

Article

Sustainable Management of Coastal Wetlands in Taiwan: A Review for Invasion, Conservation, and Removal of Mangroves

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Abstract: Mangrove management has been a sustainable concern in coastal wetlands for decades, especially for original near-shore wetlands and environments without mangrove forests. Although studies outlining environmental, social, and economic benefits of mangrove forests have been increasing, few studies have examined sustainability and policies for reducing or removing mangroves. This study explores the current implemented strategies pertaining to the invasion, conservation, and removal of mangroves for wetland sustainability. A total of 19 mangrove sites were sorted out to develop the main patterns and factors for the destruction or protection in estuaries on the western coast of Taiwan. For traditional wetland management, when faced with development pressure, having protected areas under certain laws is a good direction to go for mangrove sustainability. Furthermore, due to the invasion of mangroves in the mudflats, the Siangshan Wetland indicated mangrove removal can be a positive conservation case as an appropriate habitat rehabilitation strategy for benthic organisms. Under special conditions, mangrove removal provides useful insights into the sustainability of wetlands. These insights contribute to facilitating the worldwide move towards sustainable management on mangrove wetlands. The study also presents the following strategies to further reduce or remove mangroves in the coastal wetlands that contain no mangrove forests: (1) Conducting studies to evaluate the effectiveness of mangrove removal; (2) implementing policies to ensure positive influences on coastal wetlands, and (3) providing mangrove conservation education for sustainable development.

Keywords: sustainable management; mangrove invasion; wetland policy; conservation strategy; habitat rehabilitation

1. Introduction

A wetland is a place where the land is covered by water, either salt water, fresh water or concentrations in between the two extremes [1]. The classification of wetlands are differentiated by their developmental characteristics and the environment in which they exist, including bog, fen, marsh, swamp, and shallow water [2,3]. A previous study not only proved the value of wetlands to humans but also reviewed some of the endangered and threatened flora and fauna, and examples of endangered and threatened reptiles, amphibians, fish, and birds that depend on wetlands [4]. Wetlands are the most productive environments in the world and are vital for human survival. The importance and benefits of wetlands include freshwater supply, food and building materials, rich biodiversity, carbon storage, flood control, groundwater refill, and climate change mitigation [5]. However, the value of the landscape is important but easily overlooked [6]. Understanding the factors controlling wetland vegetation community composition is vital to conservation and biodiversity management [7]. Recently,

wetland management has faced a global challenge as wetland areas and their quality continue to decline and ecosystem services are compromised.

Mangrove forests are an important type of wetland ecosystem that provides numerous valuable services to the marine environment and people. In tropical and subtropical regions, mangroves cover an area of approximately 180,000 km² [8,9]. By satellite imagery, the total area of mangroves in the year 2000 was 137,760 km² in 118 countries of the world [10]. Mangroves are beneficial for the following purposes: aquaculture, agriculture, source of firewood and building material, medicines, and for other local subsistence uses [11]. In the natural environment, mangroves serve as important breeding and nursery habitats for juvenile fish species, crab, shrimp, and mollusk species [12]. In general, mangrove areas have been identified to have high diversity and good ecological value [13] because they provide food and shelter, thus resulting in rich ecosystems [14,15]. Functionally, they provide protection to coastal communities against natural hazards such as cyclones, tsunamis, and shoreline erosion [16–18]. They maintain water quality and clarity by filtering pollutants and trapping sediments that originate from the land. In summary, mangroves provide fishes, timber, plant products, coastal protection, and scope for tourism, which are conservatively estimated to be worth US\$186 million each year [19].

Unfortunately, mangrove forests are already one of the world's threatened environments mainly by urban development. When wetlands are impacted by urban development, the ecosystem services of these wetlands are lost [20]. Moreover, at least 35% of the area of mangrove forests has been lost in the past two decades [21]. Mangrove deforestation is occurring globally at a rapid rate, and is causing serious ecological and economic losses [22]. Hamilton and Casey (2016) mention that many countries showing relatively high amounts of mangrove loss include Myanmar, Malaysia, Cambodia, Indonesia, and Guatemala. Global mangrove deforestation continues, with annual declines of approximately 0.16% to 0.39%. In particular, the deforestation rate of mangroves in Southeast Asia is between 3.58% and 8.08% [23]. In 2000, only 6.9% of the total mangrove area was protected by the existing protected area network (IUCN I-IV) [10]. The desire for reversion of estuaries to their previous state is the greatest issue for the mangroves [24].

In Taiwan, due to topographical factors and the fragility of the soil in the upstream catchment, a large amount of sediment has been deposited in the West Coast estuary via rivers [25]. Kao et al. (2008) documented fluvial mud and sand concentrations during flooding indicating that fluvial material in Taiwan's rivers is mainly composed of mud (>70% and up to 98%) [26]. Thus, this deposition forms a series of shoals and the swamps are suitable for mangrove growth and expansion. The total of 37 relatively complete mangrove colonies has an area of approximately 1286 hectares (Figure 1). There are some kinds of ecosystem services provided by mangroves in Taiwan, including breeding and nursery habitats, food and shelter, aquaculture and fishery, pollutants trapping, coastal protection, and tourism [12,27,28]. Therefore, mangroves have become one of the main habitat types of coastal wetlands in Taiwan. In the past, the pressures to develop reclamation and recreation areas and to construct roads have been characterized by artificial disturbances [29,30]. Forest loss, habitat destruction, and reduced biodiversity still occur in mangrove areas. Actually, artificial construction has been more than 50% on Taiwan's shoreline [30]. In order to understand the sustainable management of wetlands, it is vital to discuss mangrove problems, issues, management, strategies and laws.

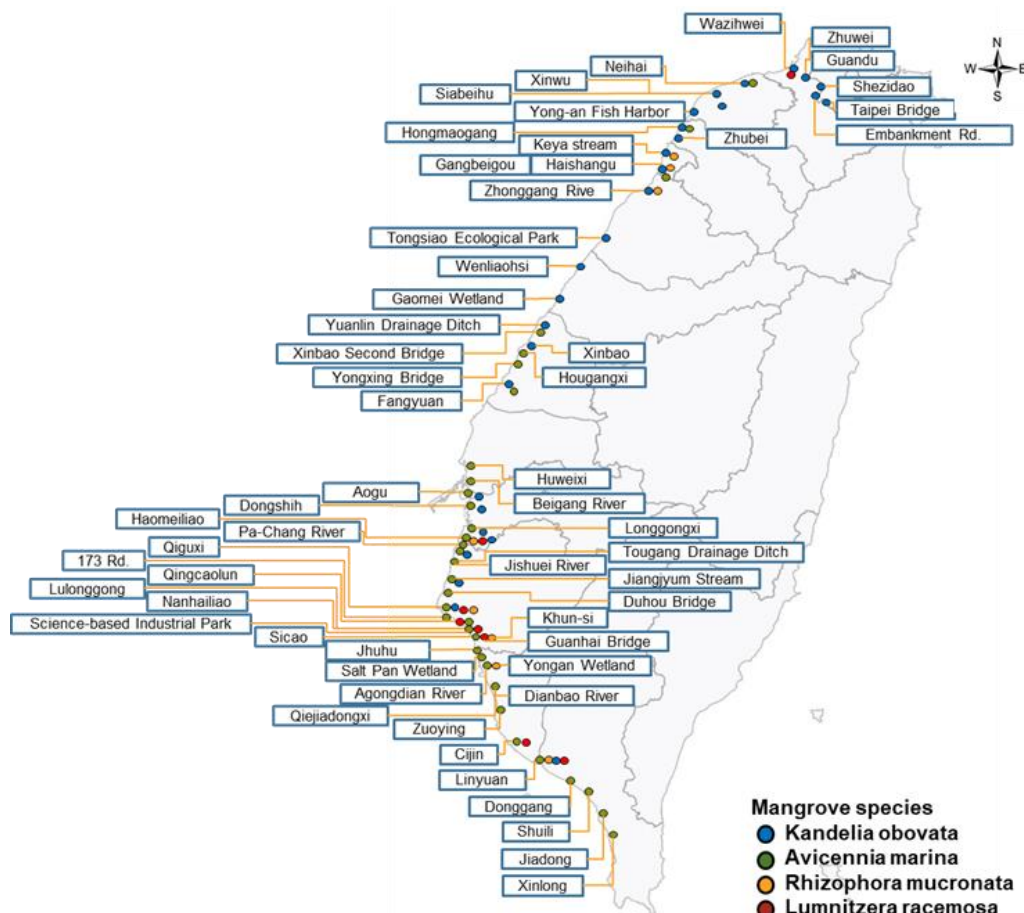


Figure 1. Distribution of mangroves in Taiwan.

At the same time, paying attention to the management status of neighboring countries is also very helpful for sustainable management. However, in most areas trees have been cut down and the mangroves removed to construct aquaculture farms, for coastal development purposes, or by local residents to acquire firewood and other products (Diop, 2003) [31]. In Japan, there is no aquaculture development in mangrove areas because the total area is small (553 hectares) and is strictly protected. The main utilization of mangroves is for wild fisheries and tourism [27]. In Hong Kong, such as the Mai Po wetland, most of its area provides ecotourism and also consists of shrimp ponds, or gei wais, and fish ponds [28]. An aspect that deserves concern is that for reasons of biodiversity, the government and Non-Governmental Organization (NGOs) plant mangroves on the coastal areas and have an impact on the ecology in the non-mangrove areas. In Australia, two aspects of early management have been recognized and discussed, including the political aspects of management and the technical aspects of management, such as public perception of mangrove systems, legislative framework, administrative fragmentation, identifying objectives and strategies, and rehabilitation approaches etc. [32,33]. Based on the time series of Landsat data from 1987 to 2014, mangroves were observed to extend seawards and inland invasions occurred along many rivers in the tidal reaches [34]. Conversely, before the early 20th century, there were no mangroves in the Hawaiian Islands. In 1902, *Rhizophora* mangle was introduced to Molokai Island, mainly to stabilize coastal mudflats. However, unlike other countries, in Hawaii, they see it as an alien species. Known negative effects include lowering the habitat quality of endangered water-birds, leading to drainage and aesthetic problems [35]. In northern New Zealand, conservation and restoration works have been undertaken by the mangrove management project to avoid the destruction and degradation of mangrove habitats [36]. Alfaro (2010) also reported that mangrove removal in temperate northern New Zealand had particular effects on benthic communities and sediment characteristics [36].

Despite the considerable increase in the awareness of the environmental and socioeconomic importance of mangrove ecosystems, they are still destroyed in many parts of Taiwan. Sustainable management of mangrove ecosystems should be conducted because they are likely to be irreparably lost with long-term implications. Although the number of studies that outline the environmental, social, and economic benefits of the mangrove forest is growing, few studies have examined the sustainability and policy pertaining to mangroves in Taiwan. Mangrove degradation is a well-documented trend and the conservation of mangrove has become an important issue. However, the spread of mangroves which leads to invasion throughout the estuary region and the removal of mangroves are concerned issues for the sustainable management of coastal wetlands. The aim of this research is therefore, through the method of wetland sorting, literature review, and case study, to explore the appropriate strategies for the sustainable management of mangroves in coastal wetlands.

2. Methodology and Approach

The benefits of mangroves are well documented in many studies, but few studies have examined the sustainability and policies related to mangrove invasion and removal in the coastal wetlands. The lack of sustainability studies aimed at invasion, conservation, and removal of mangrove in the coastal environment was the driver for this study. This study reviewed the current status of international management practice-related strategies and policies not previously described in academic study. To address the limitations and problems associated with the invasion, conservation, and removal of mangroves, a systematic literature and NGO websites review was conducted to assess the current sustainable management. Searches were conducted using ProQuest, Science Direct, Web of Science, and Google Scholar. The search terms include “mangrove invasion”, “mangrove conservation”, “mangrove removal”, “mangrove management”, “sustainable management”, “sustainability”, “policies”, and “legislation”. Some cases are also provided as a proof or for comparison. Finally, results describing sustainable management, sustainability, or evidence related to the invasion, conservation, and removal of mangrove are included in this study. Based on these results, recommendations to support the current and future strategies or policies on sustainable management of mangrove wetlands for future research were identified.

3. Legal Connotation of Taiwan’s Wetland Conservation Act

Since 2006, wetland ecotourism and education have been conducted for conservation. The Construction and Planning Agency Ministry of the Interior completed the delineation of the “National Important Wetlands” in Taiwan. In 2011, there were 100 important wetlands, including 51 “international wetlands” and “national wetlands”, 40 “local wetlands” and seven undetermined wetlands [35]. Moreover, the Wetland Conservation Act was passed on July of 2013, and the implementation of the Act began on 2nd February, 2015. Therefore, Taiwan has become one of the areas of wetland protection and specific legislation. Su (2014) indicated that the new law enables the society to achieve sustainable utilization on wetland ecological services and allows the government to evaluate and assign a specific area as a “wetland of importance” [37]. After 2015, a total of 42 “National Important Wetlands” and 41 “Local wetlands” were included, with a total of 83 nationally important wetlands. The total area of 83 nationally important wetlands was confirmed to be 47,627 hectares from the 56,865 hectares announced in 2011.

After the implementation of the Wetland Conservation Act, developers have to prepare a usage plan for review [37]. Otherwise, any development activities in the mangrove area will be prohibited. The usage plan also follows the “wise use” principle to protect the wetland and biological service system. However, this unclear standard has no legal distinction between the types of “wise use”. If the government deems that a particular development is necessary, the law provides a process to compensate for lost wetlands and provides additional habitat for a variety of species. We know that conservation and management rely heavily on systematic studies and fundamental data. It is a complex

challenge for policy implementers, biologists, and lawyers to identify and adopt the scientific content and turn it into an executable mechanism.

4. Sustainable Management on Mangroves Wetland

Saenger (1999) indicated that problems of mangrove management can be attributed to information failure, market failure, and intervention failure [38]. Mangroves are usually viewed as wastelands with mutually conflicting uses or allowing exploitation. Mangrove ecosystems have been generally undervalued and often perceived as dispensable [39]. These failures are usually due to the ineffective policies or management of the government, thus leading to irreparable wetland mismanagement.

In Taiwan, there are six mangroves species: *Kandelia candel*, *Rhizophora mucronata*, *Avicennia marina*, *Lumnizera racemosa*, *Bruguiera conjugate*, and *Ceriop tagal*. The native habitat of the mangroves is mainly distributed in the estuary area of Taipei City, Tainan City, and Kaohsiung City on the western coast of Taiwan. There have been no mangroves in the history of the coast from Hsinchu County to Chiayi County. Beginning in 1984, the Taiwan government has drawn 12 marine protected areas with the main goal of promoting biodiversity [40]. However, due to planting and natural drifting, mangroves have grown everywhere. The problems of Taiwan's mangrove wetlands are shown in Table 1. Here, we sorted out the main factors for the destruction and implementation of protection in Taiwan as follows.

4.1. Development Pressure and Conservation

Mainly, there are various development plans in the coastal areas of Taiwan, such as expressway construction, aquaculture fishery, coastal strata subsidence, wastewater treatment plant and landfill, fishing port construction, and scenic areas [25,27]. Identically, mangroves were rapidly destroyed in the last decades due to massive reclamation and infra-structural developments in Hong Kong [28]. Mangrove forests in Thailand and Philippines lost 60%–70% area due to construction of shrimp ponds [8,28]. Spalding et al. (2010) mentions that most of the remaining mangrove areas in early Taiwan were concentrated on the west coast, especially in the Tanshui estuary and further south, some of which have legal protection in the Chan-Yun-Chia reserve [9]. Thus, mangroves have remained stable over the past 40 years and have expanded in most areas of Taiwan (Table 1). Therefore, due to the implementation of laws and policies of Taiwan, most of the mangroves were protected by including them as a protected area (Urban Planning in 1975), an ecological conservation area (Regional Planning in 1977), a fishery resource reserve (Fisheries Act in 1978), a nature reserve (Cultural Heritage Preservation Act in 1982), a wildlife sanctuary (Wildlife Conservation Act in 1989), an important wildlife habitat (Animal Protection Law in 1991), a national park (National Park Law in 2010) and an important wetland (Wetland Conservation Act in 2011).

In addition, marine protected areas (MPAs) are mainly planned in accordance with the Fisheries Act, the National Park Law, the Wildlife Conservation Law, and the Cultural Heritage Preservation Act. The total area of MPAs is about 30,035 square kilometers, and the proportion is about 46.15% of the coastal area [35]. At present, the Coastal Management Act was enacted in 2015 to maintain natural systems, ensure zero loss on natural coasts, respond to climate change, prevent coastal disasters and environmental damage, protect and rehabilitate coastal resources, promote coastal integration management, and promote sustainable development in coastal areas.

Table 1. Comparison of Taiwan's Mangrove Wetlands.

Wetland Location	County	Area (ha.)	Mangrove Species	Habitat Type	History Events	Conservation Implement	Sustainable Management
Zhuwei mangrove	New Taipei	60	<i>Kandelia candel</i>	river flat	Sanitary wastewater, Garbage pollution	Important Wetland (National)	Reservation
Guandu wetland	New Taipei	57	<i>Kandelia candel</i>	morass marsh	Tourist interference, Garbage pollution Eutrophication	Nature Preserve Guandu Nature Park Important Wetland (National)	Reservation
Wazihwei wetland	New Taipei	15	<i>Kandelia candel</i>	estuary river flat	Tourist interference	Nature Preserve	Reservation
Sinfong mangroves	Hsinchu	50	<i>Avicennia marina</i> <i>Kandelia candel</i>	estuary marsh	Waste incineration and soil dumping	Important Wetland (National)	Reservation
Siangshan wetland	Hsinchu	400	<i>Kandelia candel</i>	intertidal zone mud flat	Oysters heavy metal pollution	Important Wetland (National) Wildlife Sanctuary	Removal
Zhonggang stream	Miaoli	1.5	<i>Kandelia candel</i>	estuary river flat	Excessive human interference, pollution		Reservation
Tongsiao mangroves	Miaoli	0.5	<i>Kandelia candel</i> <i>Avicennia marina</i>	intertidal zone sand beach	Oil leakage heavy metal		Development damage
Fangyuan wetland	Changhua	5	<i>Kandelia candel</i> <i>Avicennia marina</i>	intertidal zone mud flat	Industrial wastewater pollution	Important Wetland (National)	Removal
Aogu wetland	Chiayi	25	<i>Kandelia candel</i> <i>Avicennia marina</i> <i>Rhizophora mucronata</i>	estuary river flat marsh	Wastewater, Land subsidence	Important Wetland (National)	Reservation Development damage
Budai Salt Pan wetland	Chiayi	20	<i>Avicennia marina</i> <i>Rhizophora mucronata</i> <i>Kandelia candel</i> <i>Lumnizera racemosa</i>	lagoon mud flat floating island	Land subsidence	Natural Reserve Important Wetland (National)	Reservation Development damage
Shuang Chun	Tainan	2	<i>Rhizophora mucronata</i> <i>Avicennia marina</i> <i>Lumnizera racemosa</i>	marsh	Development pressure		Reservation Fish farm damage
Beimen wetland	Tainan	1791	<i>Avicennia marina</i>	lagoon floating island	Development pressure, wastewater pollution	Important Wetland (National)	Reservation Highway damage Fish farm damage

Table 1. Cont.

Wetland Location	County	Area (ha.)	Mangrove Species	Habitat Type	History Events	Conservation Implement	Sustainable Management
Jiangjyum stream	Tainan	10	<i>Kandelia candel</i>	estuary river flat	Development pressure, wastewater pollution	Important Wetland	Reservation Development damage
Cigu Salt Pan wetland	Tainan	1210	<i>Lumnizera racemosa</i> <i>Avicennia marina</i>	lagoon	Development pressure, Binnan industrial zone and the Cigu international airports	Wildlife Sanctuary Important Wetland (National) Taijiang National Park	Reservation Highway damage
Sihcao wetland	Tainan	10	<i>Lumnizera racemose</i> <i>Rhizophora mucronata</i> <i>Avicennia marina</i>	lagoon	Recreational pressure, waterway siltation	Important Wetland (International) Wildlife Sanctuary Taijiang National Park	Highway damage
Yongan (Salt Pan) wetland	Kaohsiung	28.5	<i>Avicennia marina</i>	waterway	Harbor construction, LNG receiving station	Important Wetland (Place)	Power plant construction damage
Cijin	Kaohsiung	0	<i>Lumnizera racem</i> <i>Avicennia marina</i>	waterway	Commercial port construction		City development damage
Dianbao river	Kaohsiung	2.9	<i>Avicennia marina</i> <i>Kandelia candel</i>	estuary waterway	Embankment cementation		City development damage
Dapeng Bay	Pingtung	13.5	<i>Avicennia marina</i>	lagoon	Recreational pressure, waterway siltation	Important Wetland (National) National Scenic Area	Reservation Scenic area development damage

4.2. Planting, Invasion, and Removal

For example, the 4th River Management Office (RMO), Water Resource Agency, planted Taiwan's original mangroves species—*Kandelia candel* and *Avicennia marina*—in 1993 at Fangyuan, Changhua County. In the beginning, the RMO implemented the dream of greening, but it eventually turned into an ecological nightmare. Dr. Cai Jiayang, chairman of the Changhua Environmental Protection Union, said that mangroves will cause mudflats to accumulate and change the muddy structure of the habitat [29]. If benthic organisms are unable to adapt to such a fine mud environment, they will be replaced by other species. Therefore, the removal of mangroves was initiated in 2006 because the original habitat was previously free of mangroves [41].

Another example is Siangshan Wetland, which is located in Hsinchu City. Mangroves (*Kandelia candel*) have been planted since 1969, thus causing a change in the original habitat and posing a serious threat to the endemic Taiwanese fiddler crab species (such as *Uca formosensis*). The invading mangroves changed the structure and functions of the habitat for benthic organisms, caused sediment to accumulate with estuary flooding in heavy rain, and allowed invasions of the small black mosquito (*Forcipomyia taiwana*) [12]. Therefore, the Hsinchu City Government have launched several small-scale mangrove removal projects since 2000 and the mangrove area covered approximately 107 hectares. Related mangrove-removal projects are all entrusted to NGOs, ranging from 1–14 hectares were implemented from 2007 to 2014. In March 2016, the cumulative removed mangrove area was 348 hectares. The annual removal rate of mangrove deforestation is about 5.61%. In particular, the growth rate of mangroves is 14.07%. The average cost for the removal was NT\$360,000 per hectare. Up to 3–4 hectares of mangroves were removed per year as the limited available funds dwindled. Mr. Zhang Dengkai (2018), the Society of Wilderness, said that after the mangroves were removed, the habitat gradually recovered into a sandy texture.

Wetland status is influenced by various anthropogenic and environmental stressors that necessitate ecosystem-based, integrative approaches to enable sustainable management. It is necessary to critically analyze the current strategies and policies governing wetland usage for a sustainable wetland management. Traditionally, six strategic actions for sustainable management were proposed, including encouraging community regulation, zone mangrove ecosystems, developing mangrove management plans, reassessing the value of mangrove ecosystems, improving community information, and rehabilitating degraded mangrove systems [38].

However, without a sound legislative and policy-making framework, wetlands and their ecosystem services will continue to degenerate due to increasing numbers of agribusinesses, developmental projects, and economic investments [42]. Weak policies and management strategies particularly present in many countries severely and negatively affect the conservation and sustainable management of wetland resources [43]. In early 1987, “A Framework for Wetlands Policy in Canada” identified “wetlands management” as a significant land use issue, and developed a wetlands policy statement to supplement the “wise land use” provisions of the Federal Policy on Land Use [44]. Some efforts also have been made to improve the public awareness on wetland ecology in Brazil. With specific legislation of wetland protection in 2013, the Wetland Conservation Act in Taiwan presented the potentials of sustainable development of wetland. Wetland conservation and sustainable management should be given a high legislative priority [45].

Moving toward sustainable management of wetlands necessitates a series of ecological patterns that are responsive to anthropogenic and environmental pressures, are capable of identifying changes in the state of wetland ecosystems, and are related to sustainability objectives. However, some mangrove areas have been removed to construct aquaculture farms and conduct coastal development or have been cut down by local residents to acquire firewood and other products [31]. Conservation and restoration operations have been undertaken by the mangrove management project to avoid the destruction and degradation of mangrove habitats [36]. Nevertheless, mangrove removal for these purposes clearly differs from the purpose of mangrove removal in the study by Chen et al. (2018) [12].

Usually, major gaps in a specific wetland policy are of two types: (1) the lack of standardized criteria by which wetlands can be defined and delineated to reflect the specific ecological conditions of the country, and (2) the lack of a national classification system of wetlands that considers the specific hydrological conditions and respective plant communities [45]. Mangroves (*Avicennia marina*) have rapidly colonized intertidal sandflats within a number of estuaries in the North Island of New Zealand. Many local residents perceive this change to be detrimental to the ecology and aesthetics of their estuaries; however, little empirical data is available to support these perceptions [46]. As aforementioned, most of the mangroves in estuaries have been protected despite the above two removal examples.

Therefore, we have found two patterns for sustainable management of mangrove wetlands. The first pattern “Development pressure and conservation” presents the disappearance of mangroves because of urban development. Based on this pattern, most of the mangroves were considered as “important wetlands” and protected under the Wetland Conservation Act in Taiwan. In addition to the Wetland Conservation Act, other protected areas include the wildlife sanctuary for benthic organism in Siangshan Wetland, and the fishery resource conservation area for breeding prawns (*Austinopecten edulis*) in Wanggong, Changhua County. The second pattern “Planting, invasion and removal” is of particular concern and includes plantation and removal of mangroves from areas where there is no mangrove forest, thus causing ecological impact. Such a pattern can be considered as a sustainable management strategy for the original benthic organism.

For over 10 years, many countries have signed the Ramsar Convention, an international treaty focusing on conservation of wetlands of international importance. A major obligation under the convention is the implementation of principles for the wise use of wetlands. The convention defined the “wise use” of wetlands as their “sustainable utilization for the benefit of humankind in a manner compatible with the maintenance of the natural properties of the ecosystem.” In the “wise use” for the original benthic organisms and the planted mangroves, it is impossible to obtain a balance for comparing which aspect has a higher value. In this study, we believed that the influence of the original habitat caused by planted mangroves exceeds the value of mangrove existence. Sustainable management can be defined as the management of existing resources to meet the needs of the present without compromising the ability of the future generation to meet their own needs. Perhaps, we say that we can meet our current needs without compromising the original state and meeting its requirements. In addition to historical reasons, the mangroves have not existed in the original habitat for decades. In other words, the presence of mangroves is an invasion of the original habitat. Therefore, the second pattern can be said to be another sustainable management strategy for coastal wetlands.

5. Proven Rehabilitation of Mangrove Removal in Taiwan

This case presents Siangshan Wetland and includes a detailed report by Chen et al. (2018) [12]. Siangshan Wetland is an important muddy wetland with abundant species and biodiversity in Taiwan. Large numbers of shrimp, crabs, shellfish, and benthic organisms were nursed in this breeding ground (National Important Wetland Conservation Project, 2014). The mangroves of Siangshan Wetland were planted in 1969. In 1992, 5300 mangroves were found and areas estimated of 0.1 hectare by the Taiwan Endemic Species Research Institute in 1995. In 2000, the mangrove area covered approximately 107 hectares, as reported by the “Siangshan Wetland Mangrove Removal and Benefit Assessment Program” by the Hsinchu City Government. Therefore, the Hsinchu City Government has been launching some small-scale mangrove removal projects since 2000. Since 2001, Siangshan Wetland has been officially known as the Hsinchu City Coastal Wildlife Sanctuary. According to the “2011 National Important Wetland Ecological Environment Investigation and Rehabilitation Project—Hsinchu City Wild Animal Sanctuary Habitat Rehabilitation Program,” mangrove trees were cut with chain saws, manually transported to the shore, and then transported by truck to an incinerator. During this period, the mangrove plantation projects for coastal protection resulted in the unexpected spreading of mangroves. In 2015, the mangrove area covered approximately 400 hectares.

To solve the problem of mangrove over-spreading, a large-scale removal project was planned in October 2015. In this project, the mangrove forest was divided into two dense regions and a scattered region. A mechanical removal method was applied in the denser regions and a manual removal method was used in the scattered region. The process of mechanical removal was divided into five steps—trenching, shoveling, digging, compacting, and healing. In the scattered region, workers used hoes to remove the branches and roots and then carried the debris to the shore for stacking. Finally, the waste was transported to the incinerator via dump trucks. In March 2016, the cumulative removed mangrove area was 348 hectares, which included 48 hectares from the denser regions and approximately 300 hectares from the scattered region.

The change in the benthic density and the number of species is presented in Table 2. In the mangrove regions, the benthic density was approximately 0–6 ind./m², and the species ranged from 0–1 before mangrove removal. After mangrove removal, the benthic density increased to 4–44 ind./m², and the species range increased to between 1 and 4. The increased benthic organisms were *Uca formosensis*, *Macrophthalmus banzai*, and *Mictyris brevidactylus*, and two species of *Bivalvia*, *Tellina jedonensis*, and *Mactra veneriformis* were found [12]. These results revealed that the benthic density and the number of species increased after mangrove removal.

Table 2. Comparison between the statistics before and after mangrove removal in the mangrove and non-mangrove areas.

		Before Removal October 2015	After Removal April 2016
mangrove	Species no.	0–1	1–4
	Density(ind./m ²)	0–6	4–44
	H'	0.00–0.00	0.00–1.18
	J'	0.00–0.00	0.73–0.96
	SR	0.00–0.00	0.00–1.44
non-mangrove	Species no.	5–25	10–19
	Density(ind./m ²)	20–60	25–130
	H'	0.68–2.17	0.77–1.77
	J'	0.73–0.88	0.70–0.85
	SR	0.51–2.66	0.55–1.85

In the non-mangrove region, the benthic density ranged from 20–60 ind./m², and the species ranged from 5–25 before mangrove removal. After mangrove removal, the benthic density increased to 25–130 ind./m², and the number of species increased to 10–19. The variations in the Shannon–Wiener index (H') and Palou's evenness index (J) are presented in Table 2. The results revealed that both the Shannon–Wiener index (H') and Palou's evenness index (J) increased, thus indicating an increase in biodiversity after mangrove removal. These results revealed that the benthic organisms were forced to migrate from their original habitat to the nearby areas due to the spreading of mangroves. After mangrove removal, the species returned to their original habitats. Mudflats are critical habitats for mangrove megafauna (e.g., fishes, crabs, gastropods, and prawns) in subtropical estuarine wetlands. In the case of the Danshui River estuary in northern Taiwan, the water and sediments differed significant among the restored mudflat, the tidal creek, and the mangrove control site. This case demonstrated that controlling the spread of estuarine mangrove forests could increase biodiversity and could particularly benefit the migratory shorebird community [47]. An investigation of mangrove removal in 2010 and 2011 revealed that the benthic habitat gradually changed from mudflats to sandy flats, and the biological diversity in the area in which mangroves were removed was significantly higher than that in the mangrove control area [48]. After mangrove removal, the composition of the sediment changed from a muddy to a sandier habitat, and clams began to appear [49]. Rehabilitation efforts such as mangrove removal and reconstruction of tidal creeks can improve the diversity of habitats for the mangrove organisms [12,30,47].

6. Other Cases of Mangrove Removal

Similar results were reported for Matapouri Estuary in northern New Zealand. In this estuary, benthic species abundance and biodiversity in mangrove habitats were significantly below those of the adjacent seagrass habitats [50]. The dominant benthic organisms derive nutrients from a variety of sources, such as bacteria and algae. However, the mangrove-derived nutrients may have only a localized effect on the food web with slight export of organic matter to adjacent habitats, such as sandflats [51]. Alfaro (2010) reported that mangrove removal in temperate northern New Zealand had particular effects on benthic communities and sediment characteristics. Near-immediate changes in sediment from a muddy to a sandier environment were observed after mangrove removal, and a subsequent overall increase was observed in the abundance of crabs, snails, and bivalves [36]. Alfaro (2010) provided direct evidence of the effects of mangrove removal on benthic faunal characteristics, and these results are consistent with those of our study [36]. The unrestricted spreading of mangroves leads to the reduction and destruction of other habitats and has attracted the attention of many community groups and environmental managers who considered that mangrove expansions adversely influence ecology and socioeconomics [52].

In Hawaii, the red mangroves (*Rhizophora mangle*) were first introduced to Moloka'i in 1902. They spread to all major Hawaiian Islands, mainly to Molokai and Oahu, including colonial salt marshes, protected coral reefs, tidal flats, fish ponds, estuaries, canals, lagoons, streams, and other spots (Chimner et al. 2006) [53]. In their current state, they have been considered highly invasive due to their rapid propagation and dispersion. (Allen and Krauss 2006) [54]. Particularly, they have caused the disappearance of 10% of endemic and endangered black-necked population and at least 16 species of native fish. Therefore, several projects of mangrove removal have been developed at the sites of Wai 'Opae, Poho'iki and Paki Bay in Puna, Onekahakaha in Hilo, Alula Bay in Kona, working in collaboration with the Keala Ching and Na Wai Iwi Ola Foundation and the Kaloko-Honokohau National Historical Park. After 20 years of effort with thousands of volunteers, more than \$2.5 million was spent, and more than 20 acres of mangroves removed. Mangroves were cleared by hand, shovels, and chain saws in archaeologically sensitive areas and grappling with heavy tracked equipment in less-sensitive areas [55].

In Hong Kong, due to the high population density, most of them were concentrated in coastal areas. Almost all of the coastal areas have been drained and reclaimed for agriculture, fishponds, salt pans, and urban development. Tiny areas of mangrove are found in scattered sites around the coast, but the Mai Po Ramsar Site in Inner Deep Bay is the largest remaining mangrove area in Hong Kong (Tam & Wong, 2000) [9,28]. In the estuaries of Yuen Long Shan Pui River and Tin Shui Wai Main Drainage Channel, due to the rapid growth of mangroves, the drainage system on the upper channel has caused backwater and increased the flood risk. Chan et al. (2016) mention that mangrove vegetation is an important factor that influences water velocities and water levels in a mangrove estuary and therefore directly relates to the flood hazard potential. In 2003, in order to restore the flow of the channel, mangrove pruning was carried out at the estuary of Shan Pui River but after a few years, the mangroves continued to expand and returned to their original appearance [56]. As mentioned by Chan et al. (2016), there have been similar cases reported from several other countries, including New Zealand, Taiwan, and Singapore, where management intervention was needed in response to excessive mangrove expansion blocking waterways, reducing tidal access, and causing increased flooding hazard potential. In the last decades, mangrove vegetation has been destroyed due to large-scale reclamation and infrastructural developments. The Mai Po site is managed as a nature reserve, and attracts a large number of visitors. In order to protect the remaining mangroves, a comprehensive ecological study was carried out in 1994–1997, dividing 44 remaining swamps into five categories based on overall conservation value [28]. Tam and Wong (2002) suggest that mangrove protection from strict ecological protection to sustainable development must take into account the needs and requirements of different regions. In particular, the protection of biodiversity and the maintenance of ecological processes must be given special attention [28].

In Japan, since mangroves are typically tropical vegetation, they extend into the southern part of Kyushu by climate limitation. These are the northernmost mangroves in Asia and consist of small stands of *Kandelia candel* [9]. Mangroves are scattered throughout the Ryukyu Archipelago reaching as far north as Kiire on southern Kyushu. The total area is small and is largely concentrated on the islands of Ishigaki and Iriomote in the Okinawa prefecture. Iriomote has the largest and most diverse communities and eleven species of mangrove have been recorded. A few strong typhoons pass over the Ryukyu Islands every year and these can damage the trees, typically restricting canopy height to 10–15 m [9]. The main impacts on mangrove vegetation have been sorted: (1) cutting mangrove forests for firewood and construction material, (2) disturbance by building river-bank levees and by road construction, and (3) reclamation for urban and industrial areas. These activities alter, degrade, or completely destroy the vegetation of the mangrove community. As a result, some mangroves have been conserved as a protected natural environment, and attempts have been made to reforest damaged mangrove areas in some coastal areas of southern Japan [57]. Deforestation is not permitted except in some cases such as research [27]. There is one case of a fishing port construction site. In order to maintain the stability of the beach and protect the environment, there is a mangrove area, planted by the government. Non-profit organizations and several companies have also planted mangrove seedlings. Some of these companies have even studied ways to grow seedlings [27].

Mangrove rehabilitation projects worldwide are conducted mostly to restore forest cover and habitat functions [58,59]. Rehabilitation is defined as the act of partially or fully replacing the structure or functional aspects of an ecosystem that have been reduced. Rehabilitation is different from restoration, which aims at the return of an ecosystem to its original condition [60]. Many rehabilitation projects have been conducted by planting mangroves and/or seedlings. Rehabilitation projects are most successful when they match the environmental conditions [61]. In the study by Chen et al. (2018), the rehabilitation effort of mangrove removal was applied to improve the habitat for benthic organisms [12].

7. Further Recommendations

Although some studies highlight the removal of mangroves by following the policy introduced pertaining to the habitat rehabilitation for benthic organisms [12], studies related to environmental sustainability are still lacking. Studies are required to assess whether reductions or removal of mangrove in coastal wetland are maintained. More studies are required to determine whether these reductions have a positive influence on aquatic or coastal environments. For accurately quantifying the effectiveness of various strategies (i.e., invasion controls, source of plants), regionally coordinated monitoring campaigns are required in which data can be collated across studies to provide a clear picture of the effectiveness of the intervention strategies. This study seeks to measure and demonstrate the benefits of these policies by using quantitative methods. Moreover, the benefits to the environment, economy, and society should be considered.

Tam and Wong (2002) suggest that the possibility of using mangrove wetlands to remove pollutants appears to be an attractive way to raise public awareness and educate the community. Also, it is one of the most important strategies in different conservation strategies [28]. Education programs for modifying public behavior should be widely adopted. Incorporating education pertaining to wetlands, invasion pollution, and mangrove management in schools could be extremely valuable. Education and behavioral changes in children are crucial as children are an important source of social influence among their peers, parents, and community. Targeting youth and other stakeholders (e.g., citizens, governments, industry, and NGOs) is an effective way to promote positive change and help increase awareness.

8. Conclusions

This study reviewed the current implemented strategies in Taiwan pertaining to the development pressure, conservation, and removal of mangroves for wetland sustainability. A total of 19 mangrove

sites were sorted out to determine the main patterns and factors for destruction or protection. For wetland management, some mangroves sites have been stable and protected in the past years, due to the implementation of laws and policies. In contrast, mangrove removal is a sustainable implementation for the restoration of non-native mangrove habitats and provides valuable ecological information for coastal managers or officials seeking to control the spread of mangroves. The two cases in Siangshan Wetland and Fangyuan Wetland indicate that mangrove invasion changed the original habitat structure and caused some impacts on benthic organisms, and it also provided direct evidence of the beneficial effect of mangrove removal. This study provided useful insights on the performance of sustainability, which contribute to facilitating the worldwide move toward sustainable management on mangrove wetlands. Moreover, the present study indicates the following strategies to further reduce or remove the mangroves present in the coastal wetlands that do not contain a mangrove forest: (1) conduct studies to evaluate the effectiveness of mangrove removal; (2) implement policies to ensure a positive influence on coastal wetlands; and (3) provide mangrove conservation education for sustainable development.

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