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MANGROVE FOREST DEGRADATION AND SHORELINE EROSION IN THE MEKONG DELTA: A CASE STUDY FROM BEN TRE PROVINCE

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Abstract. Viet Nam's coastline faces many natural and human-induced threats, such as erosion, floods, sea-level changes, pollution and saltwater intrusion. Low lying deltas, such as the Mekong Delta and the Red River Delta of Viet Nam are frequently subjected to such threats. The present study investigated the degradation of mangrove forests and changes in shoreline along the coast of Ben Tre. For this purpose, we used spectral indices, such as the normalized difference vegetation index (NDVI) for mapping mangrove vegetation and the normalized difference water index (NDWI) for estimating shoreline changes. The possibilities, advantages and limitations of coastal vegetation, such as mangroves, casuarina and pandanus, as a bioshield for shoreline protection in Ben Tre coast of the Vietnamese Mekong Delta (VMD) were also discussed. The results show that coastal areas covered with newly planted mangroves showed reduced or no erosion. Currently, several hard structures have been used for short-term protection from coastal erosion in Ben Tre. For long-term coastal protection, the present study suggested an ecosystem-based adaptation using bioshield for Ben Tre coast. A combination of hard structures reinforced with bioshield is recommended for long-term and sustainable coastal protection in Ben Tre.

Keywords: bioshield, coastal erosion, coastal protection, Ben Tre, mangroves.

Classification numbers: 3.2, 3.4.4, 3.8.2.

1. INTRODUCTION

Coastal areas in Southeast Asia are highly dynamic and provide several ecosystem services [1]. The population in the coastal areas of Southeast Asia is high and the economy of these areas depends on natural resources to a large extend [2]. The coastal resources in this region are vulnerable to both natural (e.g. sea-level rise, coastal erosion, severe storms, typhoons, floods) and anthropogenic degradations (e.g. aquaculture, deforestation, urbanization, tourism-related developments) [1, 2]. Coastal vegetation (e.g. mangrove forests) is an important natural resource along with the coastal areas in the Mekong River Delta (MRD) in Southeast Asia in general and Viet Nam in particular [3]. There was a rapid loss of coastal vegetation (e.g. 50 % loss of mangroves between 1998 and 2015 in Ben Tre) along the coastal areas of the VMD in recent years due to the expansion of aquaculture and infrastructure development [4]. In addition, there has been a concern over the loss of coastal vegetation because the presence of such vegetation is important for protection against floods, tsunamis, and other natural calamities [5]. A number of coastal vegetation, such as mangroves, seagrasses, and salt marshes, provide natural protection from the above-mentioned catastrophes [6]. A classic example of coastal protection by vegetation is the role of mangrove vegetation in alleviating the negative effects of the 2004 Indian Ocean Tsunami [7]. Such protective functions can be useful in protecting the coastal areas of the VMD. The MRD is an important source of resources in Viet Nam, which is influenced by floods, salinity intrusion (during dry season), and human [8].

Biogenic coverage (e.g. mangroves, salt marshes, seagrasses) is an important natural resource in coastal areas in the tropical latitudes. Among the three categories (special-use forests, protection forests, and production forests) of forests in Viet Nam, mangroves and other types of coastal vegetation can be classified into protection forests (according to the National Assembly of Viet Nam). However, mangrove forests in the VMD have been classified as either protection or special use forests or mangrove national parks [9 - 12], which often results in conflicting interests of different administrative agencies [9]. The continuous and unpredictable loss of biogenic coverage, including mangroves, from coastal areas has upraised concerns as they protect the coastal communities from shoreline erosion, floods and other natural disasters [5, 12] and hence reforestation initiatives using such coastal biogenic coverage can be useful in reducing the aftermaths of future coastal hazards.

In the present study, the degradation of mangrove forests, variations in aquaculture ponds, and changes in shoreline along the coast of Ben Tre were investigated.

2. MATERIALS AND METHODS

2.1. Study site and environmental conditions

The study site, Ben Tre Province (106°48′-105°57′E, 9°48′-10°20′N), is located in the lower Mekong River Basin in southern Viet Nam (Figure 1). Ben Tre province consists of seven districts and a township. In addition, there are four estuaries (Dai, Ba Lai, Ham Luong, and Co Chien) which are also located in this province [9, 10]. Aquaculture ponds and fishing areas are some of the notable economic activities that can be found in the coastal areas of Ben Tre. In addition, a number of shrimp ponds are already abandoned and new ones were being constructed every year.

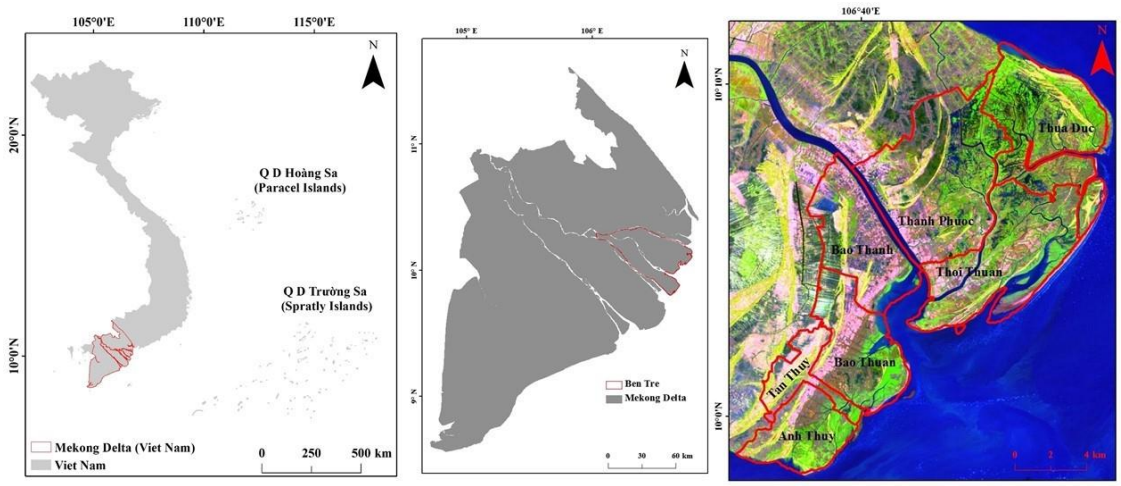

Figure 1. Study areas in Ben Tre relative to the VMD.

Veettil *et al*. [10] reported that the recent decades have witnessed drastic mangrove deforestation in Ben Tre during the conversion of these areas to aquaculture ponds and agriculture fields. The same study estimated that overall 52.5 % of mangrove areas were depleted in Ben Tre during the period from 1998 to 2015. In some areas (e.g. Thanh Phu district), the increase in aquaculture areas was 120 % during the same period. The widely distributed mangrove species in Ben Tre coast are *Sonneratia caseolaris*, *Avicennia alba*, *Nypa fruticans*, *Excoecaria agallocha*, and *Rhizophora apiculata* (Figure 2). The reforestation in this region is conducted mainly using *Rhizophora* spp.

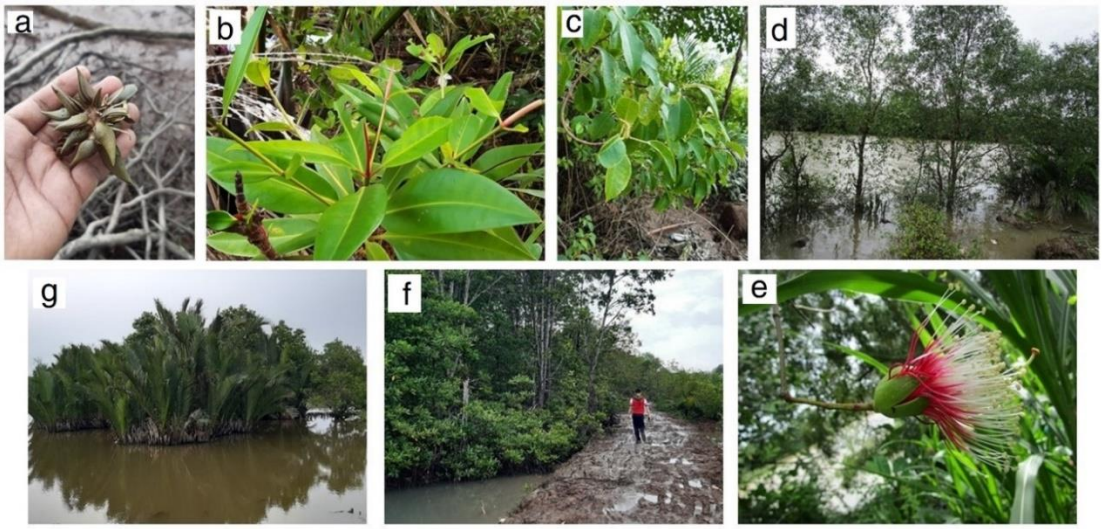

Figure 2. Common mangrove species in Ben Tre: (a,b) *Avicennia alba*, (c) *Excoecaria agallocha*, (d,e) *Sonneratia caseolaris*, (f) *Rhizophora apiculata*, (g) *Nypa fruticans*.

Most of the estuaries (e.g. Dai, Ba Lai, Ham Luong and Co Chien) in Ben Tre are subjected to dry season salinity intrusion via river systems (saltwater entering Ben Tre via Mekong, Ba Lai, Ham Luong and Co Chien rivers). In a recent study, Veettil *et al*. [3] revealed that, in addition to river water salinity changes, soil salinity is also increased in recent years in Ben Tre.

The same study mentioned that the expansion of shrimp ponds that require brackish water is one of the reasons behind soil salinity changes in Ben Tre. However, shrimp farming is one of the key economic resources in the province and, hence, complete disruption of shrimp farming may have severe negative impacts on the regional economy. With this view, alternative environmental management strategies need to be implemented for the sustainable development of the coastal areas of Ben Tre. Shoreline erosion, sea-level rise and tides from the East Sea are other coastal environmental threats affecting the population in the coastal region of Ben Tre [10]. It was reported that a 1 m rise in the sea level height may cause floods in more than half of the land area in Ben Tre [11]. Veettil *et al*. [3] reported that the sea level heights along the Ben Tre coast fluctuated under El Nino conditions, which also influences saltwater intrusion into river systems in the region. Coastal erosion in Ben Tre has been, so far, protected using hard structures and breakwaters using wooden piles (Figure 3).

Figure 3. Hard structures (a-b) and breakwaters (c-d) used for coastal protection in Ben Tre.

2.2. Materials

We used both field investigation information and spaceborne data for this study for mapping the spatiotemporal changes in mangrove vegetation and aquaculture ponds in Ben Tre province. Field visits have been supported by the Institute of Tropical Biology (Ho Chi Minh City, Viet Nam). Northern districts of Binh Dai and Ba Tri were chosen as test study sites for field investigation (September 2020 and March 2021) and preliminary analysis for understanding the current status of shoreline erosion, coastal environmental conditions, and vegetation.

Multispectral spaceborne data are useful in understanding land cover changes, such as variations in vegetation coverage, shoreline erosion and expansion of aquaculture ponds [1, 10].

Remote sensing data used for this study include Landsat-8 OLI and Sentinel-2A imagery and digital elevation models (DEM). Both the Landsat and Sentinel data can be downloaded from the United States Geological Survey (USGS) EarthExplorer (https://earthexplorer.usgs.gov/) at no cost. We tested both ASTER and SRTM DEMs for understanding the geomorphological characteristics of the study site. All multispectral satellite data used in this study were acquired in January/February in order to reduce the seasonal influence on data quality. One of the key processes adapted in this study to apply mangrove reforestation is to estimate the areas of abandoned aquaculture ponds in Ben Tre. For this purpose, abandoned aquaculture ponds have been detected using the latest satellite data (Landsat and Sentinel-2). Estimating the changes in shoreline over the past two decades has also been done based on satellite data.

2.3. Field data analysis

Field investigation provided a clear picture of shoreline erosion areas, the distribution of aquaculture ponds, and the type of native vegetation along the Ben Tre coast (Figure 4). Shoreline erosion was estimated based on current shoreline position from fieldwork, satellite-derived shoreline since the 1980s at selected locations in Binh Dai and Ba Tri and also using GoogleEarth data. Special consideration was given to the Ba Lai river mouth, where Ba Tri and Binh Dai districts were separated by the Ba Lai river. The extend of existing hard structures for shoreline protection in Ben Tre has been surveyed and evaluated for their role in protecting the shoreline and foreseeing future threats due to sea-level rise and waves. We estimated the extent of natural mangrove regeneration as well as reforested areas with Rhizophora spp. In addition, a feasibility study on the reforestation of coastal vegetation in abandoned aquaculture areas has also been conducted during the field study.

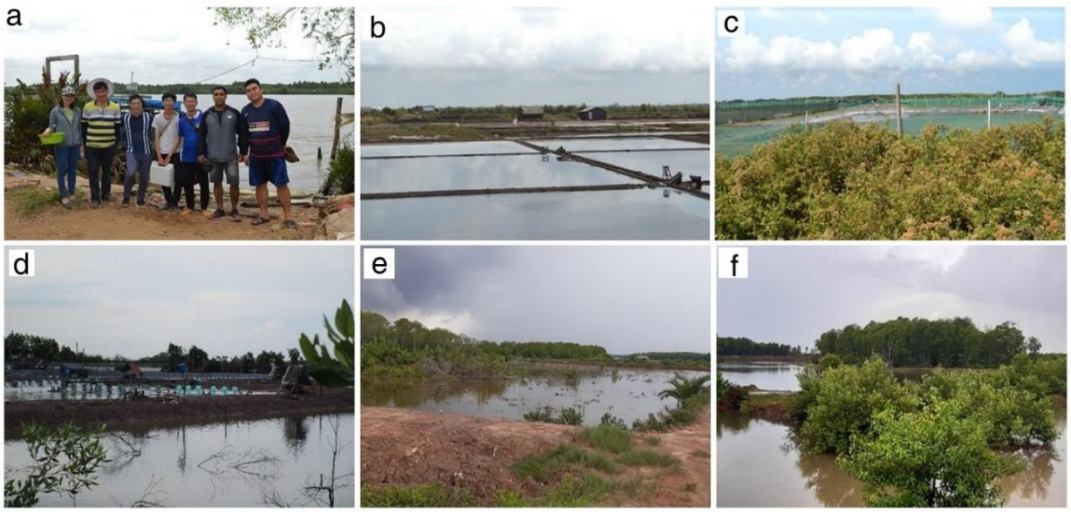

Figure 4. Field work conducted in Ben Tre coastal areas (March 2021). (a) the research team; (b) salt ponds; (c, d) active aquaculture ponds; (e) mangrove regeneration in abandoned ponds; (f) mixed mangrove-fish ponds.

2.4. Spaceborne data analysis

Detailed changes in aquaculture areas between 2015 and 2021 have been estimated using satellite imagery. We applied the same datasets (Landsat imagery data acquired in 1998, 2006

and 2015) used by Veettil *et al*. [3] for detailed mapping of aquaculture ponds in Ba Tri and Binh Dai. It is assumed that the abandoned and dried up shrimp ponds can be, if not used for other economic purposes, used for mangrove reforestation, including agriculture or settlements. Changes in mangrove vegetation between 1988 and 2020 in the study area have been estimated using normalized difference vegetation index (NDVI).

Shoreline erosion in Binh Dai and Ba Tri districts was estimated using NDVI and normalized difference water index (NDWI) applied to Landsat data. As mentioned previously, in order to understand the shoreline changes since the 1980s and to estimate the effects of hard structures constructed along the southern coast of Ben Tre to prevent further erosion, we used satellite data in the 1980s and 1990s. Image differencing technique (using infrared channels) is easy to apply and is a straightforward method to understand whether accretion or erosion is occurring during a specific time interval. This method has been previously applied in Quang Nam province [1] and has been applied to Binh Dai and Ba Tri in the present study.

For mapping active and abandoned aquaculture ponds and the recent changes in aquaculture areas, we used NDWI method as well as cross-comparison with GoogleEarth data. A maximum distance of 600 m and a minimum distance of 200 m from the shoreline, and 1 m from the embankment are suggested by some studies [13, 14] for the establishment of coastal bioshields, particularly for protecting from cyclones and storms. Considering the low elevation of the current study site, areas not utilized for economic purposes which are within 800 m from the sea can be chosen for establishing bioshield.

3. RESULTS AND DISCUSSION

3.1. Results

From the field observation, it was observed that a large number of mangrove species are found naturally growing in Ben Tre. There exists a connection between soil salinity and species distribution of mangroves in Ben Tre. The field survey of mangrove species along the Ba Lai river from the downstream to the upstream of the irrigation dam reveals this difference in species distribution (salinity decreases from the downstream to the upstream). For example, *Rhizophora* spp. is mostly found in the downstream (brackish/seawater) near the coast whereas *Nypa fruticans* is mainly found in the upstream or far from the coast (freshwater/brackish) and *Sonneratia* spp. is found in both freshwater, brackish and seawater (S.apetala: brackish/seawater; S. caseolaris: freshwater/seawater; S. griffithii: brackish).

The results of spaceborne data processing indicated an extensive loss of mangroves in Ba Tri and Binh Dai in the period 1988-2020 (Figure 5a). However, it is interesting to note that, due to afforestation practices, a considerable area (particularly at the Ba Lai river mouth) has recently been covered with new mangrove vegetation (Figure 5b). It is seen that a large area of mangroves was planted along the coast of Ba Lai river mouth whereas mangroves were lost along the northern coast of Ben Tre. Despite the newly planted mangroves in this region, there was a loss of 46 % of the mangrove areas (Figure 5c) between 1988 and 2020 (mangrove areas in 1988, 2015 and 2020 were 42.5 km^2, 30.7 km^2 and 22.8 km^2, respectively). In fact, 17.6 km^2 of mangrove vegetation mapped in 2020 are situated in reforested areas.

Shoreline changes observed along the coast of Binh Dai and Ba Tri districts showed some interesting facts. It is seen that, despite erosion reported from the southern coast of Ben Tre, coastal areas surrounding the Ba Lai river mouth showed accretion (Figure 6). It has to be noted that a dam has built in the Ba Lai river in 2002 and this would have resulted in reduced sediment

transport from the upstream, thereby causing an erosion in the coast surrounding the river mouth. However, this was not observed from the results of this study. One of the possible explanations can be the presence of afforested mangrove vegetation along the banks and mouth of Ba Lai river, which would have helped in trapping the sediments in addition to natural accretion that occurred along the coast. This observation underlines the application of mangrove vegetation as a coastal bioshield against shoreline erosion in Ben Tre in particular and MRD in general. Interestingly, the northern coast of Ben Tre underwent erosion, where mangrove loss was also higher over the last three decades (see Figures 5a, 5c).

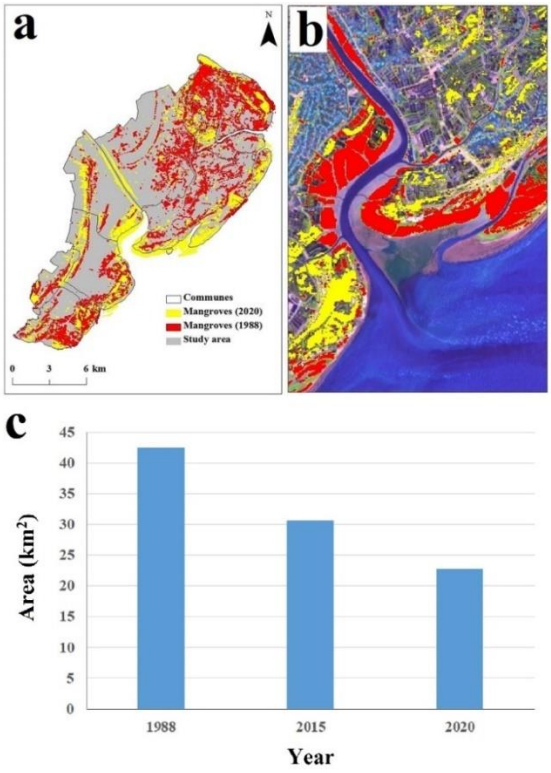

Figure 5. (a) Mangrove areas in 1988 and 2020, (b) areas showing newly planted mangroves (red) at Ba Lai river mouth, and (c) area changes in mangroves (1988-2020).

As seen from Figure 7, a number of shrimp ponds were abandoned between 2015 and 2020 in the study area. About 54 km^2 of shrimp ponds in 2015 were decommissioned in 2020 and new ponds were installed on 37.5 km^2 by 2020. It was observed during the field investigation that the regeneration of Rhizophora spp. in the abandoned aquaculture areas was rapid. This indicates that the decision of the local authority to conduct mangrove reforestation using Rhizophora can give positive results in terms of mangrove regenerative capacity. However, it should be noted that while using abandoned aquaculture ponds, which are private lands, for mangrove reforestation, consideration on the livelihood of the population depending on aquaculture in the area should be taken into account. For example, mixed mangrove-shrimp culture can be practiced as an alternative method. However, nearshore environments do not require such consideration for mangrove restoration/afforestation as these areas belong to the local government.

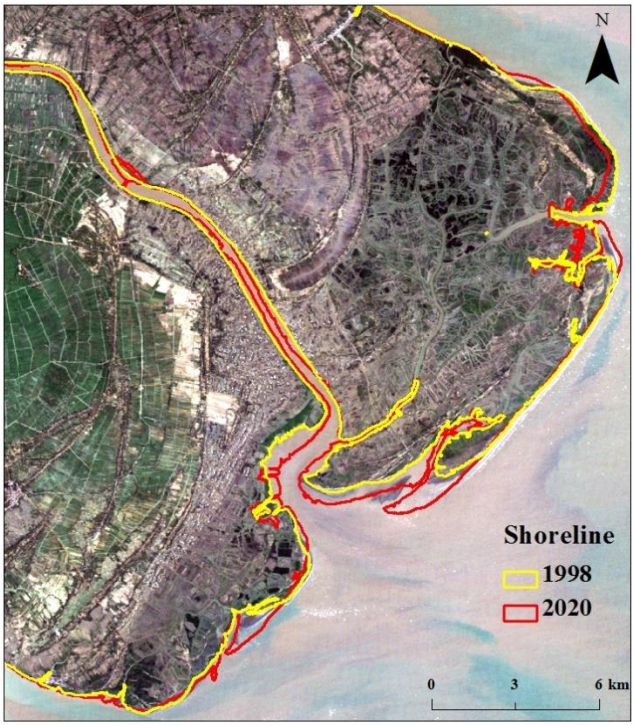

Figure 6. Shoreline changes in Ba Tri and Binh Dai (1998-2020). Shoreline polygons superimposed on Landsat image taken in 1998.

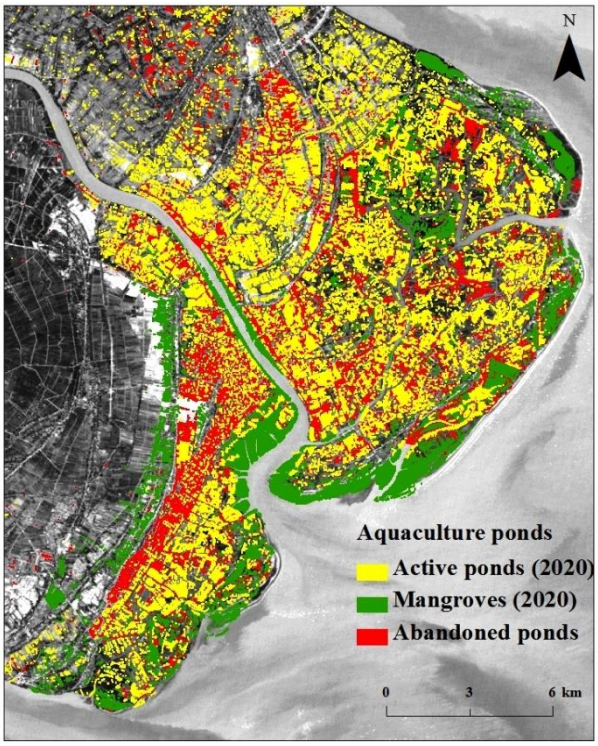

Figure 7. Active and abandoned aquaculture ponds (1998-2020) and mangrove areas in 2020.

3.2. Discussion

Coastal areas of the VMD underwent rapid socio-economic development after the Vietnam War [15], mostly based on aquaculture, fishery and urbanization. It is evident from the present study as well as the literature that the coastline of Ben Tre has been eroded heavily in the 1980s since the expansion of aquaculture and agriculture along the Ben Tre coast during the post-war period [12]. However, a large number of concrete hard structures (as shown in Figure 3) have been constructed since then, which resulted in less erosion in some areas. In a recent study, Veettil *et al*. [3] stated that the recent shoreline erosion in the Ben Tre coast was not uniform, probably due to the installation of hard structures in some areas. The southern coast of Ben Tre is still showing severe erosion [3], whereas northern areas were protected by hard structures. Nguyen and Parnell [12] also reported a serious coastal erosion in Ben Tre between 2012 and 2013. The present study showed that the coastal areas at Ba Lai river mouth (Figure 6), where mangroves were planted, underwent less erosion between 1988 and 2020. Even though the protection offered by this vegetation is not rapid compared to hard structures, mangroves can provide sustainable and long-term coastal protection [16]. Ben Tre province can be considered as a good representative of case study sites for the assessment of typical coastal area land use management practices in the VMD [12], particularly related to coastal vegetation loss and restoration.

Natural regeneration and reforestation using natural species and mangrove associates can be considered as an effective strategy for protecting the shoreline from erosion in Viet Nam [16]. The existence of vegetation bioshield has been reported to have protected a number of coastal areas in the world from different natural disasters varying from tsunamis to floods [17]. For example, it is evident that the presence of mangrove vegetation helped a few coastal areas of Myanmar (during Cyclone Nargis) [7] and the Andaman and Nicobar Islands of India (during the 2004 Indian Ocean tsunami) [18]. However, few studies [19] argued that the coastal protection offered by mangrove forests is not sufficient against strong cyclones and storms, even though their protective services against shoreline erosion continue to be undisputable [16, 20].

A number of recent studies [3, 13, 16, 23] suggested the use of abandoned aquaculture areas as a suitable ground for mangrove plantations for using this vegetation as coastal bioshield. However, planting mangroves in abandoned aquaculture pond areas is not a straightforward process. A number of abandoned shrimp ponds that are still disrupting the natural hydrological regime were found in Ben Tre during the field investigation. Restoring natural hydrology (removal of constraints on fresh and tidal water fluxes), such as breaching aquaculture pond walls, is important for the success of mangrove plantations [21]. Sedimentary processes (e.g. sediment flow) of coastal areas also have a key part in the success of mangrove restoration [22], particularly in an eroding coast like the MRD. Sidik *et al*. [21] mentioned that, depending on sediment dynamics (including erosion/accretion), allochthonous sediment inputs may be required before initiating mangrove restoration. In other words, mangrove-sediment-hydrodynamics interactions are the key in establishing a vegetation coastal bioshield in the MRD in general and Ben Tre coast in particular. Sediment dynamics are important in terms of shoreline protection as erosion occurs when the sediment supply is low. Soil salinity conditions also influence the zonation patterns of different mangrove species, which are visible from the upstream of rivers to the estuarine and coastal areas of Ben Tre.

A number of factors influence the success of mangrove reforestation and the possible use of coastal vegetation as bioshield. These factors are environmental conditions, hydrology and geomorphology of the area, native species composition and unsuitable planted species,

inappropriate site selection, lack of post-planting care, and socioeconomic factors [21]. For example, many mangrove reforestation programs in Southeast Asia were unsuccessful due to the lack of favorable environmental conditions specific to different mangrove species [23]. This shows that the restoration of hydrology and sediment dynamics of the land area before planting seedlings and propagules is important [21]. Reforestation of native plant species as coastal bioshield has a number of advantages. For example, in Ben Tre, *Rhizophora* spp. and *Avicennia* spp. are commonly found. It has been reported that intertidal surface elevation is an important factor for a successful mangrove rehabilitation of abandoned aquaculture ponds [23], which underlines the use of a high-resolution DEM for mapping adequate areas for planting mangroves. For example, *Heritiera fomes* is found at a higher elevation compared to Avicennia spp. and this needs to be under consideration while planting mangroves as a bioshield in Ben Tre.

In Ben Tre, the regeneration and succession of *Rhizophora* spp. have been found to be successful, particularly due to its environmental and geomorphological characteristics. The reforestation with *Rhizophora* spp. has a few more advantages compared to Sonneratia spp. in the context of shoreline protection. The root systems of *Rhizophora* spp. is superior in sediment trapping due to high turbulence [2, 21] (both are found in Ben Tre). The shoreline changes along the Ba Lai river mouth can be an indication of the usefulness of mangrove vegetation in shoreline erosion reduction (shoreline erosion in the northern coast of Ben Tre, where mangrove degradation was greater, was also higher).

In addition to mangroves, further studies can be conducted on the effective use of non-mangrove vegetation (e.g. *Casuarina* spp. and *Pandanus* spp.) [16]. Casuarina species have been already planted in some areas of Ben Tre and the coastal region of Ba Ria-Vung Tau province for coastal protection. Casuarina trees have already been planted in a few coastal areas in Ben Tre and have been used for coastal dune stabilization in Viet Nam. Pandanus plants have a stronger root system that penetrates the soil, which makes them effective in protecting the coastal areas from erosion and floods. However, care must be taken before introducing alien (non-native) plant species as coastal bioshield as it may result in negative impacts [14], such as invading native ecosystems (e.g. mangroves).

A combination of hard structures and vegetation bioshield (i.e. hybrid barriers) has been applied for enhanced protection against coastal erosion together with environmental benefits [16]. In addition, coastal protection offered by bioshields, if maintained properly, can be used for a long time compared to hard structures, such as rock walls or sea dykes. Immediate coastal hazard mitigation is offered by hard structures. However, hard structures suffer from a number of limitations, including the decline in visual appearance of the beach, horizontal and vertical access restrictions that may lead to pollution and eutrophication of the coastal area [16]. Hard structures also inhibit natural sediment transport and enhance the loss of natural biodiversity of coastal areas [16].

4. CONCLUSIONS

With the aid of field survey and satellite imagery, the present study showed that, despite the reforestation conducted, there was an extensive loss (46 %) of mangrove coverage in the coastal communes of Binh Dai and Ba Tri districts of Ben Tre province in the Vietnamese Mekong Delta. Shoreline changes observed were not uniform along the coastline of Ben Tre. Some areas, where mangroves were planted extensively, showed even accretion between 1998 and 2020. A number of aquaculture ponds (54 km^2) were found to be abandoned recently between 2015 and 2020 in the study area, even though new aquaculture ponds were also being installed. It is

proposed in this study that coastal vegetation can be used as a bioshield for shoreline protection. In addition to mangroves, other plant species, such as Casuarina and Pandanus, can also be considered as candidates for coastal bioshield.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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