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Review

Configuration of Allocated Mangrove Areas and Protection of Mangrove-Dominated Muddy Coasts: Knowledge Gaps and Recommendations

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Abstract: Mangrove-dominated muddy coasts have been allocated for developing livelihood models, particularly in developing countries. Uncontrolled allocation causes the mangrove forests to be vulnerable and even severely eroded. Restoration of vulnerable and eroded coastal areas has been merely conservation-driven, leaving livelihood-oriented mangrove forests unprotected. As a consequence, mangrove-dominated muddy coasts have not been well-protected. How livelihood-oriented mangrove forests are configured towards protecting coasts and protecting local livelihoods remains a challenge. This study employed a critical review for addressing this matter. The results reveal that there is limited practical knowledge of configuring livelihood-oriented models for protecting the coasts. The configuration process reported in this study is merely based on technical recommendations in South East Asia to date. The recommended configuration commences with the first stage of voluntarily designating a certain percentage of allocated forests on the seaward side to protect coasts, relocating livelihood models in the gaps among current stands of mangrove forests landward. Abandoned ponds are ecologically restored using sediment trapping structures for providing suitable substrate for promoting regrowth of local mangrove species as the second stage, followed by designation of an appropriate percentage as mangrove belts on the seaward side. The two-step configuration is highly likely to be replicable and applicable nationally and regionally due to full consideration of different political, sociocultural, and environmental characteristics in Vietnam and Indonesia.

Keywords: abandoned ponds; configuration of allocated areas; ecological restoration; livelihood improvement; mangrove belts

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1. Introduction

Mangrove-dominated muddy coasts are environmentally and economically valuable resources [1]. In these coasts, mangrove forests provide shelters and feeding grounds for numerous marine faunal species [2,3], assist in dissipating the energy of incoming waves, and currents associated with storms, cyclones, and even tsunamis [1,4], well adapt to negative effects of sea level rise [5], and significantly contribute to delta progradation through trapping of sediments [6,7]. To date, these forests have been overexploited for economic development, particularly in South East Asia; for example through fishing, aquaculture, and the supply of timber and charcoal [8–10]. The overexploitation, both in intensity and extent, threatens the function of, and indeed survival of, many mangrove forests [11,12]. In addition, the forests and their ecosystems have been increasingly impacted by negative effects caused by climate change [13–15] and sea level rise [16].

1.1. Current Protection of Mangrove Forests

Mangrove forests are managed in protected areas [17], through community-based mangrove models [18] or privately-owned schemes. Protected areas are managed using legal actions [17] or through co-management schemes [19]. Legal actions are issued in order to boost conservation [17], or mitigate negative effects of sea level rise and climate change [20]. Co-management schemes promote the involvement of local communities in protecting state-owned forests in return for legal use of a certain percentage of protected mangrove resources for aquaculture development. This involvement is normally undertaken through contractual arrangements [21]. Legal use of the resources included use of mangrove forests for tourism development [22], or aquaculture development [9,23,24]. Allocated mangrove forests were negatively degraded or even lost as a consequence of poor technical guidance on configuring allocated mangroves and poor law enforcement [21,25–27].

The community-based model is operated under direct supervision of local government agencies [18]. This model aims to promote the well-being of community members as the primary objective and mangrove protection as a secondary goal [18]. This promotion is normally undertaken through institutional rights [18]. Community based mangrove models have been reported [18,28,29]. However, mangrove forests managed by community based models have also experienced degradation and erosion [30], and pollution by marine litter and microplastics [31–33]. Privately owned mangrove forests are managed mainly for economic development [21,22]. The forests are cleared to maximize aquaculture ponds or agriculture areas as a consequence of poor technical guidelines put in place by government agencies [21,30]. The clearance has exposed aquaculture ponds and agricultural areas to erosion of varying degrees [22,30].

1.2. Current Restoration of Eroded Mangrove Forests and Remaining Challenges

Efforts have been made to restore eroded coastal areas towards protecting mangrove-dominated muddy coasts. The restoration has been undertaken using ecological engineering solutions [34–36] or engineering solutions [37–40]. Engineering solutions negatively affected marine and coastal hydro-dynamics [37–40]. Ecological engineering solutions have had limited success in controlling the erosion in South East Asia [41]. However, aquaculture-induced erosion, allocated aquaculture ponds and privately owned coastal areas (here called livelihood-oriented mangrove forests) have been less emphasized in protecting mangrove-dominated muddy coasts. To date, recommendations have been provided for converting abandoned ponds into mangrove belts for coastal protection, but no detailed plans have been presented [42,43].

Against the background discussed above, four questions remain unknown: (1) how livelihood-oriented mangrove forests are configured towards protecting coasts; (2) what elements should be prioritized for the configuration process; (3) how abandoned ponds should be configured/restored for mangrove belts and protection of ponds; and (4) what lessons should be learned from the configuration for sustainable management of livelihood-oriented mangrove forests in the future. These questions become urgent and overdue in the context where conversion of mangrove forests to aquaculture ponds has continued to be a significant driver of mangrove loss [44–46]. Livelihood-oriented mangrove forests have been vulnerable to erosion [22,30,47]. Aquaculture-induced erosion has caused a significant burden for local communities [48]. This trend has become dominant, particularly in developing countries [12,49]. Therefore, this paper aims to review publications that report configuration of livelihood-oriented mangrove forests and abandoned aquaculture ponds for mangrove belts and protection of aquaculture ponds in order to gain a thorough understanding of how the configuration has worked toward protecting muddy coasts from erosion, and provide feasible recommendations for sustainable management of livelihood-oriented mangrove forests in the future.

2. Methods

Three sources of data (*Web of Science*, *ScienceDirect*, and *Google Scholar*) were used in search of publications in this review. *Web of Science* is an online platform containing almost 1.9 billion cited references from more than 171 million records. *ScienceDirect* is an online journal archive providing access to millions of scientific publications. *Google Scholar* is particularly useful in finding obscure but important sources as it references non-refereed publications.

Four terms—'*configuring mangrove forests for coastal protection*', '*configuring allocated mangrove forests for coastal protection*', '*configuring mangrove forests as a coastal erosion control*', and '*restoring abandoned ponds for mangrove belts*'—were used for searching for publications on these data sources. The authors admit that the review could have missed relevant publications due to the use of the terms. However, the use of these terms enabled the authors to critically review publications in relation to configuration of livelihood-oriented mangrove forests and restoration of abandoned ponds for mangrove belts and protection of mangrove forests, and provide feasible recommendations for sustainable management of these mangrove forests in the future.

On *Web of Science*, the search was limited using filters provided by Web of Science: Time span—all years (1965 and 2020); Science Citation Index Expanded (SCI-EXPANDED)—1965–present; Social Sciences Citation Index (SSCI)—1965–present; Conference Proceedings Citation Index—Science (CPCI-S)—1990–present; Conference Proceedings Citation Index—Social Science and Humanities (CPCI-SSH)—1990–present; and Emerging Sources Citation Index (ESCI)—2015–present. The hits were refined using the filters article, review, and proceedings papers. The search resulted in three hits.

On *ScienceDirect*, the search was undertaken using the terms and refined using two filters: reviewer articles and research articles. Of ninety-six hits, eight hits were selected for initial review because these hits discuss the issues related to restoration of eroded muddy coasts/abandoned ponds for mangrove belts and/or configuration of active aquaculture ponds for mangrove belts. Hits that neither discussed nor provided technical recommendations on restoration of eroded coasts and configuration of active ponds were excluded from the review.

The search on *Google Scholar* was refined using the English category. Of seventeen hits that directly discussed restoration of eroded muddy coasts, five hits were selected for further analysis because the remaining hits were duplications of those retrieved from other data sources. As a result, sixteen hits (Table 1) were selected for final review, and classified into two categories: specific study (ten hits) and critical review (six hits). In addition to the analysis of the hits under the critical review category, the hits under the specific study category were analyzed in search of patterns for configuring livelihood-oriented mangrove forests in pursuit of sustainable management.

Table 1. The classification of the hits using the Rivers–Pressures–Status–Impacts–Responses framework as previously recommended [50,51].

No.	Hits	Author(s)/Source/Country	Drivers	Pressures	Status	Impacts	Responses Suggested/Implemented
			Specific Study				
1	Pilot study on the erosion and rehabilitation of a mangrove mud coast	[52] *ScienceDirect*/Thailand (Ban Khung Thien)	• Aquaculture development. • Mangrove clearance for economic development.	• Land use planning. • Mangrove forests along dykes and dams.	• Eroded areas with loss of mangrove forests. • Land subsidence. • Sediment deficit.	• Loss of mangrove forests. • Production of wild species adversely affected.	• Accumulation of onshore sediment. • Protection of narrow mangrove belt.
2	Strategies for mangrove rehabilitation in an eroded coastline of Selangor, Peninsular Malaysia	[53] *ScienceDirect*/Malaysia (Selangor, Peninsular)			Eroded coastal areas with loss of mangrove forests.		• Ecological restoration of sites before transplanting. • Provision of proper hydrology and substratum before interventions are taken.
3	An integrated approach to coastal rehabilitation: mangrove restoration in Sungai Haji Dorani, Malaysia	[36] *ScienceDirect*/Malaysia (Sungai Haji Dorani)			Eroded areas.		• Facilitation of sediment deposition to provide proper hydrologic regime. • Restoration of mangrove forests to create a sustainable coastal ecosystem.
4	Collaborative efforts on mangrove restoration in Sedari Village, Karawang District, West Java Province	[54] *ScienceDirect*/Indonesia	Converting mangrove areas into farm lands and fish ponds.	Coastal development plan.	Eroded coastal areas.	• Loss of fish ponds / farm lands. • Loss of mangrove forests.	• Provision of physical conditions in relation to hydrology, substrates. • Transplantation of proper mangrove species.
5	Coastal land use planning in Ben Tre: constraints and recommendations.	[47] *Web of Science*–Vietnam (Ben Tre)	• Aquaculture development. • Agriculture development. • Allocation for aquaculture development and protection of mangrove forests. • National defence purpose. • Transplantation of seedlings of *Avicennia* species on newly established intertidal mudflats.	• Land use planning. • Intertidal mudflats. • Stands of mature trees of *Rhizophora* species.	• Severely eroded coastal areas. • Mature trees of *Rhizophora* species being uprooted. Mature trees of *Avicennia* species died.	• Loss of aquaculture ponds. • Failure in restoring mangrove forests and protecting the coasts. • Creation of gaps and fragmentation of mangrove stands. • Weakening the capacity and resilience of mangrove forests. • Transplantation is costly but unnecessary.	• Configuration of active aquaculture ponds to designate areas for mangrove belt and proper protection of aquaculture ponds. • Stabilization of eroded muddy coasts through protection of intertidal flats and promotion of natural regeneration of mangrove species. • Ecological restoration of abandoned ponds through accumulation of fine-grained sediment.

6	Current Management of Allocated Mangroves for livelihood improvement in the Mekong Delta, Vietnam: knowledge gaps and a potential model for future management	[55] *Web of Science*/Vietnam (Kien Giang)	• Allocation policy—30 (use)/70 (protection). • Inadequate technical guidelines on allocation. • Coastal mangrove protected areas. • Private land ownership. • Zoning plan. • Mangrove restoration and coastal protection with engineering and ecological engineering solutions. • Establishment of 500 m mangrove belt.	• Aquaculture development. • Transplantation of seedlings of *Avicennia* species on newly established intertidal mudflats.	• Eroded areas with abandoned ponds. • Stable areas with active ponds.	• Severely eroded coastal areas. • Mature trees of *Rhizophora* species being uprooted.	• Configuration of active ponds to designate coastal areas for mangrove belts and protection of aquaculture ponds. • Ecological restoration of abandoned ponds through accumulation of fine-grained sediment.
7	Managing mangrove-dominated muddy coasts through integration of local and scientific knowledge in Kien Giang, Vietnam and Brebes Regency, Indonesia	[56] *Google Scholar*/Vietnam (Kien Giang) & Indonesia (Brebes Regency)	• Aquaculture development. Land use change.	• Land use planning. Stands of mature trees of *Rhizophora* species.	• Eroded coastal areas with abandoned ponds. • Mature trees of *Rhizophora* species being uprooted. • Stable areas with active ponds.	• Loss of aquaculture ponds. • Failure in restoring mangrove forests and protecting the coasts. • Creation of gaps and fragmentation of mangrove stands. • Weakening the capacity and resilience of mangrove forests. Transplantation is costly but unnecessary.	• Accumulation of onshore sediment. • Protection of intertidal flats. • Configuration of active ponds to designate areas for mangrove belts and protection of livelihood models. Ecological restoration of eroded ponds using morpho-dynamic elements.
8	Associated mangrove aquaculture farms—building with nature to restore eroding tropical muddy coasts	[57] *Google Scholar*/Indonesia					• Expansion of current mangrove areas (ideally 50 m in width) on the seaward side toward mangrove belts. Ponds are relocated landward to facilitate soil compaction and designate old dykes as proper habitat areas for mangrove belts.
9	Coastal protection for the Mekong Delta (CPMD)—a decision support tool	[58] *Google Scholar*/Vietnam					• Protection of mangrove forests. Accumulation of sediment.

10	Integrated coastal protection and mangrove belt rehabilitation in the Mekong Delta	[59] *Google Scholar*/Vietnam				• Proper physical conditions such as coastal morpho-dynamic elements and water-related parameters) before interventions are undertaken.
	Critical review					
11	Ecological engineering for successful management and restoration of mangrove forests	[60] *ScienceDirect*				Provision of suitable substrates for mangroves to grow.
12	Defining eco-morpho-dynamic requirements for rehabilitating eroded mangrove mud coasts	[61] *ScienceDirect*/Thailand (Bang Khun Thien), British Guyana and Suriname, Indonesia (Timbul Sloko)		• Land use planning. • Thoughtless aqua-culture develop-ment.	• Eroded mangrove-mud coasts. • Impacted sediment dep-osition.	• Provision of proper morpho-dynamic elements such as waves, tides and sed-iments need to be adequately consid-ered before interventions begin.
13	Mangrove allocation for coastal protection and livelihood improvement in Kien Giang province, Vietnam: constraints and recommendations	[21] *Web of Science*/Vietnam (Kien Giang)				Policy analysis
14	How to restore mangroves for green-belt creation along eroded coasts with abandoned aquaculture ponds	[43] *ScienceDirect*/Indonesia	Extensive aquaculture development.	• Land use planning. • Areas of patchy-areas with abandoned mangrove forests.	• Severely eroded coastal • Loss of aquaculture ponds. • Loss of mangrove for-ests.	• Provision of proper physical condi-tions of sites such as substratum. • Strict protection of mudflats to en-sure sustainability of mangrove belts.
15	Managing erosion of mangrove-mud coasts with permeable dams—les-sons learned	[62] *ScienceDirect*/Guyana, Indo-nesia (Demak, Gresik Re-gency), Suriname, Thailand, Vietnam (Soc Trang, Bac Lieu, Ca Mau)				• Protection of intertidal flats as coastal protection. • Provision of proper morpho-dynam-ical and hydrological elements (waves, sediments, tidal regime) be-fore interventions are made.
16	Ecological mangrove rehabilitation—a field manual for practitioners	[63] *Google Scholar*/technical re-port				• Provision of proper bio-physical conditions to promote mangrove growth. • Rehabilitation of mangrove areas

3. Results

The critical review presented the configuration of livelihood-oriented mangrove forests, identified important elements that contributed to sustainable configuration of the livelihood-oriented mangrove forests, and provided feasible recommendations for sustainable management of these forests in the future. The following sections provide the results in detail.

3.1. Overview of the Review

Of sixteen hits retrieved from three data sources, eleven hits (1, 2, 3, 4, 9, 10, 11, 12, 14, 15, and 16—refer to Table 1 for numbers) dealt with restoring abandoned ponds for mangrove belts. Five hits (No. 5, 6, 7, 8 and 15—refer to Table 1 for numbers) detailed configuration of livelihood-based mangrove forests and ecological restoration of abandoned ponds for mangrove belts and protection of aquaculture ponds. Only one hit presented analysis of the mangrove allocation policy for mangrove belts and protection of livelihood models. The hits proposed technical recommendations to ensure sustainable management of livelihood-oriented mangrove forests, predominantly for countries of South East Asia (Figure 1 and Table 1).

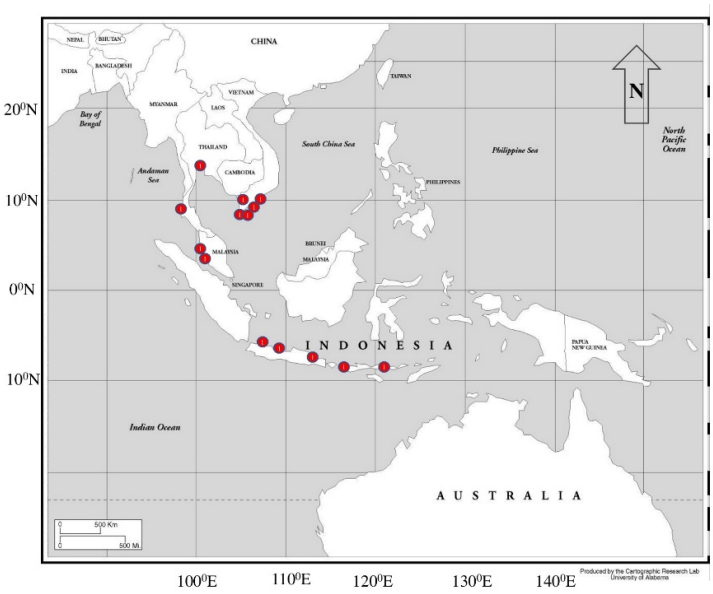

Figure 1. Locations of the places where the studies were implemented (red dots indicating locations). Background is a Google map.

3.2. The Configuration Process

The critical review produced a configuration method of livelihood-oriented mangrove forests. This configuration method is a two-stage process. The first stage involves designation of an appropriate percentage of livelihood-oriented mangrove forests on the seaward side to establish mangrove belts, relocating livelihood-oriented areas among current stands of mangrove forests on the landward side. In the second stage, eroded and vulnerable areas are restored using passive ecological restoration for providing suitable substrate for promoting regrowth of local mangrove species, followed by designation of an appropriate percentage on the seaward side as mangrove belts. Passive ecological restoration is highly likely to be an appropriate strategy because this strategy aims to facilitate degraded mangrove forests and their ecosystems gradually recover through removal of stressors facing the forests and their ecosystems, as previously recommended [64,65].

Livelihood-oriented mangrove forests are not encouraged until eroded areas are ecologically stabilized (Figure 2).

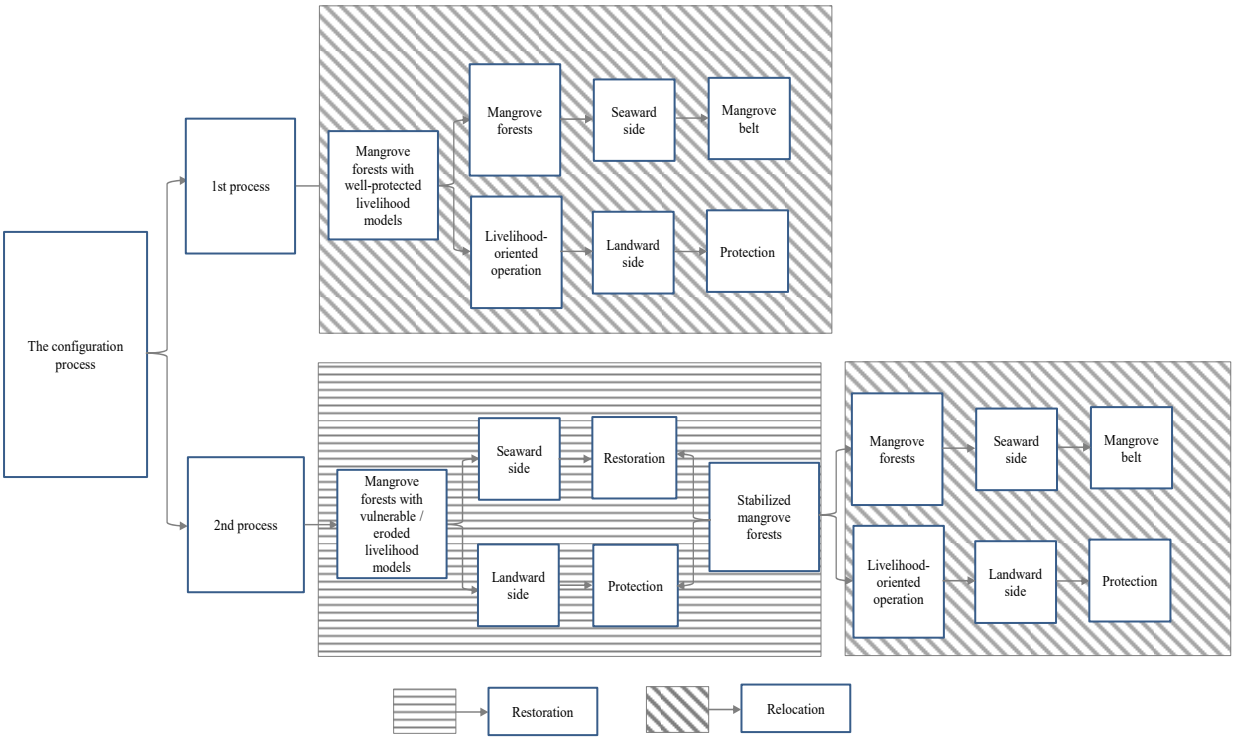

Figure 2. The configuration process.

3.3. Important Configuration Elements

The configuration process encompasses two crucial elements including relocation of current livelihood models and ecological restoration of vulnerable/eroded mangrove forests in combination with the relocation process (Figure 2). To proceed with the relocation, local willingness is a crucial element. Livelihood-oriented operators need to change their traditional operation by relocating their operation areas on the landward side in allocated mangrove forests or designate a certain percentage of mangrove forests to voluntarily establish mangrove belts in private coastal areas [66–69]. A minimum area of voluntarily established mangrove belts in private coastal areas should be first guaranteed, but could be increased once the benefits of designing areas for mangrove protection become obvious [66–69].

Passive ecological restoration commences with use of topographical conditions. Vulnerable/eroded mangrove forests are configured in a way that assists in protecting and connecting current fragmented mangroves and ecologically restoring abandoned ponds towards establishing a relatively thick mangrove belt along the coastline [47,55,56,66–69]. In addition, deep channels and rivers are taken into consideration to configure livelihood models in a way that encourages water circulation to serve livelihood-oriented areas [55].

4. Discussion

The critical review resulted in the configuration process and its important elements towards mangrove belts and protection of livelihood-oriented models. The configuration process and its elements are discussed in detail in the following sections.

4.1. The Configuration Process and Coastal Protection

The configuration process is highly likely to serve as a technical reference for revising the current coastal management policies elsewhere in South East Asia and the world in the future. The current coastal management policies of Vietnam [70–72] and Brebes Regency, Indonesia [66–68] have not provided detailed technical guidance on configuring livelihood-oriented mangrove forests. Poor technical guidance resulted in ponds being constructed of all sizes [30,69]. Ponds were vulnerable to erosion, and even eroded [30,48]. Further to this, pond abandonment has been widespread in South East Asia [12,27,48,73], with examples reported from Indonesia [69], Bangladesh [74], Thailand and Indonesia [61]. This review summarizes configuration steps on how livelihood-oriented models should be configured towards improving resilience of livelihood-oriented mangrove forests, increasing the duration of aquaculture ponds, and strengthening mangrove ecosystems. In addition, the configuration process was developed in light of political, sociocultural, and environmental characteristics in South East Asia because many countries adopted allocation mangrove as feasible management scheme; for example, Vietnam passed an allocation policy in 2001 [21,72] while Indonesia approved long-term spatial land use planning [66–68]. Together with the currently protected mangrove forests, the livelihood-oriented mangrove forests, if properly configured, are highly likely to contribute to establishing a continuous mangrove belt, which is the ultimate objective of the coastal management policies of Vietnam [21,70–72] and Indonesia [66–68,75]. The configuration process is evidently confirmed by the conclusions made by the previous study that livelihood models are sustainable on stable or progradational coasts, where models are adequately protected by wide mangrove belts [76].

4.2. The Configuration Process and the Challenges

The configuration process faces two challenges: practical testing and local participation. The configuration process needs to be practically tested because the process was developed using technical recommendations provided by the hits gained from this review. If future opportunities arise, the configuration needs to be tested for developing a complete understanding of the effectiveness of the configuration in protecting the livelihood-oriented mangrove coasts. Secondly, local participation is a crucial factor that facilitates practical testing. Model operators construct livelihood models close to water sources because they want to allow water to approach model areas [21,30,76]. The review shows that the configuration takes advantage of topographical conditions, i.e., deep channels and rivers that aim to serve model operation. Previous studies showed that local people do not follow advice made by outsiders until the advice is proven helpful [77]. In this case, operators are not likely to change their traditional operation until the configuration is proven effective. In practice, the project cycle management, as previously recommended by IUCN [78], is highly likely to be a solution to these challenges. As a crucial element of this management, the planning and input phase is a potential solution, particularly in the livelihood improvement context, because this phase facilitates choice of the most important objective of practical testing to be achieved, and defines involvement of stakeholders to avoid socioeconomic conflicts.

To summarize, livelihood-oriented mangrove forests have been overexploited and highly vulnerable to erosion due to inadequate technical guidance provided by the current coastal management policies. Restoration of vulnerable and eroded coastal areas has been merely conservation-driven, leaving livelihood-oriented mangrove forests unprotected. Meanwhile, construction of mangrove belts has been nationally or regionally emphasized to balance demands for economic development and needs for coastal protection, particularly for adaptation to negative effects caused by climate change and sea level rise. However, current efforts have failed to protect mangrove-dominated muddy coasts. To date, the communities of the countries of South East Asia have made a step forward in proposing configuration of livelihood-oriented mangrove forests that help protect their

livelihoods and establish mangrove belts. The two-step configuration was developed with adequate consideration of political, sociocultural, and environmental differences in the countries of South East Asia, which potentially facilitates replication or application for sustainable management or policy change elsewhere in the broader region and the world.

5. Conclusions

The configuration was well-documented using the comprehensive review. There is limited practical knowledge of configuring livelihood-oriented models for protecting the coasts. The configuration process reported in this study is based on technical recommendations provided by studies in South East Asia. The recommended configuration process emphasizes two elements: relocation of current livelihood-oriented models and ecological restoration of eroded coastal areas with abandoned/vulnerable ponds. The relocation aims to increase the duration of aquaculture ponds while the ecological restoration focuses on improving mangrove ecosystems that bring benefits for livelihood-oriented models in return, and creating mangrove belts towards protecting coasts for adaptation to negative effects caused by climate change and sea level rise. The configuration is highly likely to be applicable or replicable regionally and globally thanks to adequate consideration of political, sociocultural, and environmental characteristics in different countries of South East Asia.

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