerial Vehicle (UAV) Technology

The integrated mangrove sowing system (IMSS) helps to accelerate the mangrove rehabilitation process in the sites with limited access, human resources, and infrastructure or uninhabited areas. IMSS is a combination of mangrove rehabilitation mapping and monitoring using UAVs and satellite technology (Figure 1). Seed balls are deployed using UAV technology with a modified payload capacity. The most commonly used seeds in IMSS are *Avicennia* sp. and *Sonneratia* sp. based on their abundant availability and continuous production throughout the year [87]. Knowledge on phenology, germination rate, and seed ball coating determines the survival rate of the seeds in the field. The seed balls function to protect mangrove seeds from biotic and abiotic stresses, while the composition of the seed ball carrier in the form of essential nutrients and a compact structure increases the ability and viability of the seeds sown through the UAV system (Figure 2) [91]. The development of mangrove seed ball sowing technology in Indonesia is currently being tested under various natural constraints, such as tidal conditions, sediment variations, mangrove species zonation, and different levels of salinity.

6.3. The Importance of Microbes in a Mangrove Ecosystem

The interaction of mangroves and microbes in the root system in the process of nutrient exchange is essential for determining the success of the mangrove rehabilitation process. Microbial activity (bacteria and fungi) is responsible for transforming nutrients into mangrove ecosystems because such ecosystems have nutrient-deficient conditions [92,93]. Arbuscular mycorrhizal (AM) fungi constitute an advanced ecological method for mangrove rehabilitation that significantly improves plant root health and the natural regeneration of mangroves. AM fungi have an ecological function in increasing the tolerance of mangrove species to environmental stress, as well as the mangrove growth performance in natural plant communities. In addition, variations in AM colonization among different mangrove tree species and the capability of AM fungi in terms of P absorption could be of great importance in establishing diverse wetland vegetation communities and supporting the existence of a high species diversity [94]. The nutritional status of sediments and the role of AM fungi are important topics of ecological research in the process of nutrient exchange in mangrove ecosystems. While research on the existence and role of mycorrhizal fungi in mangroves is still rare in Indonesia, much information is provided by other countries (Supplementary Table S2).

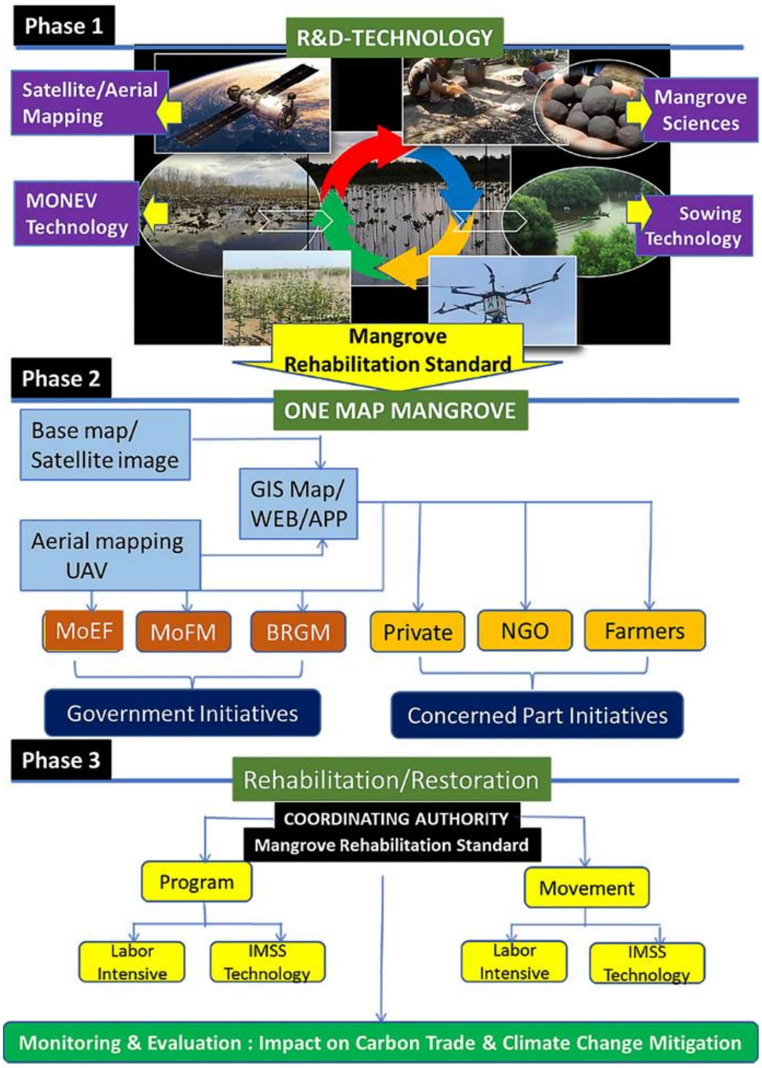

Figure 1. Advanced ecology-based mangrove rehabilitation strategy with the integrated mangrove sowing system (IMSS). UAV, unmanned aerial vehicle; GIS, geographic information system; NGO: non-government organization; MoEF, Ministry of Environment and Forestry; MoFM, Ministry of Fisheries and Maritime; BRGM, Peatland and Mangroves Restoration Agency.

AM fungi are present in the mangrove root system of mangrove species with different salinity gradient zones. *Glomus* sp. is the most dominant species among the 45 AM fungi species that belong to five genera, namely, *Acaulospora* sp., *Glomus* sp., *Scutellospora* sp., *Gigaspora* sp., and *Enterophospora* sp. The AM fungi *Glomus* and *Acaulospora* inoculated on two *Sonneratia* mangrove species have significantly increased plant growth and nutrient absorption. This finding shows AM fungi's vital role and contribution in building a sustainable mangrove ecosystem [95]. The accumulation of diazotrophs as nitrogen fixers in the rhizosphere of *R. stylosa* increases the nitrogen supply to the roots of mangroves. This suggests that sediment microbes (including bacteria nitrogen fixers) are the key to increasing productivity and are an indicator tool for the rehabilitation and conservation of mangrove ecosystems [93,96].

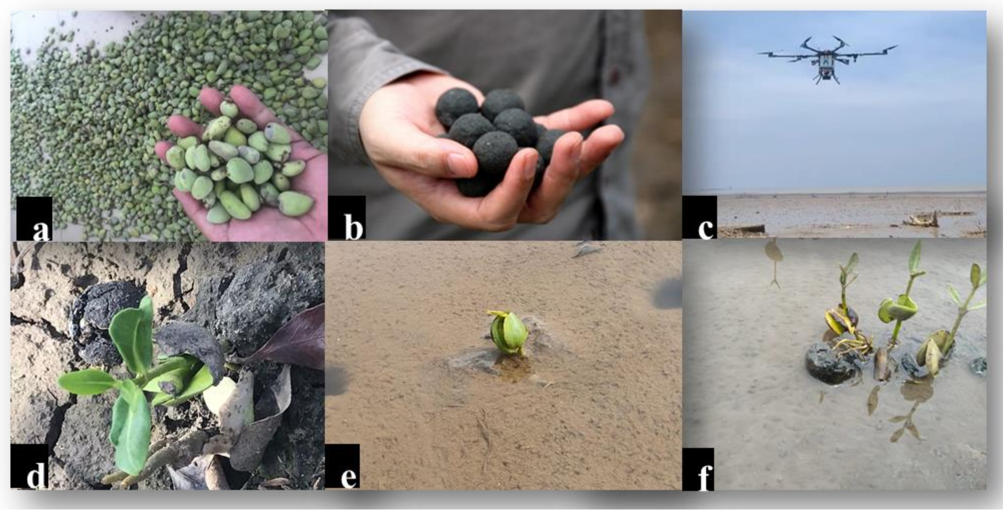

Figure 2. Advanced ecological-based mangrove rehabilitation techniques in order to accelerate successes and increase mangrove diversity with sowing seed balls by UAVs: (**a**) seeds of *Avicennia marina;* (**b**) mangrove seed balls; (**c**) UAV sowing seed ball system; (**d**) germination of *A. marina* seed balls in dry sediment; (**e**) germination progress of *A. marina* two weeks after sowing in wet sediment; (**f**) fast continuation germination of *A. marina* four weeks after sowing. (Documentation: Maman Turjaman and Consortium of Integrated Mangrove Sowing System).

6.4. Application of a Mangrove Silviculture System

There has been a long history of mangrove silvicultural systems in Indonesia. The first mangrove silvicultural regulation was promulgated during the Dutch colonization period in Indonesia on 1 July 1938 [13]. This regulation was made to manage the development of mangroves in Central Java, particularly in Cilacap city. Another result in Bengkalis mangroves (Riau province) recommended that a clear-cutting system is only applicable for areas often inundated by high tides [97]. In 1958, the standard clear-cutting system suggested by the Forest Research Institute was implemented [13]. The Forest Planning and Production Agency recommended the strip-wise selective logging system in 1972 [98]. In 1978, the Indonesian government (c.q. Directorate General of Forestry) issued Decree No. 60/Kpts/Dj/I/1978, which introduced a new silvicultural system, namely, the mother tree method. The mother tree method accommodates intensive natural regeneration in logged-over areas in order to become more ecologically resistant to numerous disturbances [99].

Previous research on the mother tree system has shown significant growth of the secondary forest, which formed a second generation cycle of mangroves in Bintuni Bay [99]. Permanent plots of five commercially dominant mangrove species (*R. mucronata*, *R. apiculata*, *B. gymnorrhiza*, *B. parviflora*, and *Ceriops tagal*) in Bintuni Bay, West Papua, have yielded moderate stands to be utilized. The forest structure is close to the primary forest, and *R. apiculata* has shown the best growth. Thus, the above five species are suitable for cultivation in logged-over areas due to their ability to form mature stands, and thus can potentially be utilized without changing the species dominance.

In addition to Bintuni Bay, a silvicultural system to rehabilitate mangrove areas was also employed along the northern coast of Java Island by Perhutani state company in 1960. Other rehabilitation systems run by Perhutani, a state-owned company, have introduced intercropping ponds, pond forests, or embankment trench ponds [13], consisting of several canals (2–5 m width and 1 m depth) with mangrove trees in the center of the pond. The ratio between ponds and forests varies: 20%:80% in Cikalong (West Java) and 40%:60% in Cilacap (Central Java)—although the optimal ratio is 54% ponds and 46% forests.

The success of mangrove rehabilitation activity in Indonesia can be seen in Supplementary Table S3. The success state of rehabilitation activities is guided by Forestry Ministerial Regulation No. P.70/Menhut-II/2008, requiring the survival rate to be 70% or more. To date, several planting designs and techniques have been applied to increase successful rehabilitation, including cluster, square, and zig zag planting designs [59]. Among these applied techniques, the mound technique provides the best seedling survival rate of more than 80% for *Rhizophora* spp. at three years old.

One good example of a successful mangrove rehabilitation story in Indonesia is that of Perancak estuary, Bali. A comprehensive strategy from planning to biophysical study and ground checking was carried out to assure the success of the planting activities. Furthermore, understanding the relationship between vegetation characteristics and hydrological and edaphic conditions is an important determinant of mangrove rehabilitation success [100]. This mangrove rehabilitation approach is comparable to the approach of mangrove rehabilitation along the Yucatan Peninsula, Mexico, which is based on the relationships among the geomorphology, hydrology, structural, and functional characteristics of mangroves [101].

7. Landscape Approach

Currently, the government uses mangrove landscape units (MLUs) to evaluate the rehabilitation programs in Indonesia. MLUs are defined as mangrove typology units of the same tidal area, with a suitable land system that functions optimally to provide ecological and socioeconomic services. The analysis of determining mangrove landscapes throughout Indonesia has resulted in 130 units of mangrove landscapes, comprising 16 units in Java, 23 units in Sumatra, 27 units in Kalimantan, 11 units in Bali and Nusa Tenggara, 20 units in Sulawesi, 11 units in Maluku, and 18 units in Papua [102].

This approach is aimed at managing mangrove ecosystems that meet social, economic, and environmental purposes [103,104]. Therefore, mangrove ecosystem management should foster a dynamic and balanced interaction between nature and humans [105]. However, although the landscape management approach has the potential to meet social and environmental goals on a local scale, to address global challenges, it requires a strong national commitment [106].

8. SWOT Analysis

We formulated a strategy for managing mangrove forests in Indonesia by identifying two factors that resulted from the condition and situation of the mangrove forests, namely, external (opportunities and threats) and internal (strengths and weaknesses) strategic factors. SWOT analysis aims to systematically identify various factors in formulating a strategy [107] by emphasizing existing strengths and opportunities and concurrently reducing weaknesses and threats. SWOT analysis is useful for analyzing the overall situation and achieving the objectives of an activity plan [108–116]. Strategy formulation with SWOT analysis is carried out according to existing data, and endeavors to use the situation and development of an activity to achieve goals. We generated SWOT based on the characteristics of mangrove forests and the social conditions of the community living in the mangrove areas (Figure 3).

Based on the identification of internal factors, six indicators were identified as strengths and six as weaknesses, while, for the external factors, seven indicators were found as opportunities and seven as threats.

These internal and external factors (Table 2) are indicators of leverage in the preparation of strategies and provide basic information that support sustainable mangrove forest management.

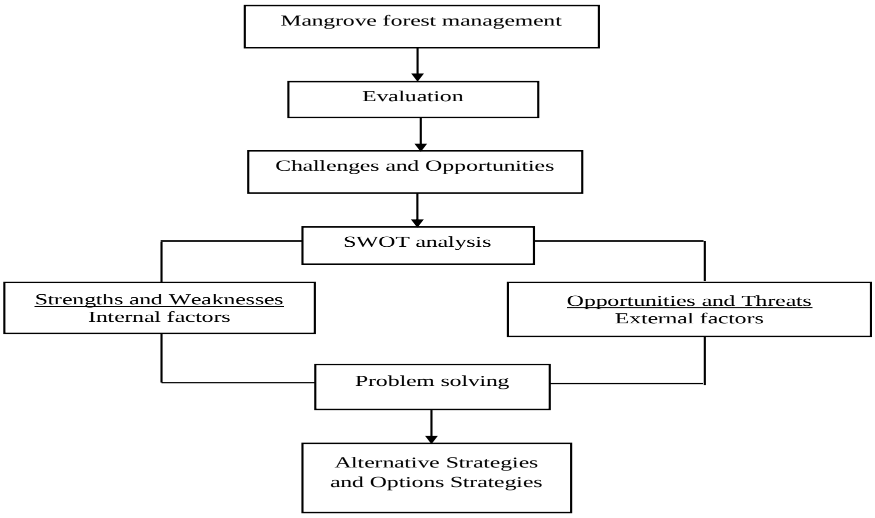

Figure 3. Stages of strategy formulation using SWOT analysis [117].

Table 2. Internal and external factors in SWOT [117].

INTERNAL FACTORS			
Strengths		Weaknesses	
S1	Indonesia has an area of 3.3 million hectares of mangrove forest	W1	Implementation of policies, regulations, and laws is still ego-sectoral
S2	Mangrove ecosystems are unique habitats full of biodiversity	W2	Utilization of mangrove forests is still not in accordance with the carrying capacity of the mangrove ecosystem
S3	Mangrove ecosystems have multiple ecological, economic, and social functions and benefits	W3	Population increase
S4	The existence of regulations and laws related to the management of mangrove forests in Indonesia	W4	Not yet optimal support from institutions at the site level
S5	Positive understanding of the community regarding conservation efforts	W5	Weak monitoring, control, and evaluation by the government
S6	It is one of the assets of Indonesia's natural resource strategy	W6	The success rate of rehabilitation and restoration is still low
EXTERNAL FACTORS			
Opportunities		Threats	
O1	Utilization supported by policies and regulations	T1	Mangrove forest degradation
O2	Benefits of high economic value	T2	Exploitation of the forest not according to land capability
O3	Product diversification of NTFP mangroves	T3	Decreased diversity of flora and fauna
O4	National rehabilitation program	T4	Loss of or reduction in mangrove habitat
O5	A harvest shelter that supports marketing of the produce	T5	Utilization of NTFPs without considering their sustainability
O6	Access to transportation that supports marketing of the produce	T6	Changes in the land cultivation system
O7	Rehabilitation technology and utilization pattern techniques	T7	Climate change affecting crop patterns

The formulation of mangrove forest management strategies in Indonesia is focused on opportunities and weaknesses to optimize sustainable management. Such strategies are expected to be the answer to the problem of mangrove forest degradation and to hinder the failure of the rehabilitation program, as this decreases the multifunctional benefits of mangrove forests. There are five strategies formulated that exploit opportunities (O) and cover weaknesses (W), which are:

1. Vertical and horizontal coordination and cooperation between agencies and related parties (W1, W4, W5, O1, and O5).
2. Capacity-building of local governments in carrying out their authority and obligations to manage mangrove ecosystems in accordance with local conditions and aspirations (W5, W6, and O1).
3. Development of advanced study, science, technology, and information systems needed to enforce sustainability of mangrove ecosystems (W2, W3, W6, O4, and O7).
4. Management of mangrove ecosystems through partnerships between the government, local communities, and businesses with the support of international institutions and communities as part of the efforts to meet global environmental commitments (W3, W5, O2, O3, O5, and O6).
5. Awareness-raising and training for the community to develop processed commodities from mangroves (S3, S6, O1, O2, O3, and O6).

Strong coordination and commitment among stakeholders are needed to build up the above priority strategies. Several alternative strategies must be supported by priority programs as a measuring tool to achieve goals. Furthermore, the sustainable mangrove forest management model requires five main elements, which are goals, changes, ecosystem indicators, constraints, and institutions related to mangrove forest management [117].

In increasing the capacity of the authority and the interests of local governments, it is necessary to plan and implement management and supervision, as well as the monitoring and evaluation of the activities laid out in the applicable rules and policies [118,119]. Strategies to increase the capacity of the central and local governments require institutional effectiveness, which is determined by the effectiveness of social interactions, including participation in the regulatory process to create a sense of ownership. Other important aspects also include communication, information, interpretation, and the meaning of the contents of the regulations that involve knowledge and experience, as well as power networks.

9. Conclusions

Indonesia has expressed a strong commitment to protect the remaining mangroves and restore those that have degraded. This action must be supported by all stakeholders at all levels to ensure the sustainability of mangrove ecosystems. Challenges are still faced in mangrove ecosystem management, including weak law enforcement, conflicting policies, a lack of community involvement, natural disturbances and constraints, and a lack of in-depth research and innovations.

Several strategies have been carried out for the management of the national mangrove ecosystem in Indonesia. These strategies include (1) ecosystem protection with the principle of sustainability, (2) improving the function and value of mangrove forests, (3) integrated mangrove ecosystem management, (4) strengthening political commitments and law enforcement, and (5) increasing the support and involvement of all stakeholders, including coastal communities, to reinforce the implementation of national strategic policies for the sustainable management of mangrove ecosystems. Developing research, science, and technology, as well as information systems, is also needed to strengthen the sustainable management of mangrove ecosystems and to achieve the global environmental commitments [120]. Hence, there is a requirement for global multidisciplinary collaborative research programs and concrete actions on mangrove management, especially to address challenges in climate change, the degradation of mangroves, and microbial diversity, pollution, and socioeconomic issues.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13050695/s1, Table S1: Mangrove rehabilitation in Indonesia (2015–2019); Table S2: Mangrove species associated with arbuscular mycorrhizal (AM) fungi; Table S3: Mangrove rehabilitation research conducted in Indonesia.

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