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Roles of mangrove ecosystem in the sustainability of communities in the Vietnamese Mekong Delta: a case study in Soc Trang and Bac Lieu provinces

マングローブ生態系がベトナム・メコンデルタの地域社会の
持続可能性に果たす役割：
ソクチャン省とバクリュウ省における事例研究

HUYNH THI CAM HONG

Doctoral dissertation

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Abstract

Mangrove forests, distributed in tropical and subtropical regions, are considered one of the most productive marine ecosystems on earth. The forests play crucial roles not only in providing unique habitats for many species as well as services for human livelihood in coastal communities, but also in mitigating adverse impacts of natural disasters. However, anthropogenic activities like agriculture and aquaculture have impacted negatively on mangrove forests globally for last decades. In the Vietnamese Mekong Delta (VMD), indeed, brackish shrimp farming has been considered as one of the main drivers causing the rapid mangrove loss and degradation. Consequently, the loss and degradation of mangroves lead to damage of the biodiversity, ecosystem function, livelihoods, food security, and coastal defense in the VMD. The objective of this study is: (1) To assess the spatiotemporal changes in mangrove forests in the southeastern part of the VMD for last 30 years and (2) To assess community awareness of using mangroves for coastal protection and determine economic valuation of mangrove ecosystem services.

In this research, the change in the mangrove forest area in two coastal provinces in VMD, namely Soc Trang and Bac Lieu, was estimated by using medium spatial resolution (Landsat-5 Thematic Mapper (TM) and Landsat-8 Operational Land Imager (OLI)) satellite imagery in four-time intervals ranging from 1988 to 2018. Multi-temporal Landsat data were analyzed to obtain land use and land cover (LULC) classification by using maximum-likelihood classification (MLC) algorithm. In the study area, there were seven major LULC types that include dense mangrove forests, sparse mangrove forests, aquaculture farming, agriculture with crops (cropped agriculture), agriculture without crops (non-cropped agriculture), settlement, and water bodies. The overall accuracy of the LULC maps was 81.2%, 83.3%, 78.3%, and 81.9% in 1988, 1998, 2008, and 2018, respectively. This study reveals that dense and sparse mangrove forests have decreased rapidly from 5,495 ha to 515 ha and from14,105 ha to 6,289 ha, respectively from 1998 to 2018. The dense and sparse mangrove area has decreased by approximately 90% and 55%, respectively, while the aquaculture area has increased by 150,720 ha, for the period of 30 years. This study suggests that the rapid growth of aquaculture farming caused the rapid mangrove loss and degradation in the VMD. Besides, mangrove forests have been partly converted to agricultural land by 8,419 hectares. Agricultural land converted into aquacultural land accounts for more

than 150,000 hectares. The quantitative assessment of LULC is considered to be useful for further management and evaluating the mangrove ecosystem services in the study area.

Based on social surveys to 300 households and local stakeholders that include leaders, forest managers and mangrove-shrimp farmers in six mangrove sites of six districts in Soc Trang and Bac Lieu values of VMD's mangroves were estimated. The values were estimated to 80.07 million USD and approximately 5,708 USD per hectare per year. The results revealed that provisioning and regulating services provided by mangrove ecosystem in the VMD were accounted for at least 36.94 million USD and 43.13 million USD per year, respectively. The major source of provisioning services was obtained from mangroves-shrimp farming, fishing, and fuel wood, whereas that of regulating services were derived from coastal protection. In the study are, mangroves-shrimp farmers who possess mangrove forests have higher level of benefits than that of fisherman and timber collectors. Eighty percent of the interviewees to the social surveys considered mangrove forests play an importance role in local communities. The results revealed that local livelihood mainly depends on the mangrove forest ecosystem. The mangrove belt in Soc Trang was wider than in Bac Lieu. The dense mangrove forest was mainly distributed in Soc Trang because coastline is accretion zone. In contrast, in Bac Lieu, reforestation is more difficult due to coastal erosion. This leads to mangrove ecosystem values (provisioning services and regulating services) in Soc Trang were higher than in Bac Lieu because these values depend on the existing mangrove areas. In this study, shrimp farms were combined in mangroves with more than 60% mangrove cover. This is the area of mangroves (sparse mangroves are less than 50% of the covered area, or dense mangroves are over 50% of the covered area). Large shrimp farms are belonging to aquaculture areas. The resolution of Landsat data is low (30m), so the detection of small areas was limited. Information on the monetary valuation of mangrove ecosystems can be used as a communication tool to ensure better informed, more balanced decisions concerning trade-offs in land-use planning.

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Chapter I
General Introduction

1.1 Background

1.1.1 Mangrove forest in the world and Vietnamese Mekong Delta (VMD)

Mangrove ecosystems are a very important category of wetland systems that shelter coastlines and estuaries. On the other hand, mangroves are one of the most threatened ecosystems in the world. In the two decades from 1980 to 2000, over 35% of the total mangrove area was lost globally (Valiela et al. 2001). The total mangrove area declined from 19.8 to 14.7 million ha worldwide (Valiela et al. 2001; Donato et al. 2011). It is estimated that the mangrove decline rate is even higher than that of inland tropical forests (Duke et al. 2007). About 90% of mangrove forests are found in developing countries. Their long-term survival is threatened by fragmentation of the remaining forests, making it possible that the ecosystem services supplied by mangroves will be lost entirely within 100 years (Duke et al. 2007). Southeast Asia has suffered the greatest loss with about half of the region's total mangrove area, corresponding to 15.4% of the global mangrove area lost in the period 1996–2010 (Thomas et al. 2017). Globally, mangrove habitats continue to disappear; the annual rate of loss was 0.66% in 2000–05 (FAO 2007).

The VMD plays an important role as 'rice bowl' for the whole of Vietnam. Most of the rice produced in Vietnam comes from the VMD. It feeds a population of nearly 95 million and provides food security in Southeast Asia (GSO 2016). It is also an extremely vulnerable and damageable flooding region compared to other countries in Southeast Asia. As a pure agricultural region, it provides food for at least 18 million residents, playing an important role in guaranteeing national food security and contributing heavily to the economic and social development of the country. Rapid expansion of shrimp farming in the VMD has contributed to economic growth and poverty reduction, but has been accompanied by rising concerns over unsustainable development and social impacts (Hong et al. 1993; Primavera 2006). Between 1987 and 1992, for example, thousands of hectares of mangrove forests were converted into shrimp farms (Pham 2011). The lack of an integrated approach for sustainable management, utilization and protection of the coastal zone and economic interests in shrimp farming have led to the unsustainable use of natural resources, thus threatening the protection function of the mangrove forest belt and, in turn, reducing income for local communities. According to the Mekong Delta Plan - the policy agenda in VMD development was exploiting the delta. The government implemented intensive initiated a dyke-building strategy to control and manage the delta waters (Biggs et al. 2012). The dykes at the coastal area are located too close to the sea and combination with the mangroves. It is in accordance with the Mekong Delta Plan to increase the wave reduction zone and allow the mangroves to grow naturally as well as to create rooms for potential aquaculture.

Mangroves are tidal forest ecosystems on muddy soils in sheltered saline to brackish environments. Mangroves are a key ecosystem lying in the tropical and sub-tropical coastlines. The vegetation possesses special root systems for both water and air supply. Because of the root systems, the trees are adapted to grow in anaerobic and unstable conditions of waterlogged muddy soils (Augustinus 1995; Ellison 2009). The vegetation is composed of trees and shrubs and copes with the harsh conditions in the intertidal, i.e. exposure to saline water, tides and waves. They often play a key role in providing nutrients to tropical estuarine ecosystems supporting aquaculture and stabilizing the tropical coastal shoreline. A rich biodiversity is observed in the mangroves with plants and animals, which are irreplaceable, and form a good genetic treasure house. Mangroves provide protective, productive and economic benefits to coastal communities. Mangroves contribute to the stabilization of the shoreline and prevention of shore erosion. They serve as a barrier against storms so as to lessen damage to coastal land and residents (Well et al. 2006; Garcia et al. 2014; Chow et al. 2018).

However, mangrove forests have been destroyed for land reclamation, shrimp farming, timber and charcoal production at an alarming rate throughout the world (Saenger et al. 1983; Valiela et al. 2001; Danielsen et al. 2005; Feller et al. 2017). Overcutting of mangrove trees often led to a significant impact on the ecological system in mangrove swamps and the nearby coastal waters; this removal of mangrove trees also resulted in coastline erosion. This happens because mangrove forests play an important role in flood defense - by dissipating incoming wave energy and reducing the erosion rates – thus decreasing wave-driven, wind-driven and tidal currents due to the dense network of trunks, branches and aboveground roots of the mangroves, which also contribute to sediment stabilization. Main species in study area are *Rhizophora apiculatta, Avicennia alba, Avicennia marina,* and *Sonneratia caseolaris*. Species for mangrove rehabilitation are *Rhizophora apiculatta*, *Sonneratia caseolaris,* and *Avicennia alba* (Tong et al. 2004; Vo et al. 2013).

Mangrove restoration projects have been implemented by many countries because of important roles in supplying economic and environmental values. In particular, mangrove restoration programs received renewed impetus after the Typhoon Haiyan in the Philippines in 2013 and the great tsunami in Indonesia in 2004 (Wolanski and Elliott 2015; Barnuevo et al. 2017). Mangrove restoration in Vietnam has also been paid attention because of coastline erosion. From 1975 to 1998, 67,600 ha of mangroves were planted in southern areas, mostly with state funding (Spalding 2010). In addition, mangrove restoration programs have received international support. Mangrove forests provide protection from the impacts of climate change, by attenuating wave energy and storm surges, adapting to rising sea levels, and stabilizing shorelines from erosion. Mangrove forests are also an incredible source of carbon sequestration and storage, giving them an important role in climate mitigation. However, there are no assessments on the effectiveness of the previous programs.

1.1.2 Value of mangrove ecosystem services

Previous studies on the economic valuation of mangrove ecosystem services have been completed over the past three decades (Barbier and Strand 1998; Sathirathai and Barbier 2001; Kaplowitz 2001; Sarnitsart et al. 2004; Tong et al. 2004; Rönnbäck et al. 2007; Hussain and Ruchi 2010). These studies have applied different valuation approaches for estimating the monetary value of different mangrove ecosystem services, such as avoided cost, contingent valuation, market price, production approach, replacement cost, and travel cost.

Globally, mangrove forests have been estimated to provide 181 billion USD (Alongi 2002) and 1.6 billion USD per year (Polidoro et al. 2010), and also support coastal livelihoods. In American Samoa, mangroves covering just 0.5 km^2 have an estimated annual value of 50 million USD (Wells et al. 2006). In Thailand, high values of 2.7–3.6 million USD/km^2 have been reported (Sathirathai and Barbier 2001). Distinct valuation approaches are likely to result in large differences in the economic value assigned. For instance, coastal protection and sediment stabilization provided by mangroves are valued higher when a replacement cost approach is used rather than a contingent valuation method (Salem and Evan 2012, Kuenzer and Vo 2013). Therefore, the best solution for the assessment of mangrove ecosystem services is always to collect and use primary, site-specific data that reflect the characteristics and context of the study site. Putting a monetary value on ecosystem services provides an incentive for landowners or those with land-use rights (both government and private owners) to make sustainable land-use decisions. It can also help in rationalizing incentive systems through the use of instruments such as payments for ecosystem services, a means of incentivizing local resource stewardship.

1.2 Study area

In the study, two coastal provinces in the Southeastern region of the VMD, namely Soc Trang (Lat. 9°12'N -9°56'N, Long. 105°33'E–106°23'E) and Bac Lieu (Lat. 9°00′–9°38′9″N, Long. 105°14′15″–105°51′54″E) were selected (Figure 1.1). Soc Trang and Bac Lieu provinces, in which the mangrove forest area has declined significantly, primarily due to the expansion of shrimp farming (Thu and Populus 2007; Tong et al. 2004). In this location, the comprehensive data of long-term changes in mangroves distribution and mangrove ecosystems were limited. The original area of mangroves has been reduced considerably, mainly due to the chemical warfare (herbicides and napalm) undertaken during the Viet Nam war (1962-1972) as mangrove forests served as bases for military operations. Thousands of hectares of mangroves were destroyed in the eastern part of the South zone, the coast of the VMD. After the war, natural regeneration and many planting programs led to partial recovery of mangrove forests. However, population pressure and conversion to aquaculture hampered the restoration of mangroves (Hong and San 1993; Tong et al. 2004; Binh et al. 2008) The total coastline is about 128 km in length, of which Soc Trang and Bac Lieu provinces cover 72 km and 56 km, respectively (Department of Agriculture and Rural Development (DARD 2017). In terms of climatic features, Soc Trang and Bac Lieu provinces are located in the tropical climate zone with high monthly mean atmospheric temperature (Evers et al. 2009; Huu 2011; Ha et al. 2018). The annual mean atmospheric temperature is 26°C, with a maximum temperature of 30°C in April and May and a minimum temperature of 20°C in December and January. These provinces have two distinct seasons, i.e. wet season (from May to November) and dry season (from December to April). The average annual rainfall in Soc Trang and Bac Lieu varies from 2,000 to 2,300 mm (DARD 2017). Noticeably, in the dry season, rainfall accounts for only 10% of the total annual rainfall, with almost no rain (often triggering droughts) in January through March, while the rainy season has continuous rain occasionally that can last for 3-5 days causing serious flooding (DARD 2017). The average annual sunshine hours are 2,500-2,600 hours (DARD 2017).

Although Soc Trang and Bac Lieu provinces are warm coastal provinces, they are less affected by storms, and tropical cyclones. However, they are under strong impacts of the semi-diurnal system of the East Sea tides and a part of the diurnal system of the West Sea. Therefore, coastal dykes play a very important role for the protection of physical assets. The monthly average water level of high and low tides in Soc Trang and Bac Lieu provinces varies between -1.9 m and 1.9 m (DARD 2017). Climate change in recent years is projected to increase the risk in the study area, due to flooding from the Mekong River as well as droughts and seawater intrusion (Toan 2014; Hak et al. 2016).

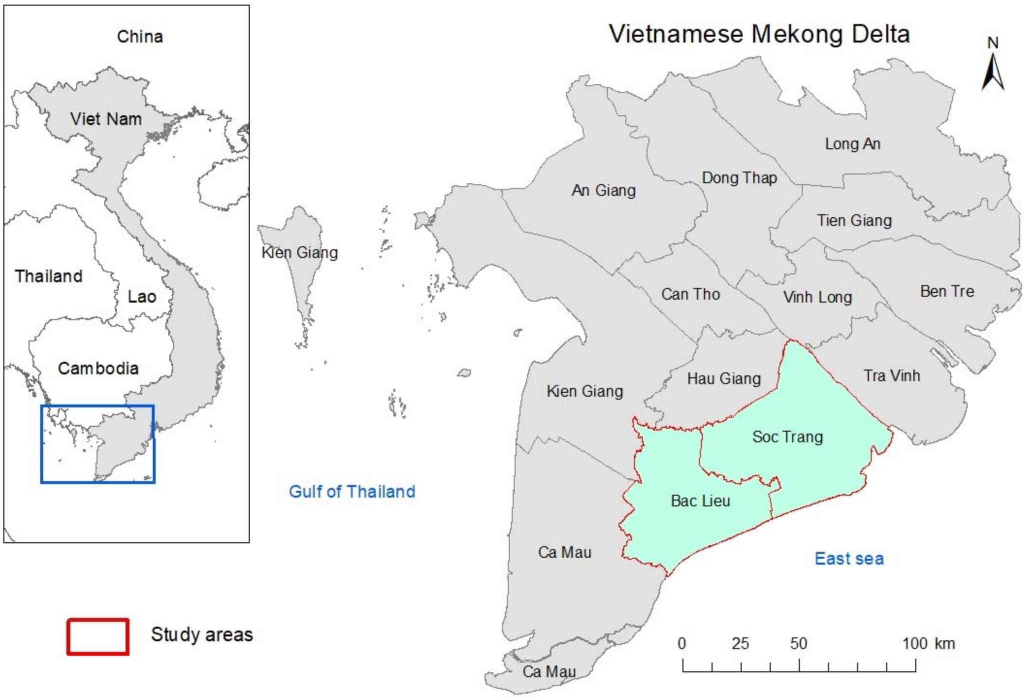

Figure 1.1 Location of study area

1.3 Objectives and Overview of Dissertation

The dissertation was mainly divided into two parts: using Landsat imagery to detect changes in mangrove forests during the past decades and determine mangrove ecosystem values. Therefore, the goals were:

i) To contribute to development of a medium-resolution database for regional mangrove forests monitoring using Landsat data. The goal of the research was therefore to investigate the applicability of Landsat data for monitoring mangrove forests in the study area using the maximum-likelihood classification (MLC); and

To map the mangrove forests in Soc Trang and Bac Lieu provinces by using Landsat imagery in the past three decades from 1988 to 2018. The specific objectives were followed:

- To produce the multi-temporal mangrove maps for 1988, 1998 and 2018, and
- To detect and analyze the changes in mangrove forests in the periods 1988-1998, 1998-2008, 2008-2018, and 1988-2018; and

ii) To assess community awareness of using mangroves for coastal protection and determine economic valuation of mangrove ecosystem services.

This dissertation consists of five chapters. Chapter I describes the background information of research, objectives, study area, and outline of the dissertation. Chapter II illustrates the analysis of mangroves changes in the last 30 years from 1988 to 2018 in Soc Trang and Bac Lieu provinces, using sets of data of multi-temporal Landsat imagery, ground truth and social survey. Based on the results obtained in chapter II and 300 household interviews, mangrove ecosystem services in the study site were estimated, as described in chapter III. Chapter IV makes a brief discussion on the results of this study and recommendations for future policy making. Finally, chapter V presents the general conclusions of the study.

Chapter II
Monitoring Changes in Land Use and Distribution of Mangroves in the Southeastern Part of the Mekong River Delta, Vietnam

2.1. Introduction

Mangrove forests are generally referred to as tidal wetland ecosystems found in the intertidal zones between marine and terrestrial ecosystems (Saenger et al. 1983). Mangrove forests are restricted to the tropics and subtropics and considered to be highly productive ecosystems that provide various ecosystem services as well as climate change mitigation and adaptation (CCMA) options (Duncan et al. 2016a). They serve as an enormous carbon sink, and at the same time provide climate and disturbance regulation services (Wylie et al. 2016). Besides, mangroves also play an important role in stabilizing the shoreline, preventing coastal erosion and are well recognized in reducing the risks of tsunamis or storms (Danielsen et al. 2005; Vo et al. 2013; Blankespoor et al. 2014; Spalding et al. 2014; Coppenolle et al. 2018). Moreover, they also provide food (e.g. fishes, crabs and shrimps), clean water, and other useful materials for local people (e.g. charcoal, wood for construction and traditional medicine) (Phan et al. 2015). In addition, mangroves provide various benefits, which include aquatic resources, entertainment, ecotourism, biofiltration and so on (Locatelli et al. 2014; UNEP 2014).

The total mangrove area accounts for 0.7% of the total tropical forests in the world (Donato et al. 2011). In the Southeast Asian region, the area of mangrove forests cover was 37,019 km^2 and 35,694 km^2 in 2000 and 2012, respectively (Hamilton and Casey 2016). The largest area of mangrove forests in 2010 was found in Asia with 42% of mangrove cover, followed by in Africa with 20% (Long et al. 2011).

In Vietnam, the area of mangroves was estimated to be about 400,000 ha in the 1960s. The area declined dramatically to 73,000 ha in 1990 due to the use of herbicides during the Indochina War (FAO 2015). Especially, since the end of the 1990s, mangrove forests have been cleared for shrimp farming in many areas. The rapid, and uncontrolled increase of shrimp farms has contributed to considerable loss of mangrove forests and environmental degradation in the VMD (Johnston et al. 2000). According to FAO statistics, the mangrove area in Vietnam changed from 269,000 ha in 1980 to 158,000 and 157,000 ha in 2000 and 2005, respectively. From these about 109,000 ha (70%) can be found in Southern Vietnam.

In the Vietnamese part of the VMD, mangrove forest ecosystems are recognized as one of the most productive and biologically complex ecosystems. These mangrove forest ecosystems have been mostly distributed along with the VMD’s coastal provinces, including Tra Vinh, Ben Tre, Long An, Kien Giang, Ca Mau, and especially Soc Trang and Bac Lieu (Cosslett 2014). In recent decades, mangrove forest ecosystems have played vital roles not only in the biogeochemical cycle but also in providing a livelihood to the local people by aquaculture and fishing. Previous studies suggested that mangrove forests used to cover the delta by more than 250,000 ha (Hong and San 1993; Thu and Populus 2007). The Indochina War, forest fires, collection of fuelwood, and other human activities have resulted in the reduction of mangrove forests (Feller et al. 2017), thus increasing the potential risks of flooding and land subsidence (Bakker 2017; Truong and Luat 2018). Especially, since the early 2000s, mangrove forests have been cleared for shrimp farming in many areas (Hong and San 1993; Hong 1995). In addition, climate change has caused the sea level rise leading to saline water intrusion, which also causes a change in land use and mangrove distribution (Nguyen et al. 2016, Dasgupta and Shaw 2017; Tran et al. 2019).

Among many factors that have affected the mangroves of the VMD, the most important factor contributing to mangrove destruction is the aquaculture activities (Thu and Populus 2007). Previous studies have demonstrated a complex relationship between mangroves and shrimp farming. Shrimp farming in the VMD has resulted in thousands of hectares of mangrove forests being converted to shrimp ponds. The pattern of land use and land cover (LULC) in the VMD has been changing significantly over the decades, consequently affecting both the economic growth and environmental sustainability in the region. There are a large number of previous studies that have been conducted, focusing on mangrove restoration and development in recent decades (Kaly and Geoffrey 1998; Ellison 2000; Lee et al. 2019). However, these studies have reported that mangrove restoration was a complex issue without sound and evidence-based restoration policies (Lee et al. 2019). Therefore, geospatial data-based information can play a significant role in providing evidence-based information about changes in mangrove forest areas and various drivers such as the expansion of aquaculture and its impacts on mangrove health. This analysis can help in understanding and identifying the complex relationship between mangrove status and aquaculture farming activities (Thu and Populus 2007).

The LULC classification is an integral part of extracting thematic information about various classes from the satellite data. It is useful for land resource management and planning. Multi-temporal LULC data are valuable sources of information to know the trajectory of various land use and cover types and change pattern. Monitoring the changes in LULC based on remote sensing was conducted in previous studies with the aim to monitor the cropping pattern (Nguyen et al. 2016; Huynh et al. 2019), as well as detecting the distribution of mangroves and urban areas at the local and global scales (Singh et al. 2010; Avtar et al. 2013; Vo et al. 2013; Avtar et al. 2016). The applications of geospatial data to study mangrove cover changes have been successfully demonstrated through previous studies (e.g. Singh et al. 2004; Muttitanon and Tribathi 2005; Giri et al. 2007; Lee et al. 2009; Vo et al. 2015; Avtar et al. 2018). Moreover, many studies have indicated that remote sensing has advantages over the traditional field-based investigation in the monitoring of mangrove forests because of the synoptic view and large area of coverage (Singh et al. 2010; Kuenzer et al. 2011; Avtar et al. 2016; Pham et al. 2019). The use of multi-spatiotemporal geospatial data can provide useful information about mangrove forests globally. Pham et al. (2019) have reviewed the role of multispectral, Synthetic Aperture Radar (SAR) as well as hyperspectral data, for estimating various biophysical parameters of mangroves. Their study summarized the most commonly used methodologies globally for estimating the biophysical parameters of mangroves. Among these methodologies, the pixel-based classification methods are considered the most commonly used in mangrove classification (Tong et al. 2004; Binh et al. 2005; Thu and Populus 2007; Kamal et al.

2011; Avtar et al. 2016) Supervised classification algorithms were effectively used for mangrove classification using traditional satellite data (Conchedda et al. 2008; Giri et al. 2011; Kuenzer et al. 2011).

Although there are many studies on the impacts of shrimp farming on mangrove change, most of them focused on limited provinces of VMD, such as Kien Giang, Ca Mau, Tra Vinh, and Ben Tre (Thu and Populus 2007; Tuan et al. 2015; Nguyen et al. 2019). In Soc Trang and Bac Lieu provinces, the sea dyke system has been built to protect the residential area for the purpose of economic development in the area. At present, coastal erosion along with deforestation for aquaculture has not been adequately controlled. Therefore, local authorities have plans to protect the mangroves and rehabilitate the mangroves outside the sea dyke, which are considered essential. In addition, local authorities have co-operated with villagers to co-manage mangrove forests inside sea dykes through the benefits of mangrove-shrimp farming (DARD 2017).

Therefore, due to the limited comprehensive data on temporal changes in the mangrove ecosystems of Soc Trang and Bac Lieu provinces, this study provides a comprehensive assessment of long-term changes in mangroves distribution and its relationship with aquaculture activities. This study investigates the potential application of Landsat data using the maximum-likelihood classification (MLC) algorithm to monitor land cover changes and mangroves distribution in the Soc Trang and Bac Lieu provinces from 1988 to 2018. Change detection methods were also used to have better visualization and understanding of changing trends of mangrove forests. This study can support the local government in the decision-making process for land use planning and management practices in the future, such as mangrove plantation plans for sea dyke's protection, policies of mangroves development along with aquaculture.

2.2. Materials and Methods

2.2.1 Field survey

In this study, two field surveys were conducted from June 1 to July 30, 2017 and from March 15 to April 15, 2018, to collect ground truth data necessary for LULC classification and validation of results. In the field surveys, 170 and 125 field sites were randomly selected in the Soc Trang and Bac Lieu provinces, respectively (Figure 2.1). Global Positioning System (GPS) device (Gamin 60x) was used to mark the locations of various LULC types. The GPS photos were also collected for various LULC types. The geo-tagged photos are highly effective in improving the accuracy of the LULC classification (Oba et al. 2014). These photos have clearly shown the difference in the vegetation vigor and density of mangrove forests in the Soc Trang and Bac Lieu provinces.

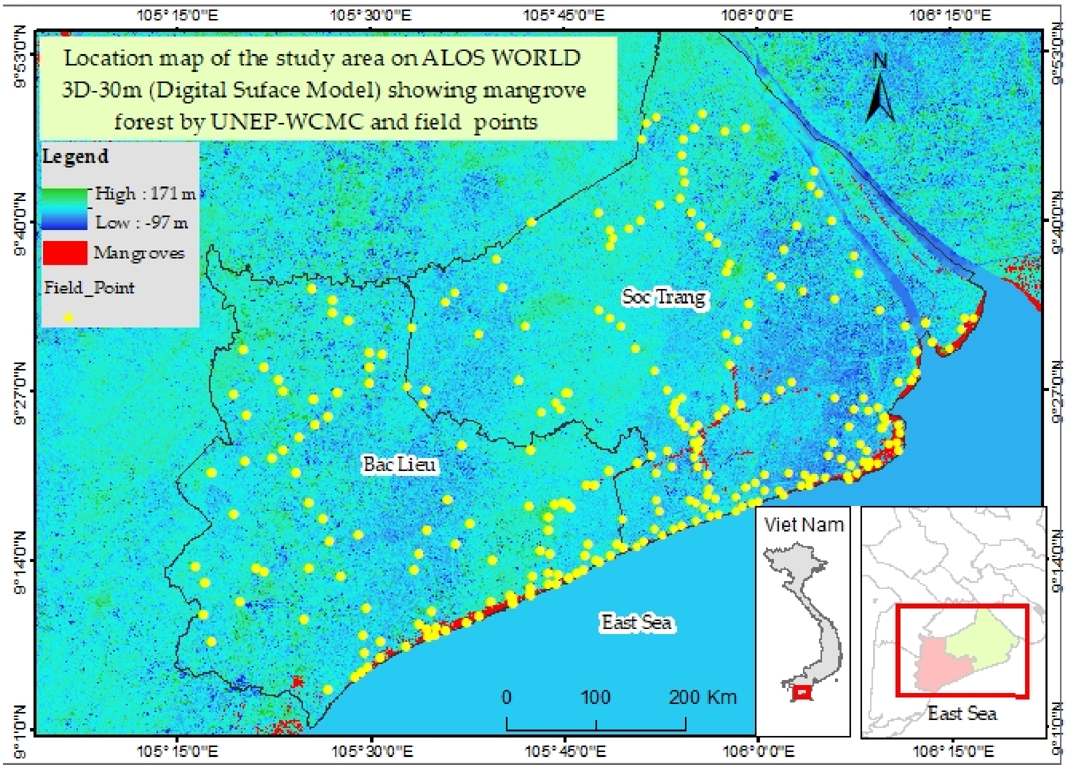

Figure 2.1 Distribution of field survey points of Soc Trang and Bac Lieu provinces in the VMD.

Random points weren't measured the distance but the distribution of sampling location was given in Figure 2.2 because of the accessibility. Ground data were collected based on homogeneity of area/class to cover representative sample of Landsat data. Based on the actual location of sampling points, the percentage of classes is calculated in Figure 2.3. It shows the distribution of the ground truth data collected during the field survey.

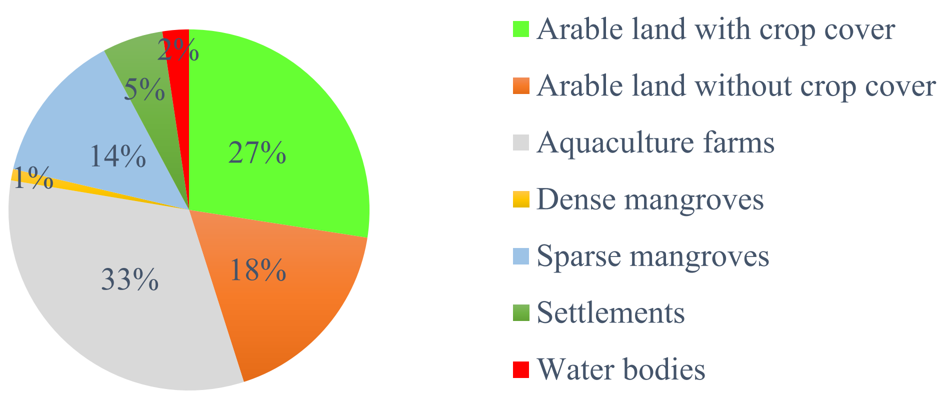

Figure 2.2 Distribution of ground truth data collected in Soc Trang and Bac Lieu provinces.

Figure 2.3 shows dense mangrove forests defined as the area in which the average mangrove density is more than 5,000 trees per ha (The People's Committee of Bac Lieu Province 2017). The mangroves are mainly located along the national sea dyke systems (Figures 2.3(a) and 2.3(b)). A part of the mangroves located outside the sea dyke systems was affected by high waves and was gradually swept into the sea water (Figure 2.3(c)).

9°23'53".45N -106°10'50".31E 9°24'28".70N -106°10'44".50E 9°21'34".26N -106°9'4".60E

(a) (b) (c)

Figure 2.3 Dense mangroves.

In Figure 2.4(a), 2.4(b), and 2.4(c), the sparse mangrove forests are shown with an average mangrove density of less than or equal to 5,000 trees per ha (The People's Committee of Bac Lieu Province, 2017).

9°17'4".33N -105°55'46".71E 9°18'40".08N -106°1'18".90E 9°9'99".54N -105°36'43".88E

(a) (b) (c)

Figure 2.4 Sparse mangroves.

At some field sites, the mangrove forests' density and age were directly observed according to information by DARD (2017) . In addition, the total percent of mangrove cover in each aquaculture farm associated with aquaculture production were also investigated. This information and data were used as training samples for the MLC of Landsat data and validation. Each training site was delineated on the images using polygons that cover multiple pixels in the homogeneous areas. The ground data were collected based on the homogeneity of the area/class to cover the representative sample of Landsat data. The status of mangrove forests and aquaculture farming areas were also recorded as pieces of evidence for the validation of results. Besides ground truth data, high spatial resolution images on Google Earth (GE) and administrative land use maps at the provincial level (Bac Lieu and Soc Trang) were used for validation of the classification results.

Xu et al. (2017) demonstrated the importance of field photographs in identifying the various LULC types and landscapes in the study area. Figure 2.3-2.7 show a number of geo-tagged photographs with the density of mangrove forests, aquaculture farms, as well as arable land with and without crop cover. The selection of ground truth data was based on the number of classes for LULC classification. Figures 2.5, 2.6, and 2.7 show the aquaculture area, arable land with crop cover, and arable land without crop cover, respectively.

9°11'1".34N -105°39'56".78E 9°7'0".08N -105°31'9".20E 9°27'34".83N -106°11'12".76E

(a) (b) (c)

Figure 2.5 Aquaculture (shrimp farming).

9°41'37".69N -106°3'8".23E 9°43'12".44N -106°2'19".62E 9°33'35".77N -105°38'10".87E

(a) (b) (c)

Figure 2.6 Agricultural land (in crops).

9°29’40”.82N -105°15’41”.33E 9°30’11”.52N -105°31’25”.98E 9°31’3”.50N -105°53’45”.50E

(a) (b) (c)

Figure 2.7 Agricultural land (no vegetation covered).

2.2.2 Satellite data

In this study, Landsat-5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) data of 1988, 1998, 2008, and 2018 were downloaded from the United States Geological Survey (USGS) server (https://earthexplorer.usgs.gov/) for land cover classification. The selection of these Landsat data was based on the availability of high-quality satellite imagery (clear and less than 10% of cloud cover). Table 2.1 summarizes the detailed information of the satellite data that was used in this study in every 10-years period. Landsat data were only collected in the dry season to eliminate not only the effects of clouds and shadows, but also the change in surface reflectance in different seasons.

Table 2.1 Detailed information of satellite data collected from the USGS server.

Satellite	Sensor	Path/Row	Spatial resolution (m)	Date of acquisition
Landsat 5	TM	125/53 125/54	30	30 January 1988
Landsat 5	TM	125/53 125/54	30	30 January 1998
Landsat 5	TM	125/53 125/54	30	9 March 2008
Landsat 8	OLI	125/53 125/54	30	5 March 2018

2.2.2.1 Landsat data processing

Figure 2.8 shows the methodology adopted in this study. Information about various objects on the earth's surface was generated from the Landsat data using reflectance information in the form of digital number (DN) (Avtar et al. 2013). Visual image interpretation techniques were also used to visualize the quality of data as well as various land cover types. Different forms of distortion or shift were noticed and considered during the visual interpretation process. Therefore, the geometric rectification, including image-to-image registration was applied. The image enhancement and histogram matching techniques were also used to enhance the quality of the image (Tokola et al. 2001; Moreira et al. 2014; Sari et al. 2016). In the study, the Normalized Difference Vegetation Index (NDVI) was also generated to monitor the spectral reflectance properties of vegetation. The NDVI was calculated as expressed in Equation (2-1):

$$NDVI = (NIR - Red) / (NIR + Red) \qquad (2\text{-}1)$$

where NIR is the reflectance at the near infra-red band, and Red is the reflectance at the red band.

NDVI has been widely used to identify various vegetation types (Rouse Jr et al. 1974; Ruiz-Luna et al. 2010; Avtar et al. 2011; Alatorre et al. 2016; Mohajane et al. 2018). The dense and sparse mangrove forests, agriculture areas, and aquaculture areas can be differentiated using NDVI values. Therefore, the NDVI was further used for MLC classification.

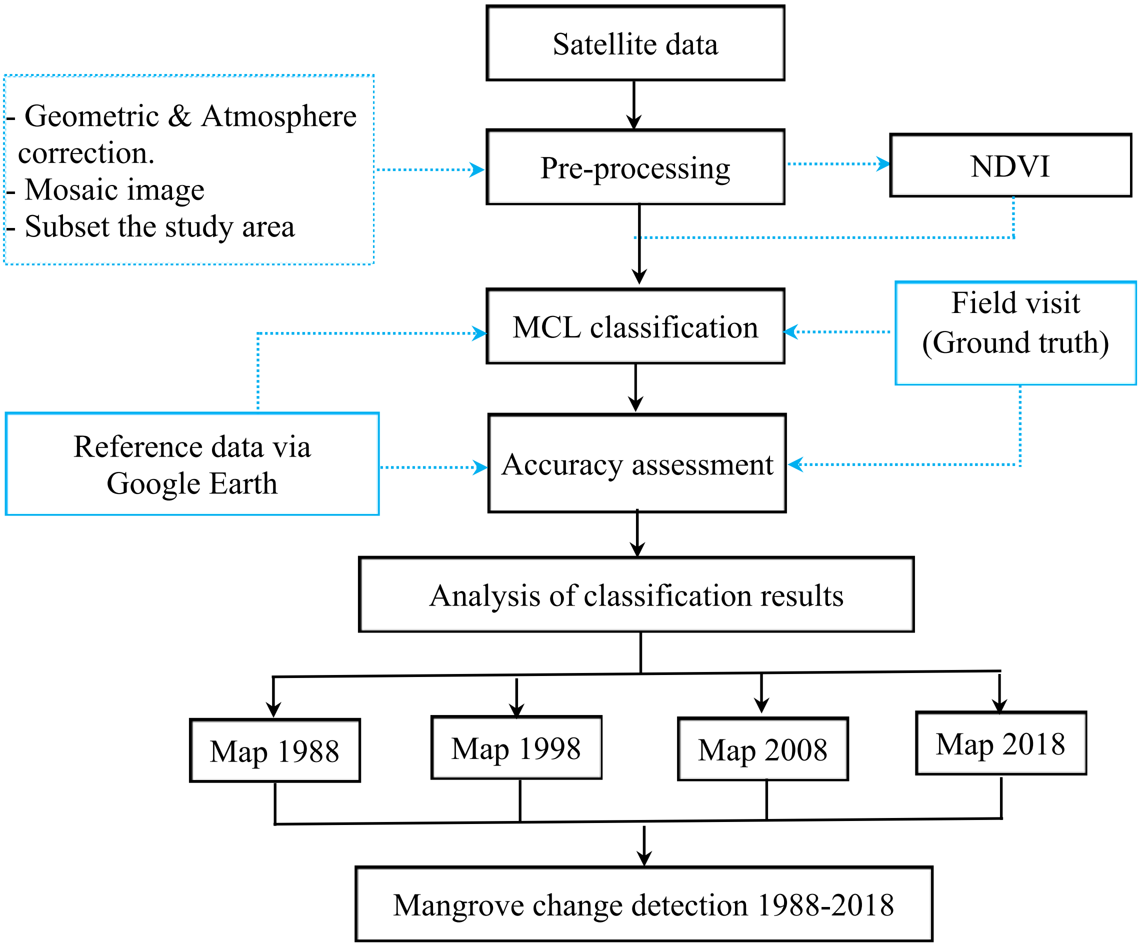

Figure 2.8 Flowchart of the methodology of the study (black rectangle = image, blue rectangle = survey data, and dotted lines = rule).

2.2.2.2 Image classification

There are various classification algorithms for LULC classification. Among these algorithms, the MLC is widely used due to its successful applications (Townshend 1992; Hall et al. 1995; Lillesand et al. 2015; Dan 2017). The MLC is a parametric classification algorithm that assumes a classed signature in a normal distribution (Gaussian statistical distribution) and statistically calculates the probability that a particular pixel belongs to a particular class (Ramsey and Jensen 1996). Each pixel is assigned to the class that has the highest probability (Dan 2017; Hall et al. 1995). The ArcGIS 10.4 and ENVI 5.2 software were used for classification and change detection. It was also a useful tool to determine the relationship between the LULC class and spectral reflectance. Each LULC map was classified into seven classes, namely, dense mangroves, sparse mangroves, aquaculture farms, arable land with crop cover, arable land without crop cover, settlements, and water bodies (Table 2.2). The selection of classes for classification was based on the fieldwork and other existing maps.

Table 2.2 Land-cover classified in this study.

Land-cover class	Description
Water bodies	Rivers, canals
Aquaculture farms	Shrimp farms
Settlements	Residence, commercial, industrial, transportation
Arable land without crop cover	No vegetation covered
Arable land with crop cover	Rice fields, fruit gardens
Sparse mangroves	Mangrove coverage of less than 50%
Dense mangroves	Mangrove coverage of more than 50%

2.2.2.3 Accuracy assessment

In this study, LULC maps were generated using Landsat data and MLC algorithm. An accuracy assessment of classified maps was done using the confusion matrix. The ground truth data collected during field surveys and Google Earth (GE) images were used for accuracy assessment of classified maps (Congalton 1991; Islam et al. 2018). The sampling points were randomly collected during the field surveys. These points were converted to GE images to see the coverage and distribution in different land cover categories. These points were compared with locations on the GE images to cross-validate their locations' accuracy. In the process of LULC classification, the maps of mangrove classification were compared with the available mangrove maps from official mapping sources to avoid misclassification between mangroves and other crops. As a result, the producer's accuracy, user's accuracy, overall accuracy, and kappa coefficients were also calculated to evaluate the agreement between reference and prediction data (Congalton 1991; Liu et al. 2008; Long and Giri 2011). Kappa coefficient for classified image was calculated following Kappa formula (Equation (2-2)) (Congalton 1991).

$$\boldsymbol{K} = \frac{\boldsymbol{N \sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k} x_{i+} x_{+i}}}{\boldsymbol{N^2 - \sum_{i=1}^{k} x_{i+} x_{+i}}} \quad (2\text{-}2)$$

where N is the total number of sites in the matrix, k is the number of rows in the matrix, x_{ii} is the number in row i and column i, x_{+I} is the total for row i, and x_{i+} is the total for column i.

2.3 Results

2.3.1 Land use and land cover maps

The spatiotemporal pattern of various LULC classes for 1988, 1998, 2008, and 2018 Landsat data using MLC classifier are shown in Figure 2.9. The agricultural area was mostly located in the upper region of the study area. The mangrove forests were commonly distributed in the coastal regions, while most of the aquaculture farms were located between agricultural lands and mangrove forests.

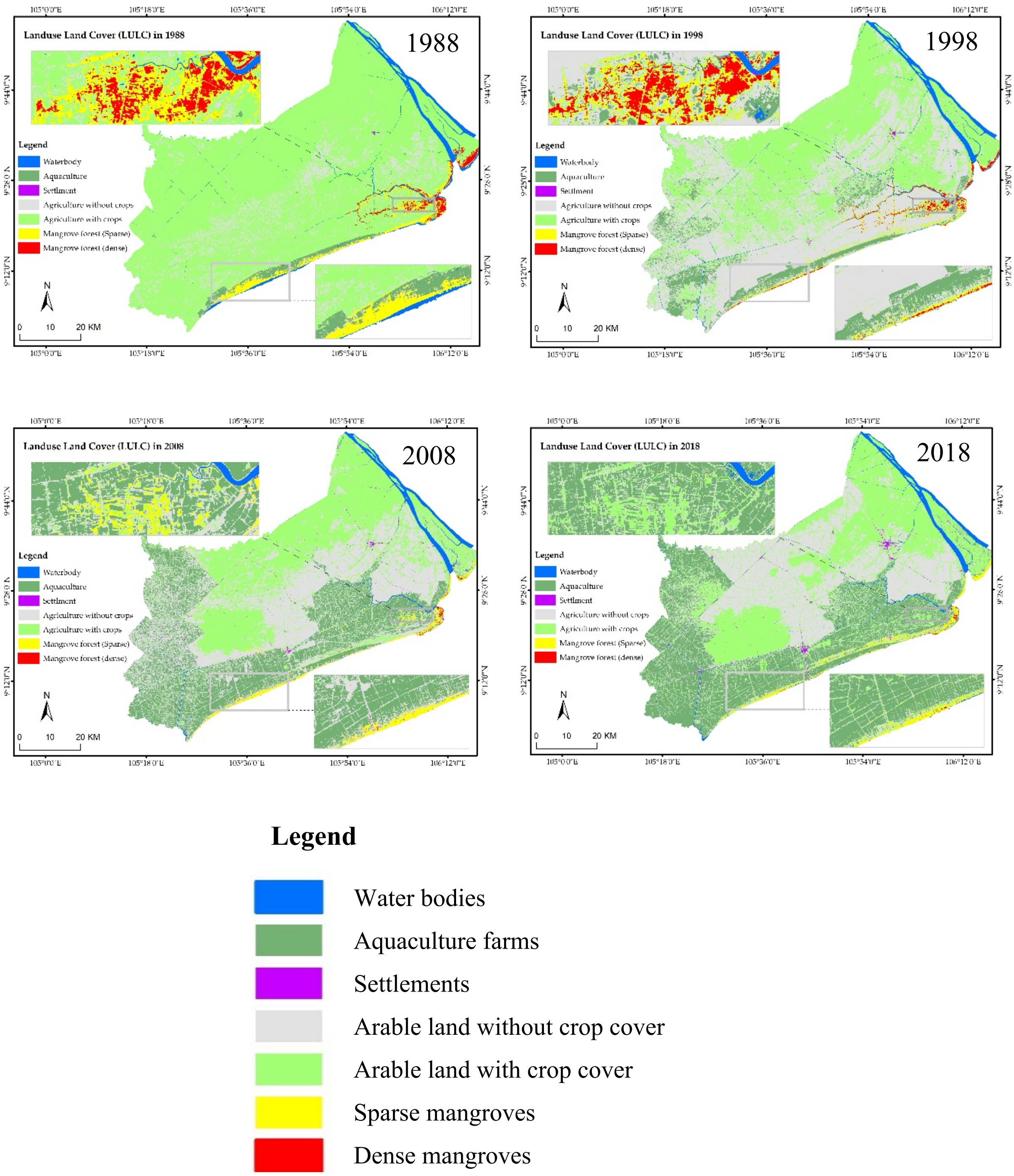

Figure 2.9 The LULC classification maps of Soc Trang and Bac Lieu provinces of the years 1988, 1998, 2008, and 2018, based on MLC of Landsat 5 TM (1988, 1998 and 2008) and Landsat 8 OLI (2018) images.

The results showed that mangrove forests were extensively distributed in the coastal regions of Soc Trang and Bac Lieu provinces and along the rivers interlinked with sea water (Figure 2.9). The temporal changes in the LULC classes from 1988 to 2018 were illustrated in Figure 2.9. The expansion of aquaculture farms was mainly occurred in between mangroves and agricultural areas, implying prominent land-use change from mangroves to agricultural areas (The yellow and red colors on the 1988 and 1998 maps changed to dark and light green colors on the 2008 and 2018 maps (Figure 2.9)).

The arable land with crop cover was the most dominant land cover type, amounting to 463,376 ha (80.9%) of the total area in 1988. The areas of dense and sparse mangrove forests were only 5,495 ha (1.0%) and 14,105 ha (2.5%), respectively, in 1988. The aquaculture area covered 9,673 ha (1.7%) in 1988. Noticeably, the aquaculture farms have significantly increased, reaching 160,393 ha (28.0%) in 2018. The opposite trend was seen in the total area of arable land with and without crop cover. The total area of agricultural land gradually decreased over the 30 years from 526,221 ha in 1988 to 387,102 ha in 2018. In terms of the settlement area, this area had increased from 95 ha in 1988 to 2,660 ha in 2018. The areas of water bodies showed a slight decrease, from 17,017 ha in 1988 to 15,646 ha in 2018, but the change may be affected by seasonal variations in water coverage in the study area.

The decrease in the areas of dense and sparse mangroves from 1988 to 1998 and from 1998 to 2008 were faster than that from 2008 to 2018. The annual rates of change in dense mangrove forests were 76 ha/year, 410 ha/year, and 13 ha/year from 1988 to 1998, 1998 to 2008, and 2008 to 2018, respectively. The annual change rates of sparse mangroves were 660 ha/year, 43 ha/year, and 79 ha/year from 1988 to 1998, 1998 to 2008, and 2008 to 2018, respectively (Figure 2.10).

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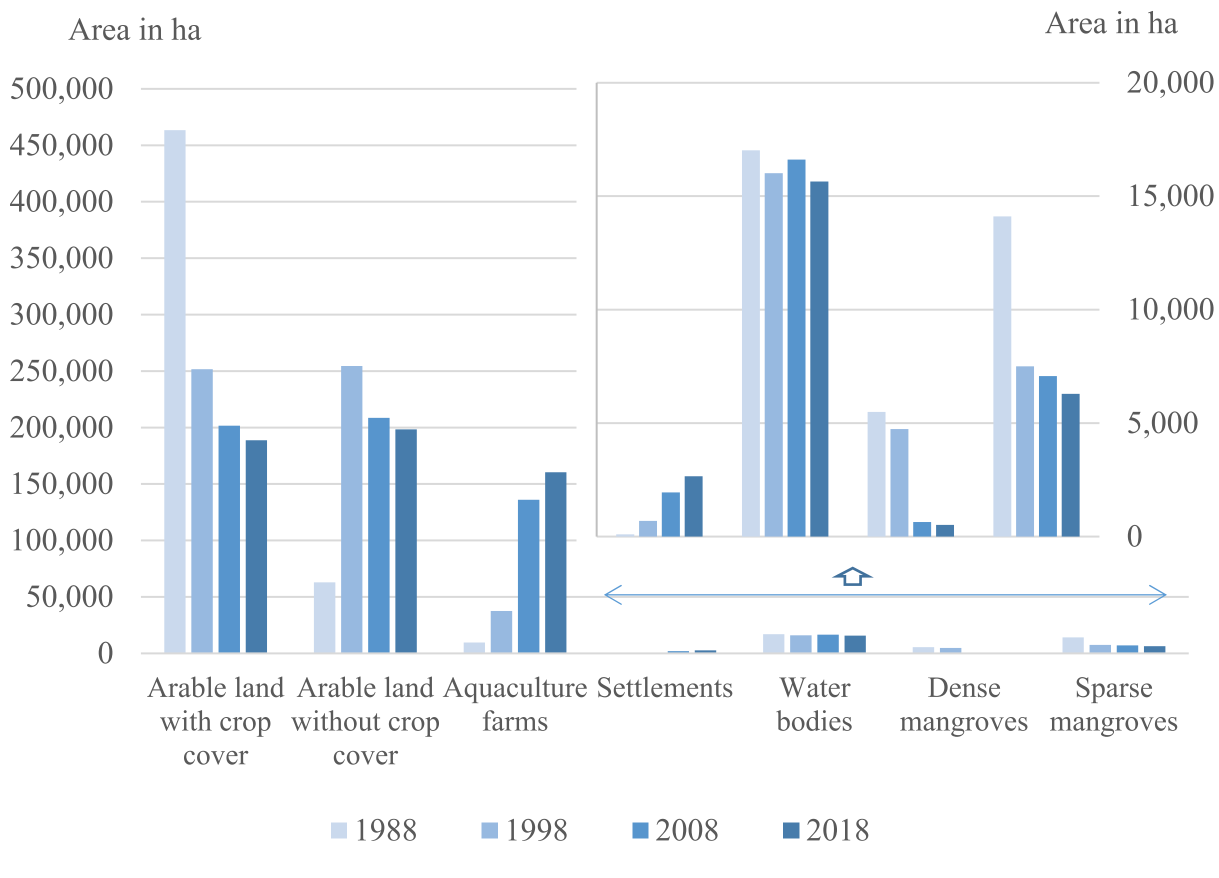

Figure 2.10 Changing pattern of LULC classes in the study area from 1988 to 2018.

The study reveals that the annual deforestation rate of sparse mangroves was more than that of dense mangroves. Mangrove deforestation in the study area was caused by various drivers in the VMD. Indeed, previous studies pointed out that these drivers include shrimp farming (De Graaf et al. 1998; Johnston et al. 2000; Ha et al. 2014), the Indochina War, and human activities such as cutting down trees for fuelwood or agricultural area expansion (Hong and San 1993; Orchard et al. 2016). The low rate of change during 1998-2008 period (43 ha/year of sparse mangroves) and during 2008-2018 period (13 ha/year of dense mangroves) were mainly due to the mangrove conservation projects and programmes in the VMD. The annual rate of change in the aquaculture farms from 1988 to 2018 was 5,024 ha/year. The aquaculture farms increased from 1.7% (9,673 ha) in 1988 to 28.0% (160,393 ha) in 2018 (Table 2.3).

Table 2.3 The LULC area in 1988, 1998, 2008, and 2018.

Land cover	1988		1998		2008		2018	
	ha	%	ha	%	ha	%	ha	%
C1	17,017	3.0	16,013	2.8	16,610	2.9	15,646	2.7
C2	9,673	1.7	37,567	6.6	136,051	23.8	160,393	28.0
C3	95	0.02	692	0.1	1,943	0.3	2,660	0.5
C4	62,844	11.0	254,474	44.4	208,580	36.4	198,326	34.6
C5	463,376	80.9	251,616	43.9	201,704	35.2	188,776	33.0
C6	14,105	2.5	7,503	1.3	7,074	1.2	6,289	1.1
C7	5,495	1.0	4,740	0.8	644	0.1	515	0.1

C1: Water bodies, C2: Aquaculture farms, C3: Settlements, C4: Arable land without crop cover, C5: Arable land with crop cover, C6: Sparse mangroves, C7: Dense mangroves.

Generally, the results of the LULC classification show the decline in the mangrove forest area, while the calculated NDVI value indicates the degradation of the mangroves. Therefore, the NDVI-based analysis can be used to monitor mangrove density as reported by previous studies (Umroh et al. 2016; Sari et al 2016). Each pixel has an NDVI value, which is averaged by a set of pixel values representing each classification. The NDVI of DM and SM were calculated for the four periods of 1988, 1998, 2008 and 2018. Figure 2.11 shows the temporal variation in the mean NDVI of dense and sparse mangrove forests. The mean NDVI values of dense mangroves were always higher than that of sparse mangroves. As can be seen from the figure, the mean NVDI values of dense mangroves show a decreasing trend. This trend shows that together with the area of dense mangrove forests, the quality (less green leaves and branches) of the dense mangrove forests has also declined from the 1988 to 2018. In the case of sparse mangroves, the mean NVDI values have increased from 1988 to

1998. During this period, the mangroves grew well, so the value of NDVI increased slightly. Then NDVI have decreased gradually from 1998 to 2018. The reason for this decline is thinning of mature trees, pruning of mangroves to expand shrimp farms. Besides, the mangrove plantation was young trees and low density, so the value of NDVI has decreased since 1998 (Figure 2.11)

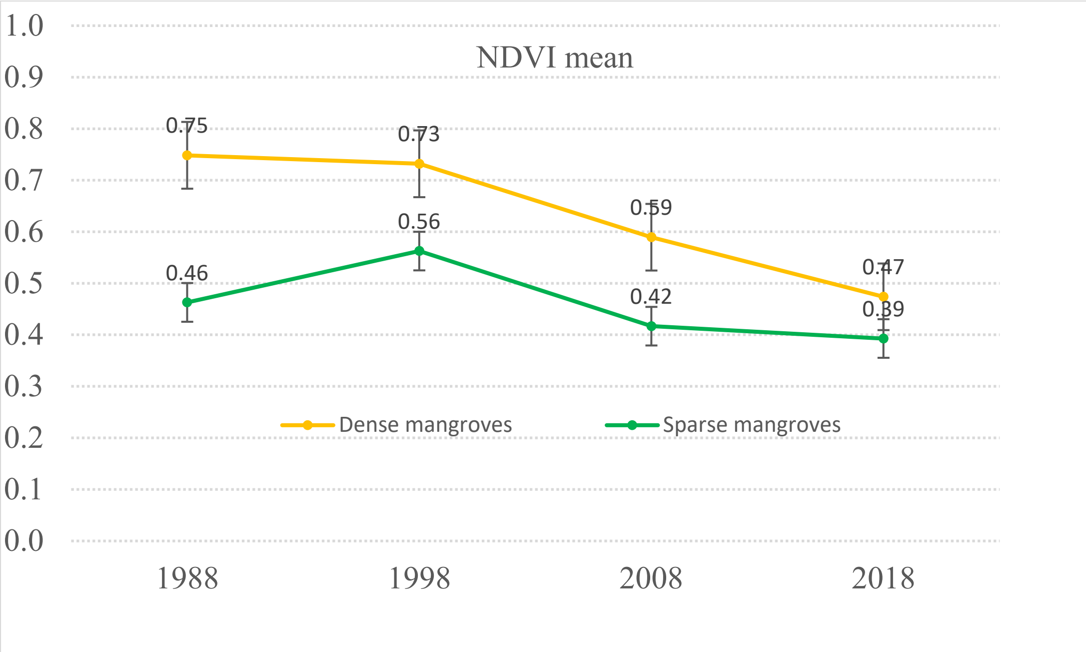

Figure 2.11 The NDVI mean values of dense and sparse mangroves in the years 1988, 1998, 2008, and 2018.

NDVI values of sparse and dense mangroves are shown in the Table 2.4. NDVI mean varied from 0.39 to 0.75 from 1988 to 2018, culminating at 1988 (dense mangroves). From 1998 to 2018, dense mangroves were occurred under decreasing NDVI, at values ranging between 0.39 (2018) and 0.73 (1998). Larger standard deviations were observed for sparse mangroves (1988) than for dense mangroves, except for sparse mangroves (2008). Because dense mangroves have large value fluctuations, so the error bar of dense mangroves is longer than sparse mangroves.

Table 2.4 NDVI value of dense and sparse mangroves.

Year	Mangrove class	Minimum value	Maximum value	Standard deviation	Mean value
1988	DM	0.655	0.909	0.059	0.748
	SM	0.046	0.734	0.111	0.463
1998	DM	0.660	0.859	0.042	0.732
	SM	0.278	0.662	0.074	0.563
2008	DM	0.560	0.695	0.021	0.590
	SM	0.235	0.630	0.087	0.417
2018	DM	0.455	0.558	0.017	0.474
	SM	0.337	0.455	0.032	0.393

DM: Dense mangroves, SM: Sparse mangroves

2.3.2 Accuracy assessment

In terms of the validation of classified images, 420 sampling points were randomly created. The accuracy assessment results are shown in Table 2.5-2.8. Tables 2.5 through 2.8 show the results of the accuracy assessment of the four LULC maps in 1988, 1998, 2008 and 2018, respectively. The overall accuracy varied from 83.3 % to 78.3% and the kappa coefficient varied from 0.81 to 0.75.

Table 2.5 Confusion matrix of L8 OLI (1988) images representing classification accuracy of supervised classification.

Class	C1	C2	C3	C4	C5	C6	C7	Total (Producer's)
C1	57	2	1	0	0	0	0	60
C2	7	45	4	3	1	0	0	60
C3	1	1	49	8	1	0	0	60
C4	0	1	3	47	9	0	0	60
C5	1	4	1	7	47	0	0	60
C6	0	1	4	0	1	45	9	60
C7	0	2	0	0	0	7	51	60
Total (User's)	66	56	62	65	59	52	60	420

C1: Water bodies, C2: Aquaculture farms, C3: Settlements, C4: Arable land without crop cover, C5: Arable land with crop cover, C6: Sparse mangroves, C7: Dense mangroves.

Table 2.6 Same as in Table A1 but for LS5 TM (1998) images.

Class	C1	C2	C3	C4	C5	C6	C7	Total (Producer's)
C1	59	0	0	1	0	0	0	60
C2	1	47	0	12	0	0	0	60
C3	0	4	48	7	1	0	0	60
C4	0	2	1	49	8	0	0	60
C5	0	7	0	8	45	0	0	60
C6	0	0	0	3	0	47	10	60
C7	0	0	0	1	0	4	55	60
Total (User's)	60	60	49	81	54	51	65	420

Table 2.7 Same as in Table A1 but for LS5 TM (2008) images.

Class	C1	C2	C3	C4	C5	C6	C7	Total (Producer's)
C1	55	5	0	0	0	0	0	60
C2	0	43	5	7	5	0	0	60
C3	2	1	43	5	9	0	0	60
C4	0	1	2	45	12	0	0	60
C5	0	0	2	12	46	0	0	60
C6	0	1	0	5	2	46	6	60
C7	0	1	1	4	0	14	40	60
Total (User's)	57	52	53	78	74	60	46	420

Table 2.8 Same as in Table A1 but for LS5 TM (2018) images.

Class	C1	C2	C3	C4	C5	C6	C7	Total (Producer's)
C1	48	7	2	2	1	0	0	60
C2	5	46	4	3	2	0	0	60
C3	0	2	51	7	0	0	0	60
C4	0	1	2	51	4	1	1	60
C5	0	0	4	4	50	2	0	60
C6	0	0	0	0	8	48	4	60
C7	0	0	0	1	3	6	50	60
Total (User's)	53	56	63	68	68	67	55	420

Table 2.9 illustrates the overall accuracy of LULC maps and kappa coefficient based on a confusion matrix. The overall accuracy of LULC maps for the year 1988, 1998, 2008, and 2018 were 81.2%, 83.3%, 78.3%, and 81.9%, respectively, and the kappa coefficient were 0.78, 0.81, 0.75, and 0.79, respectively.

Table 2.9 The accuracy assessment of the land cover maps from 1988 to 2018.

Class	1988		1998		2008		2018	
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
C1	95.0	86.4	98.3	98.3	91.7	96.5	80.0	90.6
C2	75.0	80.4	78.3	78.3	71.7	82.7	76.7	82.1
C3	81.7	79.0	80.0	98.0	71.7	81.1	85.0	81.0
C4	78.3	72.3	81.7	60.5	75.0	57.7	85.0	75.0
C5	78.3	79.7	75.0	83.3	76.7	62.2	83.3	73.5
C6	75.0	86.5	78.3	92.2	76.7	76.7	80.0	84.2
C7	85.0	85.0	91.7	84.6	66.7	87.0	83.3	90.9
Overall accuracy (%)	81.2		83.3		78.3		81.9	
Overall kappa coefficient	0.78		0.81		0.75		0.79	

PA: Producer's accuracy, UA: User's accuracy; C1: Water bodies, C2: Aquaculture farms, C3: Settlements, C4: Arable land without crop cover, C5: Arable land with crop cover, C6: Sparse mangroves, C7: Dense mangroves.

2.3.3 Change detection

Table 2.10 shows clear changes in LULC area in every 10-year period between 1988 and 2018. This study reveals that mangrove forests have decreased by 12,796 ha from 1988 to 2018 in the Soc Trang and Bac Lieu provinces. In the first 10-year period (1988-1998), the area of sparse mangroves had rapidly decreased by 6,602 ha and continued to decline by 7,816 ha for the last 30 years.

Table 2.10 The changes in LULC area in every 10-year period between 1988 and 2018.

Land cover	1988-1998		1998-2008		2008-2018		1988-2018	
	ha	%	ha	%	ha	%	ha	%
C1	-1,004	-0.18	597	0.10	-964	-0.17	-1,371	-0.24
C2	27,894	4.87	98,484	17.20	24,342	4.25	150,720	26.32
C3	597	0.10	1,251	0.22	717	0.13	2,565	0.45
C4	191,630	33.47	-45,894	-8.01	-10,254	-1.79	135,482	23.66
C5	-211,760	-36.98	-49,912	-8.72	-12,928	-2.26	-274,600	-47.96
C6	-6,602	-1.15	-429	-0.07	-785	-0.14	-7,816	-1.36
C7	-755	-0.13	-4,096	-0.72	-129	-0.02	-4,980	-0.87

C1: Water bodies, C2: Aquaculture farms, C3: Settlements, C4: Arable land without crop cover, C5: Arable land with crop cover, C6: Sparse mangroves, C7: Dense mangroves.

The magnitude of change in different LULC classes from 1988 to 2018 is shown in Table 2.11. It is clearly seen that the aquaculture farms have increased, amounting to approximately 150,720 ha during the last 30 years. The LULC classes of arable land with crop cover, arable land without crop cover, sparse mangroves, and dense mangroves converted into aquaculture farms by 27.1%, 29.1 %, 45.7%, and 35.4%, respectively. The LULC classes of arable land with crop cover converted into arable land without crop cover and arable land without crop cover converted back to arable land with crop by 34,3% and 30.2%, respectively. Both classes are agricultural land. This change is just a seasonal crop change. The LULC classes of dense mangroves and sparse mangroves also converted into agricultural land by 43.8% and 41.8%, respectively. One thing to note is that the settlements and water bodies accounted for the lowest percentages of the total LULC categories. The values with asterisks were not converted to any other classes. Values with dashes mean no values to be converted to this class. The total unchanged areas of these two classes represented 80% and 78% during the last 30 years, respectively.

Table 2.11 The post-classification change detection matrix indicating the direction of change between 1988 and 2018.

LULC classes changes		From C1	C2	C3	C4	C5	C6	C7
To (ha)	C1	13,103.73*	53.37	10.89	75.69	1,986.39	77.49	29.25
	C2	396.99	7,964.50*	-	13,899.60	137,993.94	6,560.19	1,952.46
	C3	74.34	36.72	60.03*	91.89	1,811.52	14.13	6.39
	C4	624.24	1,125.18	14.85	21,499.83*	162,931.14	3,135.42	599.22
	C5	675.27	403.29	-	15,447.15	168,181.38*	2,868.48	1,817.82
	C6	1,849.32	421.83	-	200.97	1,590.39	1,654.20*	918.28
	C7	166.95	13.32	-	2.88	7.83	61.83	190.53*
To (%)	C1	77.58*	0.53	12.70	0.15	0.42	0.54	0.53
	C2	2.35	79.50*	-	27.14	29.08	45.65	35.41
	C3	0.44	0.37	69.99*	0.18	0.38	0.10	0.12
	C4	3.70	11.23	17.31	41.98*	34.34	21.82	10.87
	C5	4.00	4.03	-	30.16	35.44*	19.96	32.97
	C6	10.95	4.21	-	0.39	0.34	11.51*	16.65
	C7	0.99	0.13	-	0.01	-	0.43	3.46*

C1: Water bodies, C2: Aquaculture farms, C3: Settlements, C4: Arable land without crop cover, C5: Arable land with crop cover, C6: Sparse mangroves, C7: Dense mangroves. Asterisks (*) show unchanged areas (the areas that were not converted to any other classes).

Figure 2.12(a), 2.12(b), and 2.12(c) shows the geospatial distribution of LULC changed and unchanged areas from 1988 to 2018. During the period 1988-2018, the total area of regional land-use change accounted for 62.9%, while the total unchanged area was 37.1%. In 2018, the total mangrove forest area in these two provinces was 6,804 ha. More than 90% of dense mangrove areas and 55% of sparse mangrove areas had reduced during the study period of 30 years. The changed mangroves position is shown in red color and the unchanged mangroves position is shown in purple color (Figure 2.12(a-c)

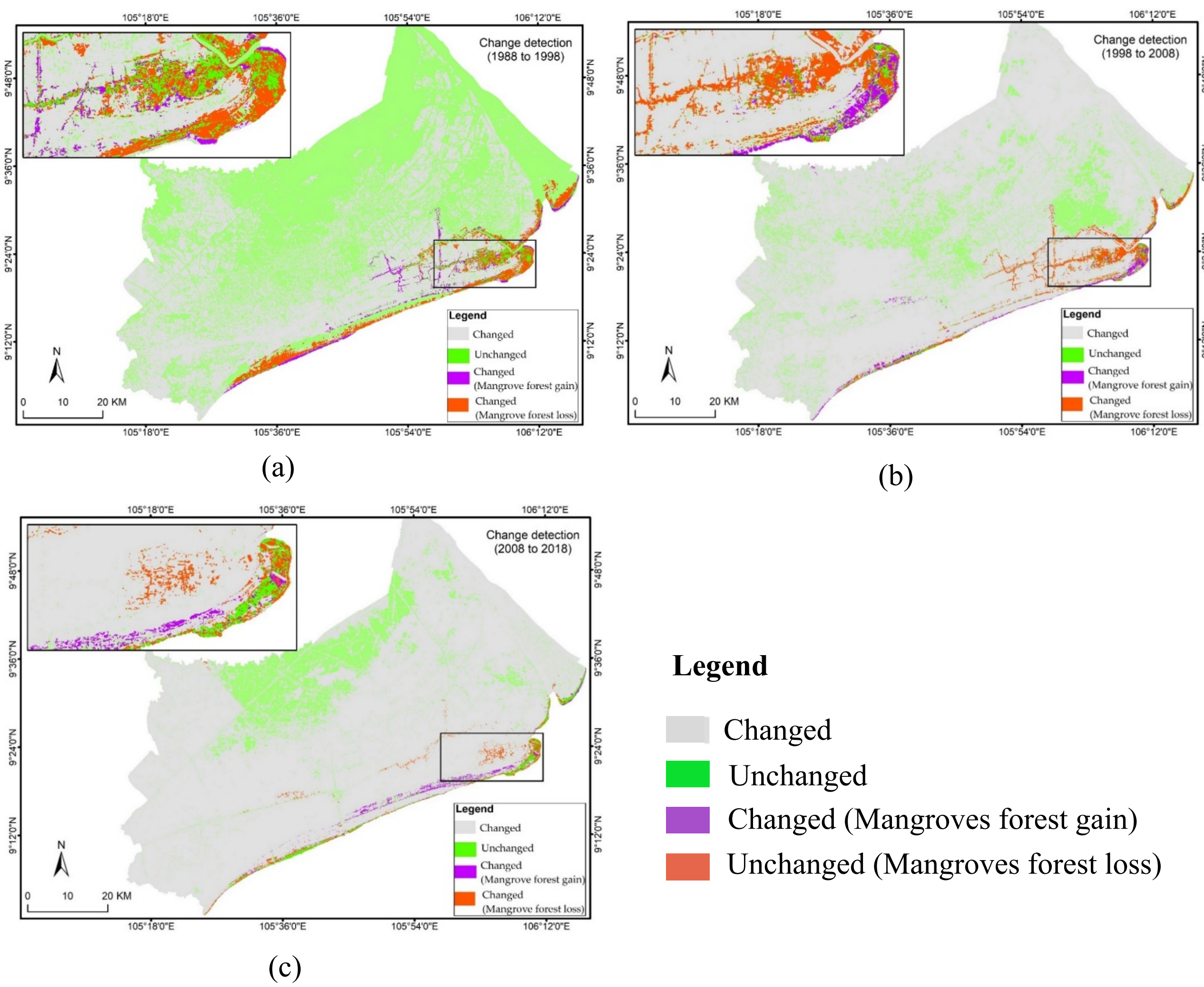

Figure 2.12 Change detection of mangrove forests (a) from 1988 to 1998, (b) from 1998 to 2008 and (c) from 2008 to 2018.

2.4 Discussion

2.4.1 Spatio-temporal changes of mangrove forests

The multi-temporal LULC maps show the changing trends of the LULC classes in a simplified way (Figure 2.9). These maps illustrate the changing pattern of various LULC classes. For instance, the aquaculture farming areas were mainly expanded in between the agriculture areas and mangrove forests, as mangrove forests serve as nurseries and food-supplies for marine and brackish water animals. Therefore, mangroves have high potentials to function as aquaculture farming areas as well once converted. The mangroves also absorb wastes generated by shrimp farming (Gautier et al. 2001; Wösten et al. 2003). The key findings of the study are that the areas of agriculture, dense and sparse mangroves, and water bodies in Soc Trang and Bac Lieu provinces have decreasing trends of LULC change, while the areas of aquaculture farms and settlements show increasing trends. Findings from this study are similar to those from previous studies (Binh et al. 2008; Tong et al. 2004). The previous studies have reported that a large number of mangrove in the VMD have been converted into aquaculture farms during the last decades. One of the recent studies (Truong et al. 2018) also reported a decrease in the mangrove forests in the VMD. In this research, a large number of both mangrove and agricultural lands have been converted into aquaculture farms during the last three decades. Consequently, it is clear that the rapid increase in the aquaculture farms in the VMD had negative impacts on mangroves and agricultural lands.

The aquaculture area in the study site has increased rapidly from 1988 to 2018. It is believed that aquaculture has brought more economic benefits than maintaining and conserving mangrove forests (Vo et al. 2013). From 2008 to 2018, both dense and sparse mangrove forests only slightly decreased, which was due to a number of national and international mangrove forest conservation projects and programs. Mangroves, mainly *S. caseolaris*, were planted in the mudflats along the coastal lines in the VMD, especially in Cu Lao Dung district, Soc Trang province (DARD 2017). The mangrove replantation in the VMD usually occurred after the sediment deposition in the shallow seabed. In Bac Lieu province, however, the replantation as well as conservation of mangrove forests have been limited in recent years due to the serious erosion in the coastal lines. Mangrove rehabilitation was planted on the site of accretion (mudflat).

Based on the analysis of NDVI, it is clear that the quality of mangroves (especially density of mangroves) has also changed. A series of results of field observation data, Landsat data and NDVI-based analysis suggest that dense mangroves have been damaged severely compared to sparse mangroves between 1988 and 2018. The NDVI-based analysis shows that there was a fluctuation in the density of sparse mangroves during the study period. It shows an increasing pattern for the period 1988-1998 and a decreasing pattern for the period 1998-2018. Noticeably, the decreasing pattern for the period 1998-2018 was mainly due to a number of mangrove forest management policies in the regional master plan that was approved by the Prime Minister in the 1996-1999 and 2000-2006 periods (FAO 2016). In this policy, mangrove forests are thinned for aquaculture development. In the policies, allocated or contracted households and organizations can convert up to 40% of mangrove area to other uses such as housing and aquaculture (mainly shrimp farms – i.e. shrimp farmers in protection and production mangrove forests must maintain at least 60% mangrove canopy cover) (Decision 186/2006/QD-TTg). In the mangrove areas for aquaculture production, allocated or contracted households can cut 100% of mangrove forests as long as they are immediately replanted (Decision 178/2001/QD-TTg). According to this plan, the mangrove areas in the VMD, including Soc Trang and Bac Lieu provinces, were divided into three zones, i.e. full protection zone, buffer zone, and economic zone. In these zones, 60% of the land area was used for mangrove forest development, and the rest (40%) was used for aquaculture (mainly shrimp farming), agriculture, and other utilizations (Minh et al. 2001).

Together with other Asian countries such as India and Thailand, the mangrove forest areas in the VMD have a decreasing trend in recent decades as a result of the economic benefits (Liu et al. 2008). The recovery of the mangrove forests as well as ecosystem protection in the VMD are major challenges for the Vietnamese government. However, recovery and conservation of the mangrove forests are crucial not only for the ecosystem protection in Soc Trang and Bac Lieu provinces but also for sustainable development in the VMD. Therefore, the application of advanced techniques for the assessment of LULC change is very essential for better mangrove forest management.

In this study, the use of moderate resolution (30 m) Landsat data has enabled the monitoring of spatio-temporal changes in mangroves in the study area because of low-cost or free data, long temporal coverage, and wider spatial coverage of Landsat data (Vo et al. 2013; Aziz et al. 2015; Giri et al. 2015; Ottinger et al. 2016). However, these data still have limitations of clouds and shadows which can affect the accuracy of classification (Avtar et al. 2013; Avtar et al. 2016). Therefore, the use of high-resolution satellite data along with in-situ information can improve the accuracy of classification. Use of SAR data can help to overcome the limitation of clouds and shadows (Vo et al. 2013; Nguyen et al. 2016; Avtar et al. 2018; Huynh et al. 2019) and can also provide more information about biophysical parameters of mangroves, such as biomass, density and height. For example Avtar et al. (2013, 2016) have successfully applied SAR satellite images to detect forest area and biomass. Pham et al. (2018) have applied SAR data to observe the mangrove forest changes in the VMD. Thus, such applications could be widely used in the VMD in the future. SAR data were not used in this study because of the unavailability of historical SAR data. In the future, I can study about relations such as between mangrove degradation and the distance from the coastal areas and between change in mangrove areas and impacts of socio-economic factors by using SAR data.

2.4.2 Driving factors of mangrove degradation

Mangrove forest dynamics are undergoing constant changes due to both natural and anthropogenic forces. The decrease in mangrove areas was mainly due to an expansion of aquaculture farms. Besides aquaculture farms, mangrove areas have been lost due to fuelwood collection and cutting of mangrove trees for house construction materials (Thu and Populus 2007). Moreover, a large part of agricultural land (more than 150,000 ha) has also been converted into aquaculture land. This affects domestic food security and world rice export. The area of inland mangroves (approximately 8,000 ha) was lost due to the conversion to agricultural land. These areas were mainly grown with short-term season crop (vegetables, corn, green bean, etc.) and uses groundwater for irrigation. In addition, rice varieties that can tolerate mild salinity are also intercropped during the rainy season. Furthermore, the rapid urbanization along the coastal regions had been noticed through the field surveys in the study area. Barbier (2016) found that the degradation of mangroves in the VMD was also caused by the short-term mangrove exploitation for immediate economic benefits by local communities rather than long-term sustainable use of mangroves. Local farmers have individually expanded their aquaculture land without land-use planning. Besides, there are small new segments of the mangroves that were planted along the coast, especially in the mudflats area outside the sea dyke systems (Albers and Schmitt 2015; Joffre et al. 2018).

Recently, the Vietnamese government has allowed local people to join mangrove protection along with aquaculture farming activities under a model of "land use allocation for forestry production purposes". For example, DARD (2017) showed that the Nha Mat district of Bac Lieu province was one of the regions that allowed local farmers to join the above model. In this model, the local people can use 30% of the mangrove area for their aquaculture production for a 5-years period (Truong and Luat 2018). However, a large number of local people had gradually cut down the roots of mangroves. As a result, these mangroves become weak or dead. The use of accurate mangrove coverage area maps can be helpful for local stakeholders including policy makers. The results of this study may assist in the decision-making process for conserving mangroves, preventing environmental degradation, and improving the ecosystem management and planning in Bac Lieu and Soc Trang provinces in the VMD.

2.5 Conclusions

Mangrove forests are important to human beings as they provide various ecosystem services to support human livelihood activities. Detecting changes in the mangrove forest areas, especially in the coastal regions, is essential for ecosystem conservation as well as coastline protection. In this study, Landsat data were used to evaluate the LULC changes caused by development activities and policies over the 30 years from 1988 to 2018. Results show a significant disappearance of the mangroves over the study period. Remote sensing-based analysis could identify low- and high-density mangrove forests based on the spectral signature. Besides, the NDVI data could also show the changes in the density and health condition of mangrove forests. This study has revealed that the expansion of aquaculture farms has been one of the major factors leading to the considerable decrease in the areas as well as the quality (density and health condition) of dense and sparse mangroves. Nevertheless, mangrove plantation activities did not compensate sufficiently for the loss of mangrove area caused by aquaculture expansion. Furthermore, the loss of mangroves is partly due to conversion to agricultural land. In addition, more than 150,000 ha of the agricultural land, which was adjacent to aquaculture land, was converted into aquaculture land. This may have greatly affected the rice production to ensure domestic food security and export to the world. Therefore, there is an urgent need for land use change research and management policies and strategies, as well as plans for the sustainable development of land use change in the coastline zone of VMD.

Chapter III

Community perception, use and Economic assessment of mangrove ecosystem services: a case study in Soc Trang and Bac Lieu provinces, Vietnam

3.1 Introduction.

Mangrove forests are mainly distributed along tropical coasts and play a crucial role in providing vital ecosystem services for coastal communities (Duncan et al. 2016). Based on the Millennium Ecosystem Assessment (MEA) classification, these services are identified and categorized (Figure 3.1). According to the literatures (Carpenter et al. 2005; Alongi 2008; Hussain and Ruchi 2010; Vo et al. 2012; UNEP 2014; Beresnev et al. 2016; Dasgupta and Shaw 2017), the main ecosystem services consist of (i) provisioning (e.g. fish, crabs, aquaculture, fisheries, timber, honey, fuel, construction material, traditional medicine, etc.); (ii) regulating (e.g. shoreline protection, etc.); (iii) cultural (e.g. entertainment, tourism, etc.); and (iv) supporting (e.g. carbon sequestration, nutrient cycling, nursery habitats, etc.).

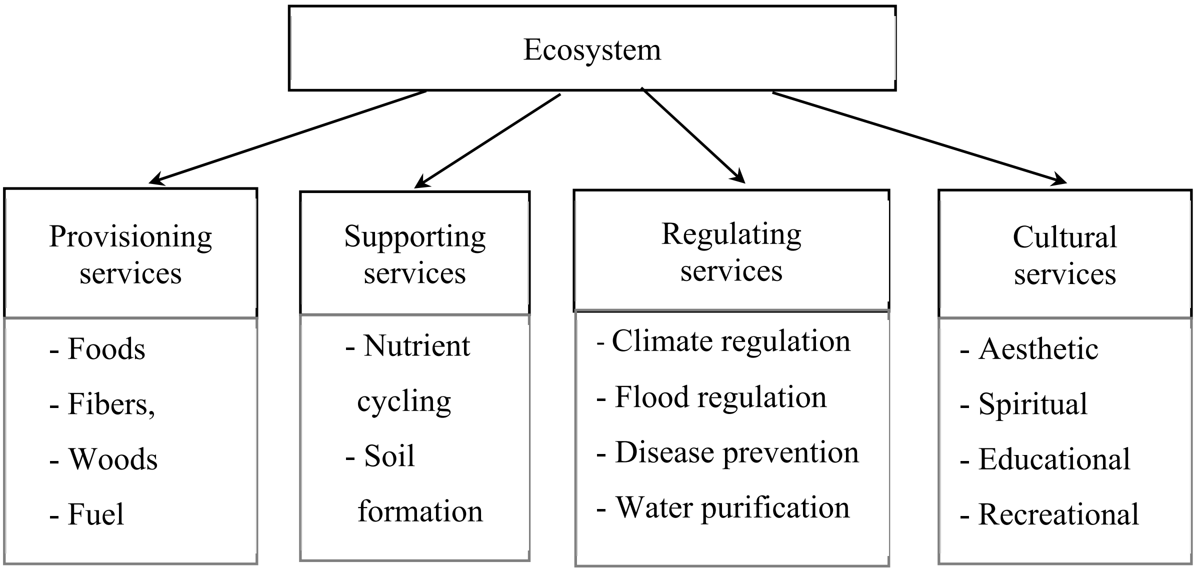

Figure 3.1. The classification of ecosystem services provided by mangrove forests (UNEP 2014).

The mangrove ecosystem has valuable in terms of direct and indirect use values (Figure 3.2). Of these services, mangroves are particularly important for commercial and offshore fisheries. According to Sandilyan and Kathiresan (2012), mangrove forests are considered as living environment, nurseries and breeding ground for fisheries. Noticeably, eighty percent of commercial fish production is caught from these forests worldwide. Besides, these mangrove forests also play an crucial role as natural barriers for stabilizing coastlines, where they dissipate destructive wave energy and mitigate the impact of hurricanes, cyclones, and storm surges (Groot et al. 2002; Seto and Michail 2007; Hussain and Ruchi 2010). Globally, economic values of mangroves range from 750 to 1670 USD/ha/year depending on market conditions and diverse valuation techniques (Rönnbäck 1999). Nevertheless, mangrove ecosystem services are often poorly evaluated and lesser accounted in regional planning, which calls for robust accounting for ecosystem values as well as direct and indirect uses of mangroves among local communities (Dasgupta and Shaw 2013, 2017a). The use and economic value of mangroves depend on a variety of socioeconomic factors, including the way its services are apprehended and used, market demand, location of the assessment, population density, etc. Moreover, mangroves also provide a number of non-market benefits, and thus, both direct and indirect values need to be accounted simultaneously (Vo et al. 2012; Malik et al. 2015). Understanding of the diversity of use and economic of mangrove forest values are essential to ensure generally regional sustainability and minimizing negative impacts on ecosystems and their services (Figure 3.2).

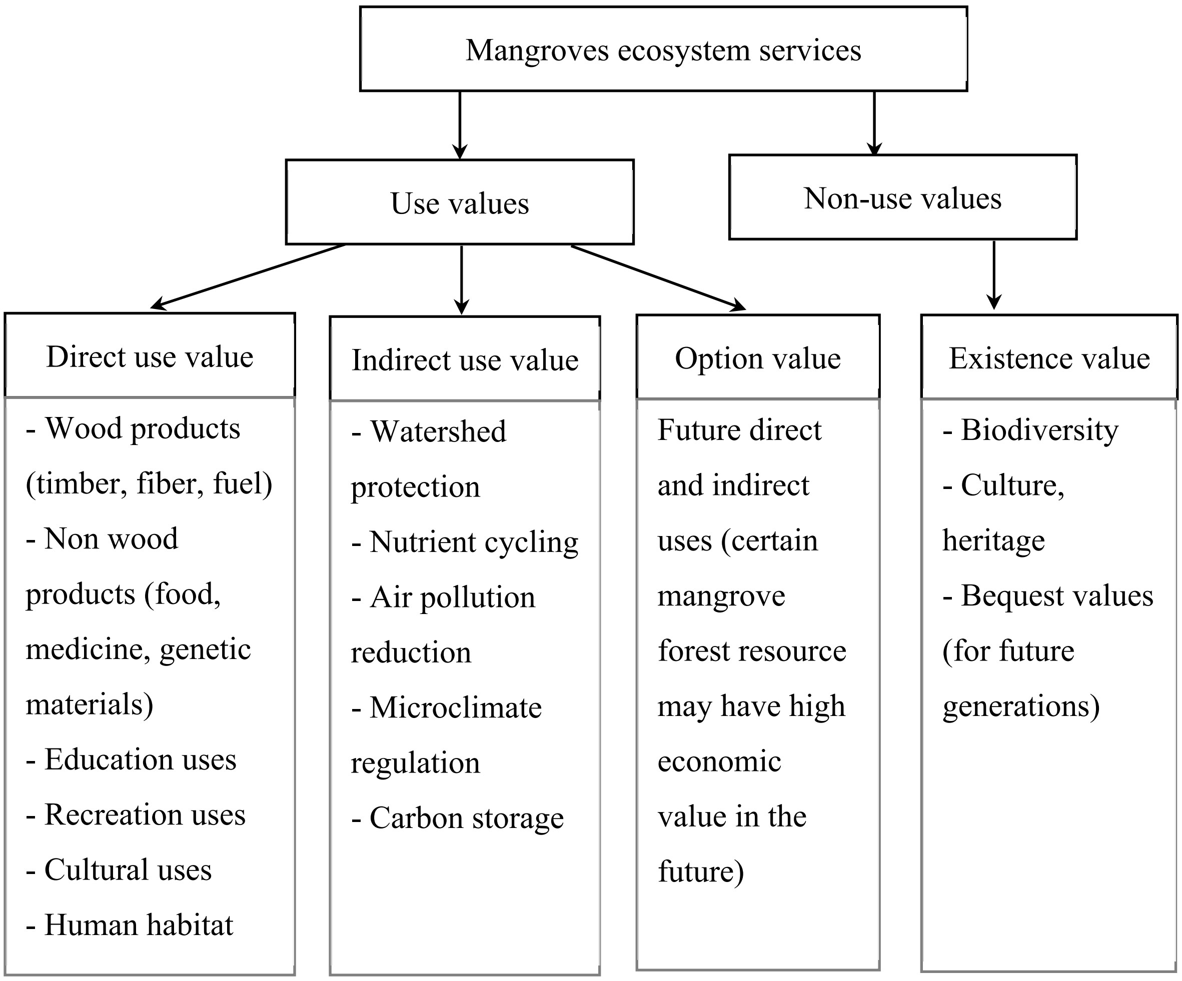

Figure 3.2 The total economic value of mangrove ecosystem (Carpenter et al. 2005).

In Vietnam, mangroves are considered an integral part of national's coastal zone in general and VMD in particular VMD. Unfortunately, in recent decades, mangroves are increasingly destroyed in the VMD due to facilitating socio-economic development. According to (Binh et al. 2005; Thu and Populus 2007). Particularly, the rapid growth of aquaculture ponds in 1980s is considered one of the key reasons causing the large decrease in the mangrove forests' area in VMD. However, mangrove planting and restoration activities have recently prioritized with intensive supports from governmental organizations, non-governmental organizations (NGOs) and local communities. A number of previous studies suggested that in Vietnam, the total estimated economic value of mangrove ecosystem services using market prices and alternative cost methods are approximately 3000 USD/ha/year in Ca Mau (Schmitt et al. 2013) and 718 USD/ha/year in Can Gio (Hawkins et al. 2010). In the VMD, an annual loss of about 0.7 tons of caught commercial fish was estimated for every hectare of lost mangrove forest (Schmitt et al. 2013).

Owing to rapid loss of mangroves as well as widespread threats from rising seaward hazards, including severe coastal erosion and land abatement, the Vietnamese government has launched a number of coastal protection programs in the late 1990s (Schmitt et al. 2013). These programs were considered as the first effort to restore and protect mangroves in the southern VMD from negative impacts caused by economic and livelihood activities. Nonetheless, coastal mangroves support large surrounding populations and foster diverse economic activities. Therefore, the restoration and conservation of mangrove forest ecosystems have become challenges and difficulties for local government (Hawkins et al. 2010). While direct using values of mangrove are well recognized, the economic cost of mangroves for coastal protection remains dubious owing to diverse accounting methodologies. Mangroves provide critical services for reducing disaster risk coastal zones and these services are particularly important in preventing the negative effects of sea level rise as well as coastal erosion in the VMD (Kathiresan 2012; Albers and Schmitt 2015).

The aim of this study is to establish a framework for linking remotely sensed spatial data and household survey data to estimate the values of mangrove ecosystem services. The overall contribution of mangrove ecosystem services to the local communities, focusing on provisioning services of mangrove-shrimp farms, fishery and timber products and regulating services (erosion control) of mangrove ecosystems. Other services, such as cultural services or genetic biodiversity, are excluded as those are outside the scope of this study. Moreover, genetic biodiversity and cultural services are difficult to measure because these services do not enter to the market at all. Understanding the economic value of mangrove ecosystems and the services they provide to local communities have become increasingly important for local, national, and global policy and decision making. Indeed, quantifying and integrating these services into decision making will be crucial for sustainable development, where short-term economic benefits should be balanced against longer term environmental and economic sustainability.

3.2 Materials and Methods

3.2.1 Methodological Framework

Mangrove forests provide all of the four kinds of ecosystem services including provisioning, regulating, supporting and cultural services. According to (Carpenter et al. 2005) based on MEA, mangrove ecosystems provide important products and services for the following ecosystem services: Regulating, provisioning, cultural, and supporting. The conceptual framework of mangrove ecosystem assessment is shown in Figure 3.3.

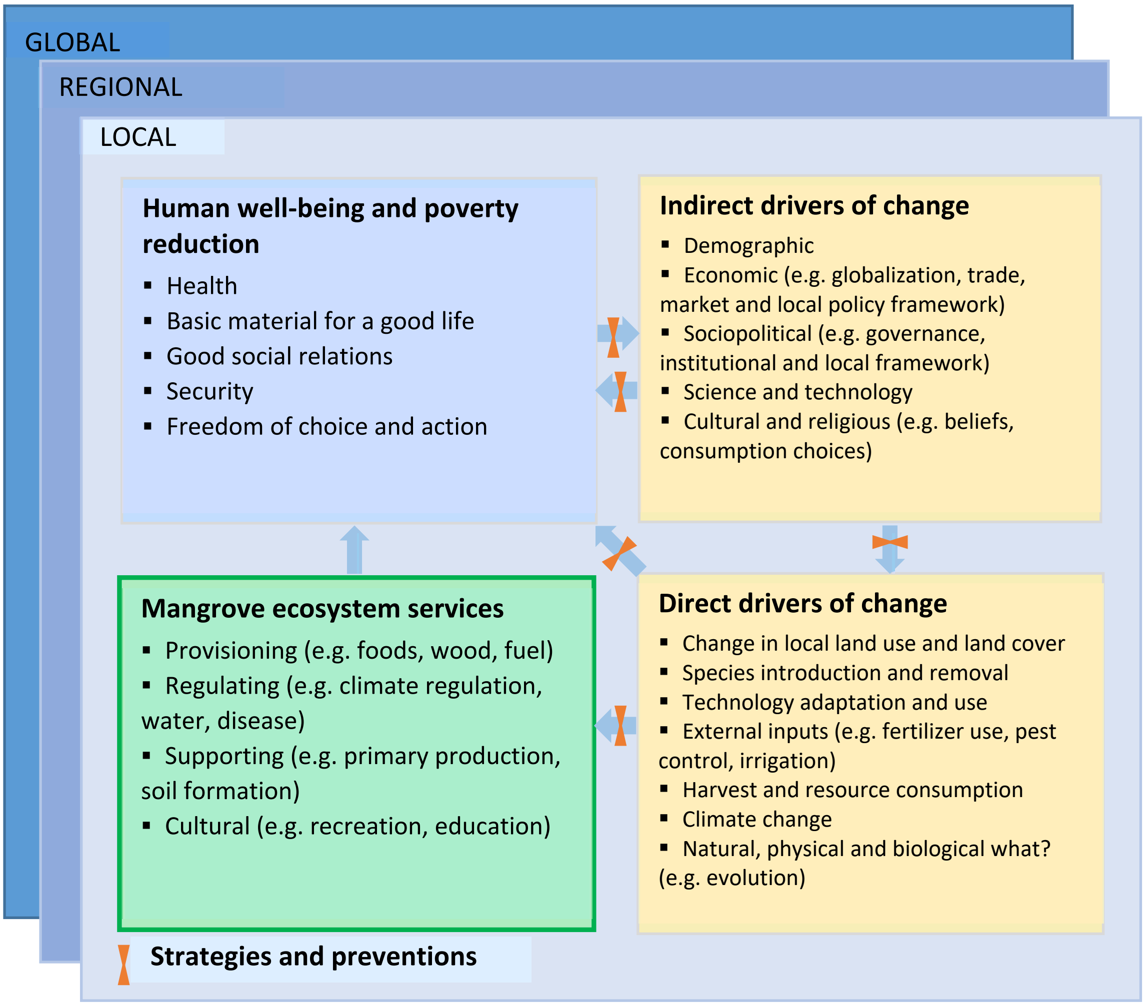

Figure 3.3 The conceptual framework of mangrove ecosystem services (Carpenter et al. 2005).

In this study, economic values of the mangrove's provisioning and regulating services were estimated, considering the most appreciated services by the local communities. Provisioning services (PS) are generally traded in markets, so the direct valuation method was used, i.e. simple accounting of traded product and their exchange values. Contrarily, regulating services (RS) are mostly non-market services, and thus, indirect valuation method was used to account for these services (Sathirathai 1998; Vo et al. 2012; Kuenzer and Vo 2013). In this study, replacement cost method was used for the valuation of RS (Barbier 2015, 2016; Vo et al. 2015).

Direct values of PS can be easily determined by household survey on the diverse use of mangrove ecosystem services. In this research, questionnaire was designed to interview local residents, who are using ecosystem services to collect information related to current mangrove ecosystem service using (Appendix A1). The designed questionnaire focused on collecting information on the frequency and number of different mangrove products that are collected on a regular basis. Besides, information on (i) residents' knowledge and understanding on mangrove forests' coastal protection role, (ii) behavior of local people towards the mangroves exploitation and protection, and (iii) community support and participation in coastal zone management as well as mangrove forest conservation were also collected and analyzed. Average income was defined as income sufficient to provide food, necessities for the family and had been designated nationally.

RS was indirectly estimated by economic value of coastal protection as indirect use values (IUV). This values include regulatory ecological functions, which lead to indirect benefits such as flood control, storm protection, nutrient retention, nursery grounds for different species, and main erosion control (Sathirathai and Barbier 2001; Barbier 2007; Das and Anne 2013; Huxham et al. 2015). As the local government considers mangrove planting for coastal protection to replace dykes, the indirect value can be considered as a replacement value for investment in the sea dyke system construction and maintenance. The replacement valuation method assumes that the value of the ecosystem service is equal to the value of replacing it with a manmade alternative (Gilbert and Ron 1998; Brander et al. 2006; Kuenzer and Vo 2013). IUV were estimated by using replacement costs and benefit transfer methods. Based on different coastal protection strategies, a replacement cost method was adopted to assess the RS. At first, based on the erosion rate, three different situations were identified, namely, erosion zone, stable coastline, and accretion zone. The total of investment and maintenance values are based on the using lifetime of different styles of sea dyke. The investment cost for mangrove plantation at coastal zones was also added into RS. In this study, all costs were calculated with Vietnamese currency

(VND) before being converted to US dollars with money exchange rate (1 dollar = 23,000VND) for the study period.

3.2.2 Data collection

Both primary and secondary datasets were used in the study. In the first step, a number of focus group discussions were conducted with the active participation of leaders and staffs from local multilevel departments (e.g. Department of Natural Resources and Environment, DARD, Forest Protection Sub-Department, Irrigation Sub-Department, Fishery Association, Aquaculture Extension Centre), communal or village leaders, and local residents. These focus group discussions were considered effective tools for collecting real information on the communities' social and environmental concerns, use of mangroves, aquaculture products, land rights, and coastal protection status in 6 coastal districts of Soc Trang and Bac Lieu provinces. Based on this initial information, questionnaire for independent household survey was designed.

In the second step of this study, detailed survey was independently conducted for every selected household of 300 households in the study area in June 2017 and March 2018, with the support from village leader and local officers. Each interview was averagely taking within 2 hours. Each household was paid 50,000 VND (approximately 2.2 USD) for spending time to join the interview. The questionnaire mainly consists of needed questions to collect information on demographic characteristics, educational background, land ownership and land size, monthly/annually income, experience with mangrove management, general utilization of mangroves and mangrove-related income, and people's general understanding of the mangrove ecosystem. The location of sample households in the study area was shown maps in the Figure 3.4.

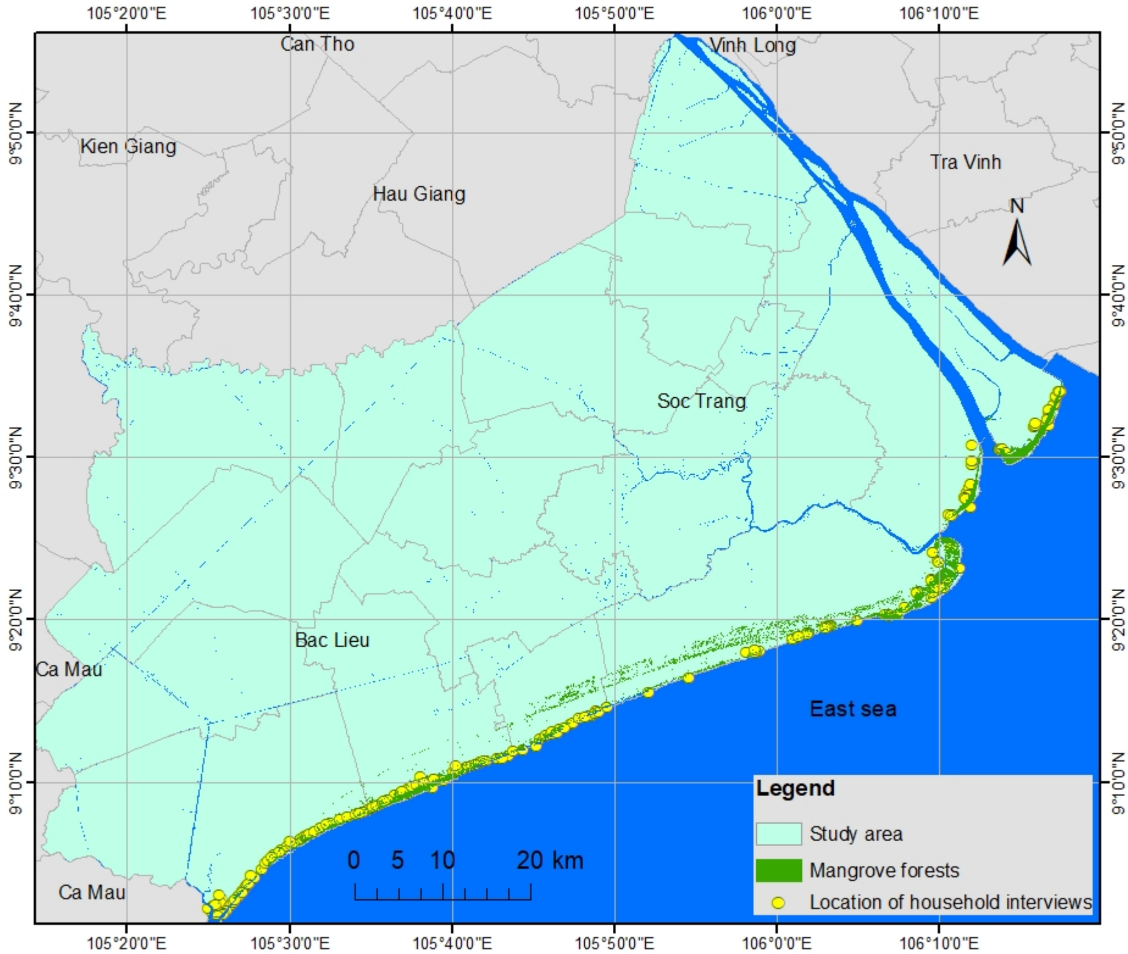

Figure 3.4 Location that household interviews were carried out (in yellow dots) in Soc Trang and Bac Lieu provinces.

In the last step of data collection process, secondary dataset was collected from governmental organizations including Department of Water Resources, DARD. This dataset includes required information related to forest management such as total area of mangrove forests, mangrove species, plantation, households' co-protection contracts of mangroves, and mangrove products. Besides, information on the location of sea dyke systems. In this study, the collected secondary dataset was especially useful for calculating and comparing with primary data in order to increase the reliability and feasibility of dataset utilized in the study. Furthermore, the data on investment cost of the sea dyke systems and their periodical maintenance as well as the assessment of their impacts on environment were collected from governmental organizations' reports and documents.

3.3 Results

3.3.1 Sample characteristics

Based on results achieved from the survey, most of the surveyed households were mangrove user groups possessing forest management contracts, and most of these households are living in the Soc Trang and Bac Lieu provinces' coastal areas within distance less than 1 km from mangrove forests. In terms of the mangrove forest contracts, a legal land-use certificate was required to the forest owners. Based on these contracts, the right of the mangrove forest ownership remained with the contractors, but the contractees were entitled to a cash remuneration for protecting their forest area. Every contract usually lasted for a 5-year period and was revised and signed depending on the satisfactory performance of both the contractors and contractees.

More than 85% of the interviewees were male, and the majority of the respondents were within the age range of 18-55 years (67%), followed by those over 55 years old (26%) (Table 3.1). The main occupation in the area was shrimp farming, which 76% of the respondents engaged in. More than 70% of the respondents belonged to Kinh and 29% to Khmer clans, respectively. Khmer communities usually lived near the river and the sea as their lives were closely associated with exploitation of aquatic products in mud flats and tidal areas. Contrarily, Kinh communities lived a little far away from the coast and most of them live on aquaculture combined with mangroves protection. Under the contract, land holders were trained on mangrove ecosystem services, international organic shrimp certification standards, and organic shrimp farming practices.

Majority of the respondents had academic background of primary or secondary school graduate (87.1%) and only a small proportion (11.5%) had that of high school or college graduate. About 1.4% of the interviewees had not received any school education at all. About one third of the interviewed households were poor (35.6%), only 10.2% are rich and 54.2% had average income levels. Local livelihoods and income sources mainly came from aquaculture combined with mangrove management of which 73% of the respondents had mangrove protection contracts. Their main income came from mangrove shrimp farming and the products obtained from mangroves. 8.1% of unemployed people were those who did not have land and did not work as hired laborers. They only exploit aquatic products from mangroves to provide food for their families. Other income sources include government officers (4.7%), traders (9.8%), and hired laborers (1%). About 81% of the respondents have settled in the study area for more than 10 years. The remain (19%) of the respondents have settled for less than 10 years and have migrated from nearby provinces. Understanding all the collected information could help local managers and policy makers to propose appropriate solutions for enhancing local people's awareness and behavior on the mangrove forests' sustainable exploitation and management.

Table 3.1 Socio-demographic characteristics of the respondents.

Features		Quantity	Percentage (%)
Gender	Male	251	85.1
	Female	44	14.9
Age	Below 18 years old	18	6.1
	18-55 years old	200	67.8
	Over 55 years old	77	26.1
Ethnicity	Kinh	207	70.2
	Khomer	85	28.8
	Hoa	3	1
Education	Illiterate	4	1.4
	Primary school	228	77.3
	Secondary school	29	9.8
	High school	14	4.7
	College or university	20	6.8
Self-ranking in economy	Fair/rich	30	10.2
	Average	160	54.2
	Poor	105	35.6
Occupation/ Main income	Government officer	14	4.7
	Shrimp farmer	225	76.3
	Trader	29	9.8
	Hired laborer	3	1.0
	Unemployed	24	8.1

3.3.2 Community perception on mangrove ecosystem services

The results indicate that most of the respondents admitted the function of mangrove forests as preventing coastal erosion (95% in Soc Trang and 94% in Bac Lieu, respectively) (Figure 3.5). Interestingly, 91% of the respondents in Soc Trang admitted the function of mangrove forests as wind break while only 29% of the respondents in Bac Lieu admitted. The coastal zones in Bac Lieu province have a thinner mangrove belt than Soc Trang province has, so it seems that the respondents in Bac Lieu were not relatively aware of the importance of the function. The function of mangrove forests as storm protection was important to the majority of both local communities (90% and 64% of the respondents in Soc Trang and Bac Lieu, respectively). The function of mangroves as barrier has the smallest percentage of local communities' agreement (51% in Soc Trang and 40% in Bac Lieu), followed by the wave break (82% agreement in Soc Trang and 66% agreement in Bac Lieu).

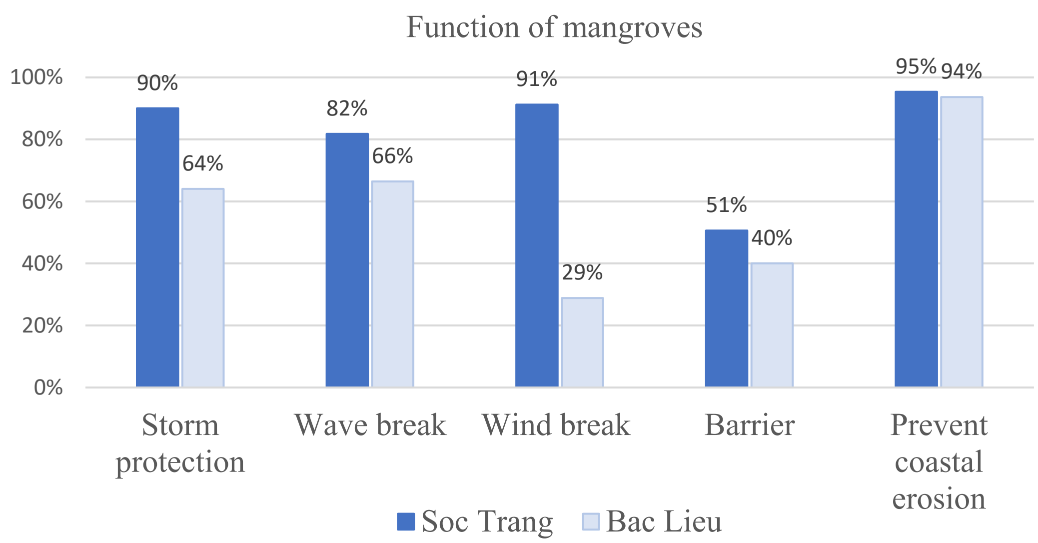

Figure 3.5 Community responses regarding function of mangrove in Soc Trang and Bac Lieu provinces.

Most of the interviewee of Soc Trang and Bac Lieu provinces (nearly 80%) considered that mangrove forest plays an important role in their life (Figure 3.6). Around half (47%) of the interviewee of Soc Trang and Bac Lieu provinces obtained their income from mangroves. 41% of households obtained almost all their income mangroves forests (Q3.8 and Q3.9 in Appendix A). Only 3% of interviewees in two provinces considered mangroves unimportant as sources for their benefits (Figure 3.6 and Figure 3.7).

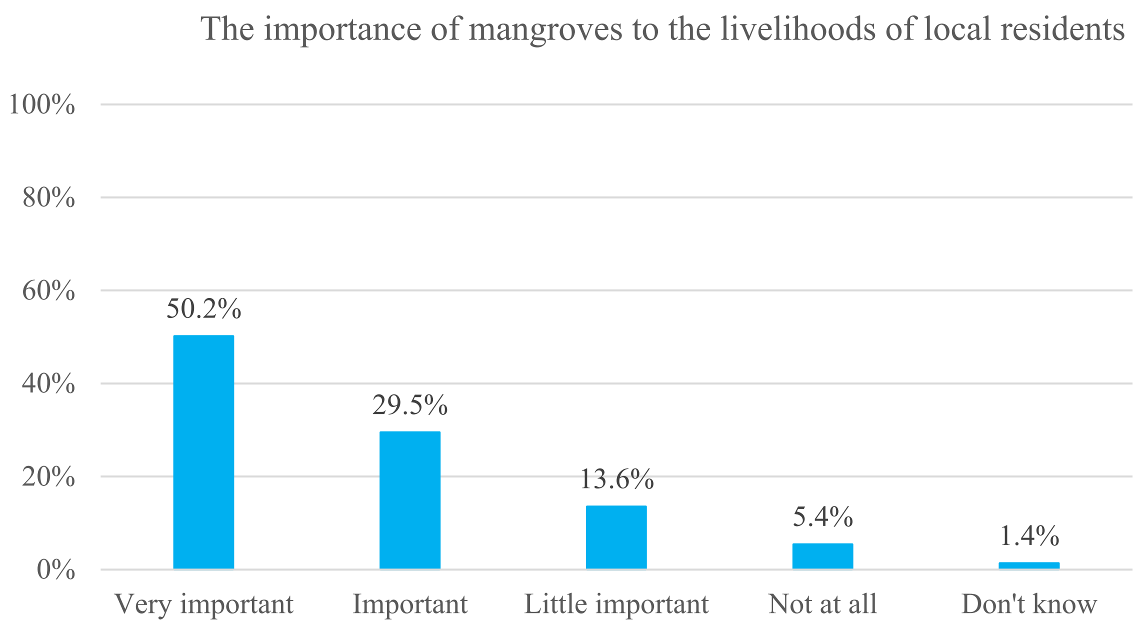

Figure 3.6 Community responses regarding importance of mangroves.

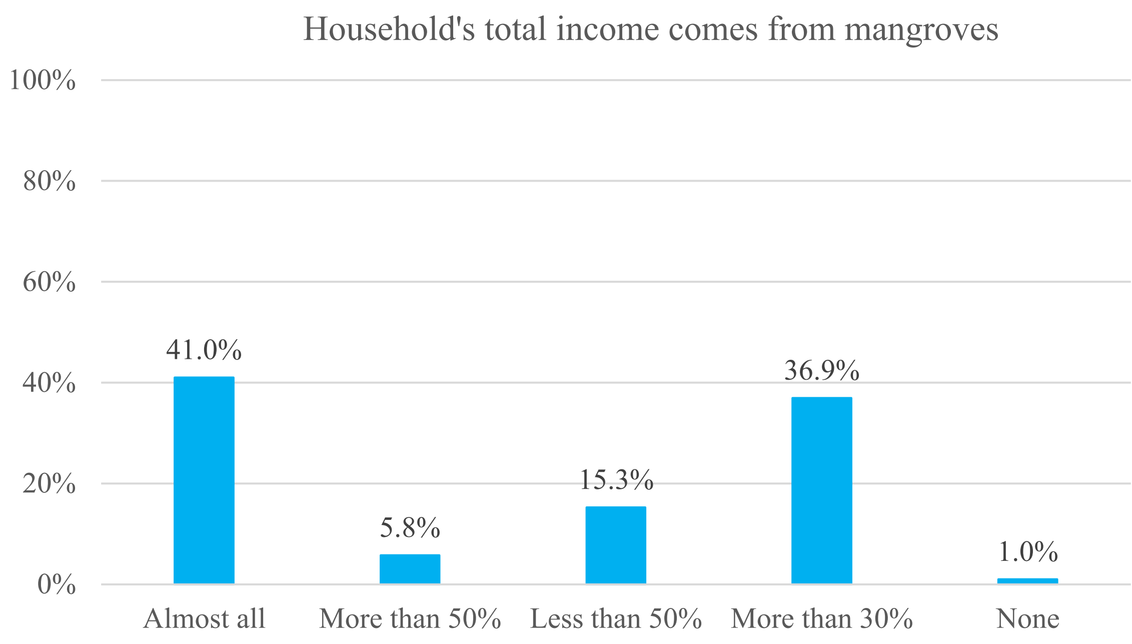

Figure 3.7 Community responses regarding mangrove utilization in households

The land use structure also indicates that farmers in the study area diversified their income and livelihood activities based on allocated mangrove land areas. As a result, the surveys revealed that the major products collected by the households in study area were various fishery and timber products. The total direct value was then calculated based on the local market price and the extension of production. Besides, households with possessing forest protection contract combined with aquaculture activities were also considered under PS. Noticeably, this is a special arrangement by the local governments, where shrimp farmers need to sign a contract with Departments of the local forest management. By doing this, shrimp farms can only be operated in conjugation with mangrove forests. Generally, this kind of shrimp-mangrove combined farming was applied with the aim at maintaining steady mangrove forests, while using these forests' services for the shrimp farms' nutrient retention.

3.3.3 Economic values of provisioning services (PS) of mangroves

The interviews with the local households revealed that the PS of the mangroves in the southeastern part of the VMD included mainly shrimp cultivation (86.8%), timber collection (1.2%), and fishing (11.9%) (Figure 3.8).

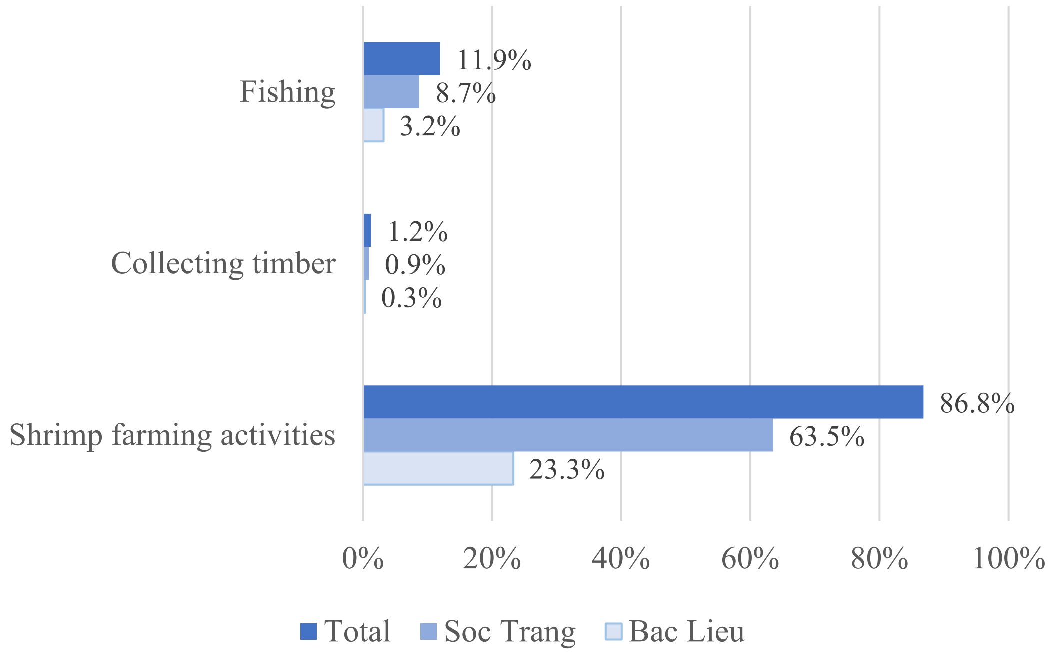

Figure 3.8 Main utilization of the mangrove ecosystem in Soc Trang and Bac Lieu provinces.

Furthermore, minor forest products such as honey, wax, and medicinal plants were harvested but mainly for domestic consumption. The estimated average annual revenues for all types of PS were approximately 37 million USD per year in FY 2018 (Figure 3.9). Among all the products, the revenue was the highest for mangrove-based shrimp farms (32 million USD), followed by fishing (4.4 million USD) and timber (0.5 million USD). Three-fourths of the interviewed households had shrimp farming combined with mangroves. The average annual net income of households from shrimp farms, fishing and timber were 2,030, 279 and 29 USD per ha, respectively. Based on these average revenues and total mangrove areas under management, the PS of mangroves were calculated from 2008 to 2017.

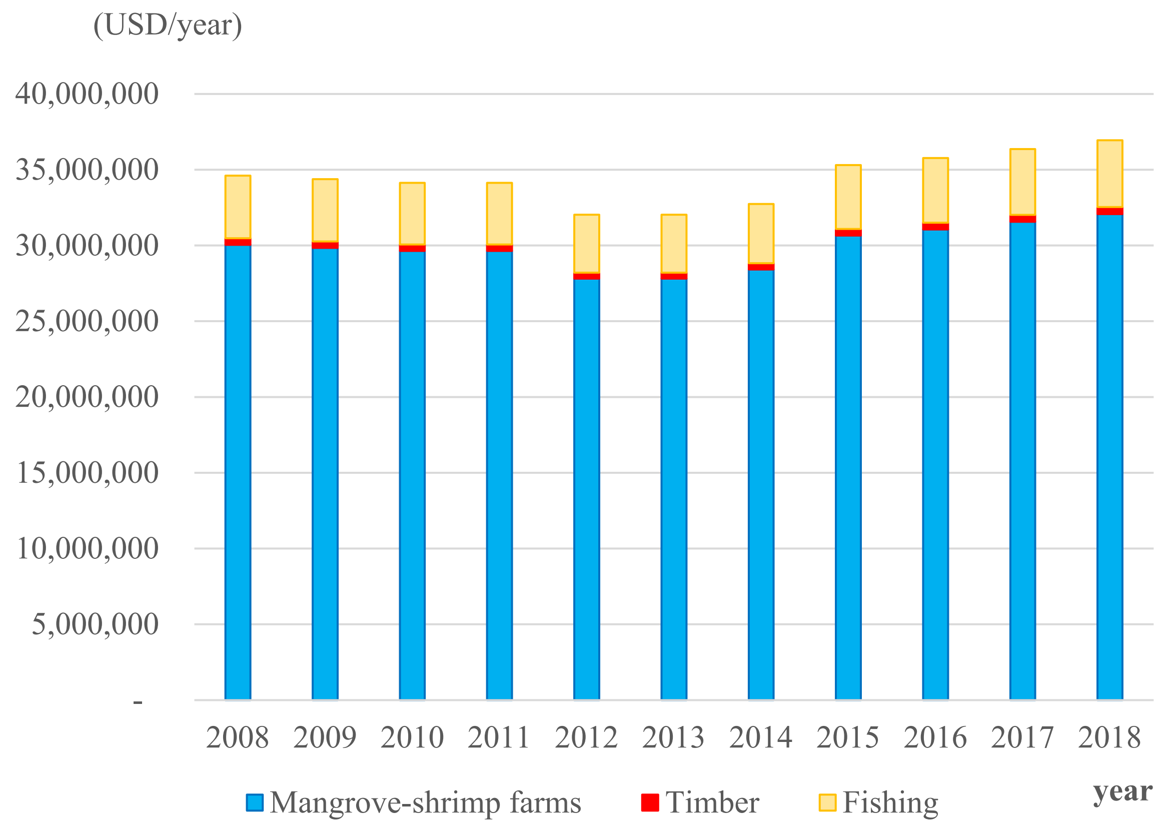

Figure 3.9 Average annual revenue (USD) of PS from mangroves of Soc Trang and Bac Lieu provinces.

Coastal fishing was the second largest exploited product in the southeastern part of the VMD. The most popular harvests were fish, shrimp, crabs and snails from the coastal water. The economic value of average daily fish catch in the mangrove forests ranged from 5 to 10 USD. Base on the results of social survey (Q4.1.10 in Appendix A), most of the fishermen, who have caught fish in the mangrove forest said that fishing is frequently conducted during the rainy season because of the increasing abundance of fish. In the dry season, the number of fishing times is less but they have to extend the time by 30% or more for each catch time compared to the rainy season.

In addition, a total of 3,833.3 m^3 timber was harvested in 2018 with average annual revenue of 0.5 million USD. The quality of timber depends on the age of mangroves and species (*Rhizopora* spp, *Sonneratia* spp and *Avicennia* spp). The average market price of mixed timber is 14 USD/m^3. The value of timber collection was calculated by the total annual number of mangroves pruned under the management of the Forest Protection Department. Besides, timber was collected along the dyke (forest border) and inside the forest.

3.3.4 Economic value of regulating services (RS) of mangroves

The RS of the mangroves in the southeastern part of the VMD mainly is value of coastal protection (Figure 3.5). The results of household surveys show that most (95%) of the respondents considered that mangroves were important for coastal protection (Figure 3.5). There are three types of coastal protection measure in VMD such as hard structure (sea dyke), soft structure (bamboo fence), natural (mangrove plantation) (Figure 3.10). Assuming that the life time is 20 years for hard structure and only two years for soft structure. (DARD 2017), Based on the results of socio-survey, bamboo fences were totally damaged after each two years, so local managers have to rebuild this dyke.

Figure 3.10 Coastal protection strategies deployed in the southeastern part of the VMD.

According to the monitoring data of the Irrigation Department from 1995 to 2017 (DARD 2017), the coast consists of four areas (① through ③ in Soc Trang province and ④ in Bac Lieu province; Figure 3.11). At ① (Cu Lao Dung district), the coast was accreted on average from 60 to 100 m per year. Similarly, at ② (Long Phu district), the coast was accreted a little less, on average from 10 to 45 m per year. At ③ (Vinh Chau district), erosion occurred regularly with the annual average of 10 through 15 m. In ④, the erosion was relatively serious, with the annual average of 17 m.

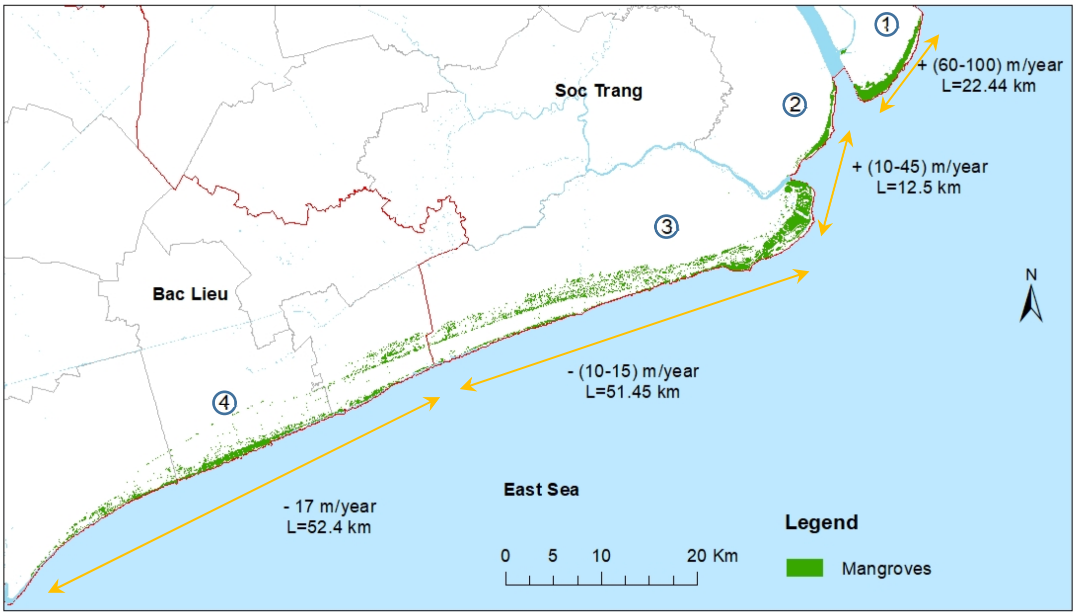

Figure 3.11. Location of erosion and accretion in the southeastern part of the VMD:

① L = 22.44 km, accretion zone; ② L= 12.5 km, accretion zone

③ L= 51.45 km, erosion zone; ④ L=52.4 km erosion zone

For each accretion and erosion site, the local government has invested in the following types of structures (Table 3.11). At the coasts have strong erosion, hard structure was invested to prevent from waves. In addition, soft structure (bamboo, melaleuca fences) were built in areas with less erosion. In mudflats area, mangroves were planted outside the sea dyke with average cost of 1,304 USD per hectare. The mangroves were planted with density from 5000 to 1000 seedlings and height from 0.8 to 1 m. The cost of caring for each hectare was 200,000 VND during the first three years. (DARD 2017).

Table 3.2 Investment value of each type of sea dyke.

Type of dykes	Total coasline (km)	Hard structure		Soft structure		Mangrove rehabilitation	
		Investment value (USD)	km	Investment value (USD)	km	Investment value (USD)	ha
Bac Lieu	56	2,173,913 (per km)	15	32,609	19	1,304 (per hectare)	1,144
				86,957 (per km)	22		
Soc Trang	72	6,521,130	18.1			1,304 (per hectare)	271.5
		8,332,870	22.4				
		23,043,478	33.35			2,608,696	600

The average value of constructing breakwater to prevent such erosion was calculated around 1,600 thousand USD per kilometer for hard structure, 11.92 thousand USD per kilometer for soft structure, and 10.22 thousand USD per kilometer for mangrove restoration, respectively. Based on Sathirathai and Barbier (2001), the equivalent cost of protecting shoreline with 75 m width stand of mangroves was estimated to be approximately 213.3 thousand USD per ha of hard structure, 1.6 thousand USD per ha of soft structure, and 1.4 thousand USD per ha of mangrove restoration (Table 3.3).

Table 3.3 Value of coastline protection.

Type of coastal protection	Hard structure	Soft structure	Mangrove plantation
Indirect use value (USD/km)	1,600,010	11,920	10,220
Indirect use value (USD/ha)	213,334	1,589	1,363

Table 3.4 estimated the RS value of mangroves forests in Soc Trang and Bac Lieu provinces. The total value of the sea dyke system was calculated for RS value. At locations without sea dykes, the coastal protection value was converted to value of mangrove forests (1,304 USD per hectare) for coastal protection. Total the RS value is 3,370.74 USD per hectare. The present values of RS were estimated to be 1,270.4 USD, 501.04 USD, and 205.95 USD with a discount rate of 5%, 10% and 15%, respectively (Table 3.4).

Table 3.4 Present value of RS.

Value of RS	Value (1000 USD/ha)
Indirect use value:	
Coastline protection	3,370.74
Indirect use values:	
(5% discount rate)	1,270.40
(10% discount rate)	501.04
(15% discount rate)	205.95

A summary of the estimates of the total economic value of mangrove ecosystem services in Soc Trang and Bac Lieu provinces is shown in Table 3.**5.** The total area of mangroves in 2018 was calculated to be 12,796 (Huynh et al. 2019). The total economic value of four selected ecosystem services provided by mangrove forests in this area was estimated to be approximately 80.07 million USD for 2018, or approximately 5,708 USD/ha/year. The value of mangrove timber, fishing, and mangroves-shrimp farms in 2018 was estimated to be 371, 3,571 and 25,976 thousand USD/year, respectively. The value of erosion control contributed to the area, at more than 3,370 USD/ha/year, accounted for 59% of the total value of ecosystem service.

Table 3.5 A summary of the estimates of the total economic value of mangrove ecosystem service (as of in 2018)

Ecosystem service	Based on (ha)	Mean value (USD/ha/year)	Value (USD/year)
Mangroves-shrimp farms	12,796	2,030	25,976,000
Fishing		279	3,571,000
Timber		29	371,000
Erosion control		3,370	43,132,000
Total value of Soc Trang	9,363		53,444,000
Total value of Bac Lieu	3,433		19,596,000
Mean value (USD/ha/year)			5,708

3.4 Discussions

The study estimated the PS and the RS of mangroves in the southeastern part of the VMD. Revenues generated from the marketable PS and non-marketable RS was considered for economic valuation. Since the mangroves are managed under the coastal protection program, mangrove forests were planted in coastal line to function as a natural barrier. Model of co-management of mangroves by local people through a contract. Local people can use up to 40% of total mangrove area for aquaculture (mainly shrimp farming) (Decision 186/2006/QD-TTg) This model would help develop people's livelihood and prevent the mangroves from further deforestation. While unplanned aquaculture development is among the leading cause of mangrove deforestation in Asia (Dasgupta and Shaw 2013), the Department of Forestry allows people to use up to 40% of the mangroves area to combine aquaculture farming (mainly shrimp farms) through forest co-management contracts. It essentially maintains sustainable production from mangroves.

Contracted and allocated local households were prioritized in protection forest. They may cut not more than 20% of the area during any one period; the harvested cannot occur until the replanted area is at least 3 years old (Decision 178/2001/QD-TTg). Decision 119/ 2016/ ND-CP policy on Coastal forest management, protection, rehabilitation and development in response to climate change was approved by Prime Minister in 23 August 2016. According to the statistics of the Forestry Department, the total area of planted mangroves in Soc Trang and Bac Lieu provinces is shown in the Figure 3.12

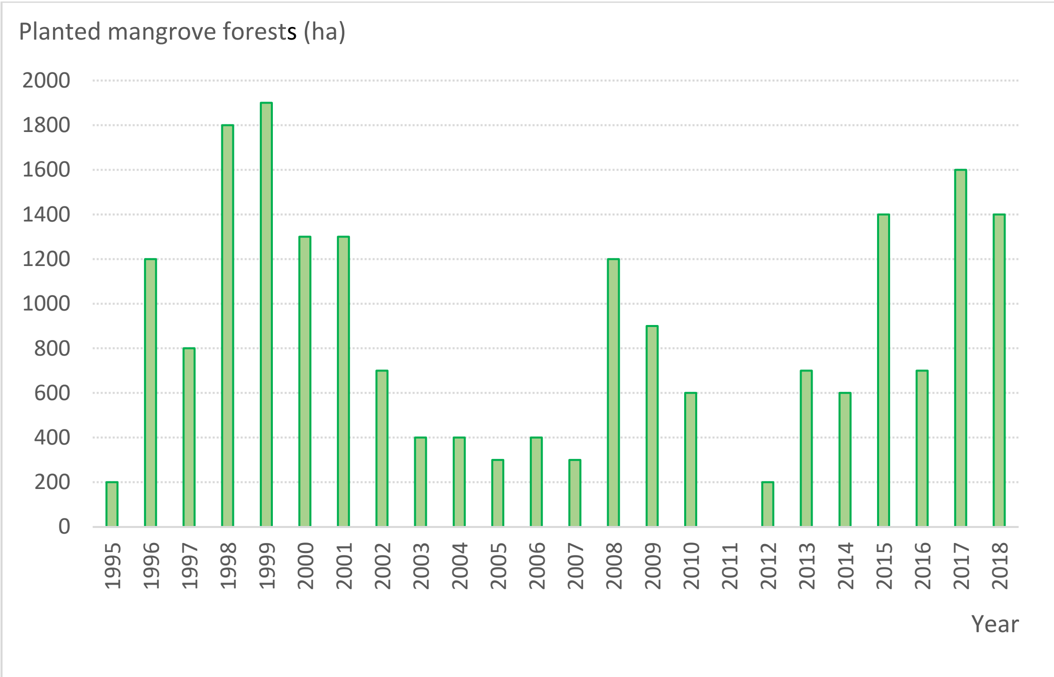

Figure 3.12 Area of planted mangrove forests (ha) in Bac Lieu and Soc Trang provinces (drawn based on the data of statistics of the Fisheries Association).

The value of aquaculture combined with mangroves accounts for the majority of PS. The other PS values may be higher because this study also observed that most of the respondents avoided or refused to mention the uses of mangrove forests. Besides, timber collection was banned law inside the mangrove forest by a law (Decision 157/2013/NĐ-CP). Co-management, as a partnership agreement in which the local population gets the right to sustainably use natural resources like mangroves, fish and shellfish – along with the responsibility to sustainably manage and protect these resources – addresses the problem of the unsustainable use of resources and the destruction of mangrove forests.

The role of mangroves in protecting our coasts against natural hazards such as storms, coastal erosion has been widely promoted. In the next few decades, VMD will have a high risk of coastal flooding due to sea level rise caused by anthropogenic climate change (Le et al. 2007; Van et al. 2012; Blankespoor et al. 2014b) . Thus, mangrove restoration not only provides better economic benefits for the community, but also creates important environmental services leading to coastal disaster risk reduction. Mangrove restoration can bring many benefits to communities as a whole in terms of both use values and non-use values, which are even higher than the net present value of aquaculture development. Accordingly, mangrove restoration should be encouraged amongst different stakeholders (rangers and coast communities), particularly households engaging in aquaculture. Results from focus group discussions revealed that aquaculture ponds bordered by mangrove forests saves household costs as mangrove forests protect the ponds from waves and sea level rise, particularly during the storm season. Forest policies in Viet Nam are still strongly protection-oriented, and forest protection and development remain major targets for the forest sector. Organizations managing forests as state properties are called on to conserve the forest resources under their responsibility, because most of the forest areas under the state management are protection and special use forests. Livelihood improvement is recognized as a condition for the sustainable management of such forests, but only as a measure for forest protection. Organizations that own forests as private properties are also responsible for the forest that they have been given.

3.5. Conclusions

In this study, values of mangrove ecosystem services in Soc Trang and Bac Lieu provinces were evaluated, especially in terms of local use of mangroves resources. The PS and RS were estimated to be 36.94 million USD per year and 43.13 million USD per year, respectively. However, most of the RS were accounted for replacement costs for the coastal protection. Thus, the real values of mangrove ecosystem services are considered to be considerably higher than those estimated in this study. These values were combined value from household interview and value of LULC analysis (total mangrove area). The disadvantage of conventional PS and RS calculation methods is that the total amount of mangrove products used by the local community was not fully known. Through in-depth discussions with managers, local leaders and key users of the mangrove forest, the household interviews were conducted directly with the users of mangroves to improve the values in the calculation.

Based on 300 socio-economic household survey undertaking in Soc Trang and Bac Lieu provinces in 2017 and 2018, the results show that the educational level was relatively low and less than 11.5% of people had a high school education. Of the households interviewed, over 74% of people in Soc Trang and Bac Lieu provinces used mangrove forests for different purposes. Furthermore, the mainly benefit from mangroves were from mangroves-shrimp farm, fish catch. The communities of Soc Trang and Bac Lieu provinces see timber collection as minor benefit. Mangroves are not only vitally important to local people, who rely on them for their livelihoods, but also provide economically valuable ecosystem services to businesses, households, and society at large. Mangrove forests located in the Soc Trang are more valuable in terms of erosion control and storm protection compared to in Bac Lieu.

Chapter IV

General Discussion

Land use and land cover (LULC) was useful to map the total area and conditions of mangroves and the density in both Soc Trang and Bac Lieu provinces. This is a quantitative information that is useful for further management and evaluating the mangrove ecosystem services in this study area. The results show that total of mangroves area in 2018 (12,796 ha) was a little less than data estimated by the government (15,800 ha; GSOs 2018). This difference is considered to be partly caused because Landsat imagery had medium spatial resolution, so it was difficult to detect small and narrow mangrove areas. Besides, in Soc Trang, most of the mangroves are planted in the mudflats, and therefore, the uncertainties of estimating the area is also considered to be caused by high tide levels.

The household survey gave clear indication that total value of mangroves ecosystem services in 2018 was estimated to be 80.07 million USD. This value is significantly lower than that in the adjacent Ca Mau province (600 million USD estimated by Vo et al. 2013). The significant difference of total mangrove ecosystem services depends on the current mangrove area (e.g. 12,796 ha in the study area while 187,533 ha in Ca Mau). The difference in estimated value may be partly arisen because the mangrove forest belt in this study area was relatively short and was difficult by being assessed by Landsat imagery. The longest and shortest mangrove forest belt was just over 1,200m and less than 100m, respectively. The estimated total value of mangrove ecosystem services was estimated to be 5,708 USD/ha/year and was slightly higher than the range (from 239 to 4,185 USD/ha/year) reported by Brander et al. (2012) and 3,316 USD/ha/year reported by Tuan et al. (2013) Most of local people were aware of the importance of mangroves and they got profits directly from the mangrove areas they manage, especially from shrimp farming in the forest. Therefore, mangroves contributed to a significant increase in income for coastal communities through mangrove co-management.

The main source of provision services (PS) was values of mangrove-shrimp farms to the local communities (35.6%). Besides, mangroves were also the major source of fishing (4.9%), and provided local communities both timbers for construction and charcoal for cooking. Without mangrove forests, farmers had to buy these materials in the market (or use alternative fuels, such as gas or oil) to meet their daily needs. The main factor that causes damage to mangrove forests is the cutting down of mangrove vegetation and it is used as firewood and building materials by people who live around mangrove forests. The main source of regulating services (RS) was values of coastal protection (59%). The social survey results show that 94% of the respondents considered the main function of mangroves was coastal protection.

The mangrove forests in Soc Trang and Bac Lieu provinces have been damaged which may be caused by a lack of public knowledge about the functions and uses of mangrove forests. To enhance their motivation to save mangroves locally, providing incentives in a clear manner is presumably helpful. The incentives may include carbon pricing toward green carbon which is ensured by the roles of mangroves, such as the ability to absorb excessive anthropogenic CO_2 to mitigate global climate change.

Chapter V

General Conclusions

The aim of this research was to investigate a new approach combining remote sensing data and socio-economic analyses to quantify the economic value of mangrove ecosystems. Emphasis was placed on medium resolution imagery (Landsat) suitable for mapping and quantifying mangroves forest like those found in Soc Trang and Bac Lieu provinces, VMD. In summary, the important conclusions drawn from this study have been described as follows:

The results of analysis using multi-temporal Landsat satellite (Landsat) imagery data show that more than 90% of dense mangrove forests in Soc Trang and Bac Lieu provinces have decreased from 1988 to 2018 by 5,495 ha and 515 ha, respectively. The major factors leading to the considerable decrease of the area and quality of mangrove forests were found to be replaced with aquaculture farms and agricultural lands by cutting mangrove forests.

The economic values of mangroves were also estimated by referring to results of social survey carried out by this study. The provisioning and regulating services were estimated to be 36.94 million USD per year and 43.13 million USD per year, respectively. The total estimated value was over 80.07 million USD in 2018 (average value 5,705 USD/ha/year) in which total value of mangroves ecosystem in Soc Trang is significantly greater than in Bac Lieu. Results of the social survey also suggested that these benefits significantly contributed to the local communities in Soc Trang and Bac Lieu provinces. The results proved that most local people have basically understood the role and importance of mangrove forests as well as the situation and depleting trend of such resources in recent years. They recognized the value of local aquatic resources from mangrove forests, especially particularly land erosion due to mangrove forest loss. On the other hand, the economic values of mangrove forests could be objective metrics for consensus building among the local communities in addressing the important of mangrove ecosystems.

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Appendix

Appendix A. Questionnaires for household survey application in the southeast of Vietnamese Mekong Delta

Dear Sir/Madam,

My name is Huynh Thi Cam Hong. I am a Ph.D student of Graduate School of Environmental Science, Hokkaido University, Japan. I am doing a research about coastal protection in the Southeast of Mekong Delta, Vietnam. Could you please to give me about 120 minutes to fill in this questionnaire? All information in this questionnaire will be kept secret and it is for research purpose only.

Questionnaire code: .... Date of interview: ....

Village, commune: .... Interviewer: ....

Coordinates (UTM48N-WGS-84): X: .... Y: ....

1. General household information

1.1. Information of household head (HH) and interviewee (if not HH)

	Household head	**Interviewee**
Name		
Phone/cell phone number		
Religion		
Status of marriage		

Province of origin		
Year of settlement		

1.2. Details of household:

No	Family member name	Relation to HH	Age	Gender	Ethnicity	Education[1]	Health condition[2]	Main occupation[3]	Income (million VND/month)
1	HH								
2	Interviewee								
3									
4									
5									
6									
7									
8									
9									
10									

[1]*Education: 1=No formal education; 2= Primary; 3=Secondary; 4=Diploma/Vocational certificate; 5= Bachelor's degree; 6= Higher bachelor's degree; 7=other …………………………*

[2]*Health condition: 1= very good, 2=good, 3=fair, 4=bad, 5=very bad*

[3]*Main occupation: 1= crop cultivation; 2= livestock raising; 3= aquaculture (shrimp, shellfish, fish, etc.); 4=trading; 5=government employee/state enterprise employee; 6=farm labour; 7=housework; 8=unemployed; 7=other………………………………*

1.3. What type of structure does your household live in?

☐ 1- Permanent house

☐ 2- Semi-permanent house

☐ 3- Temporary house (thatched, tent)

☐ 4- Others: ……………….

2. Land and farm:

2.1 Do you (or does your household) "own" land?

☐ 1 - Yes ☐ 2 - No

2. 2 If yes, for what do you use your land? (Multiple options)

No.	Land using	Area (hectare)	Other info.
1	House		
2	Aquaculture (shrimp, shellfish, fish etc.)		
3	Crop cultivation		
4	Livestock raising		
5	Mangrove planting		
6	Fallowing		

7	Others: ………………………		

2.3 Revenues and costs from land using

No.	Land using	Revenues (million VNĐ/year)	Costs (million VNĐ/year)
1	Aquaculture (shrimp, shellfish, fish etc.)		
2	Crop cultivation		
3	Livestock raising		
4	Mangrove planting		
5	Others: ……………………………		
Total			

3. Resources Mangrove and Activities

3.1 What do you understand by the term mangrove? (definition)

....

....

....

....

....

3.2 Which mangrove species do you know in your land?

☐ 1. Mắm trắng (Avicennia alba); ☐ 5. Mắm đen (Avicennia officinalis);

☐ 2. Mắm biển (Avicennia marina); ☐ 6. Mắm quăn (Avicennia lanata);

☐ 3. Đước đôi (Rhizophora apiculata); ☐ 7. Đưng (Rhizophora mucronata)

☐ 4. Dừa nước (Nipa fruticans); ☐ 8. Chà là (Pheonix paludosa)

☐ 9. Others: (Local name) ....

3.3 Do the mangroves have a particular function?

☐ 1. Wind break; ☐ 4. Barrier;

☐ 2. Wave break; ☐ 5. Storm protection

☐ 3. Water break; ☐ 6. Others: ....

3.4 Have you been taught about function of mangrove by your parents/teachers?

☐ 1. Yes ☐ 2. No

3.5 Do the mangroves have an economic value?

☐ 1. Yes ☐ 2. No

3.6 How important are the mangroves for your livelihood?

☐ 1. Very important; ☐ 3. Little important; ☐ 5. Don't know

☐ 2. Important; ☐ 4. Not at all;

3.7 Do you think that cutting down the mangroves will reduce your income?

☐ 1. Yes ☐ 2. No

3.8 Is mangrove related products a major part of your income?

☐ 1. Yes ☐ 2. No

3.9 How much percent of your household income is related to mangrove?

☐ 1. Almost all ☐ 2. More than 50% ☐ 3. Less than 50%

☐ 4. Less than 30% ☐ 5. Non

3.10 How much you think would be one hectare of land full of mangrove?

………………………………………………………………………………………(VND)

3.11 Are mangrove worth to be protected ?

☐ 1. Yes ☐ 2. No ☐ 3. No idea

3.12 It will be better in my area if more mangroves are cut down and we have more space for aquacultures

☐ 1. Agree ☐ 2. Disagree

3.13 I will be better in my area if more mangroves will be planted

☐ 1. Agree ☐ 2. Disagree

3.14 You know that mangroves have a protection value, but you cannot make money with them

☐ 1. Agree ☐ 2. Disagree

3.15 Do you have observed that decrease in mangroves led to more coastal erosion?

☐ 1. Yes ☐ 2. No

3.16 Fish variety in mangrove areas is larger than in areas without mangroves

☐ 1. Agree ☐ 2. Disagree

3.17 Mangroves hinder my smooth moving (by boat)

☐ 1. Agree ☐ 2. Disagree

3.18 You actually do not care about mangroves

☐ 1. Agree ☐ 2. Disagree

3.19 If all mangroves in the Mekong Delta disappear, it will not have a big effect

☐ 1. Agree ☐ 2. Disagree

3.20 If there are no mangroves, maybe there will be a bit more shore erosion, but you do not mind

☐ 1. Agree ☐ 2. Disagree

3.21 You would love to have more mangroves in and around of your village

☐ 1. Agree ☐ 2. Disagree

3.22 Tourism plays a role in your region

☐ 1. Agree ☐ 2. Disagree

4. Utilization of mangrove

4.1 General **uses of mangrove**

4.1.1 Do you use mangroves for any purpose?

☐ 1. Yes ☐ 2. No

4.1.2 Do mangroves play a role in your life?

☐ 1. Not at all ☐ 2. Sometimes ☐ 3. Very much

4.1.3 What are the positive aspects of mangroves

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

4.1.4 What are the negative aspects of mangroves

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

4.1.5 How many hectares of mangrove forests do your family have?

☐ 1. Natural mangrove forest: .... ha

☐ 2. Planted mangrove forest: .... ha

☐ 3. Caring/ Protecting mangrove forest: .... ha

4.1.6 When was the mangrove planted? ………………………… (year)

4.1.7 What are your main uses of mangroves?

☐ 1. Fuel (firewood, charcoal)

☐ 2. Construction (house, fence, furniture, utensils)

☐ 3. Medicinal

☐ 4. Chemical (dyes, poisons)

☐ 5. Food (honey, alcohol, animal feed)

☐ 6. Fishing

☐ 7. Recreation purposes (resting, tourism)

☐ 8. Others………………………………………………………………………

……………………………………………………………………………………

4.1.8 How far do you travel to collect the above? ……………km

4.1.9 In the last 12 months, what benefits has your family gained from the mangrove forest?

	Code for product distribution:	Income (VNĐ)/last year
☐ 1. No benefits	-	-
☐ 2. Fuel (firewood, charcoal)		
☐ 3. Construction (house, fence, furniture, utensils)		
☐ 4. Medicinal		
☐ 5. Chemical (dyes, poisons)		
☐ 6. Food (honey, alcohol, animal feed)		
☐ 7. Fishing		
☐ 8. Recreation purposes (resting, tourism)		

☐ 9. Other benefits: ………………………………………………………….. ………………………………………………………….. …………………………………………………………..	………… ………… …………	………… ………… …………

Code for product distribution:

1 - Personal and family consumption

2 – Sold in

3 - Sold commercially (outside of the local market)

4 – Others: ……………………

4.1.10 In the last 12 months, is there any difference in **income** between the dry season (from October to April) and rainy season (from May to September)?

☐ 1 - Yes ☐ 2 - No

If yes, give your opinions (priority arrangement):

1. …………………………………………………………………………
   …………………………………………………………………………
2. …………………………………………………………………………
   …………………………………………………………………………
3. …………………………………………………………………………
   …………………………………………………………………………

4.2 Uses of mangrove combined with aquaculture

4.2.1 Do you combined mangrove with aquaculture?

☐ 1. Yes ☐ 2. No

4.2.2 How is the ratio of mangrove and aquaculture?

☐ 1. 80% mangrove, 20% aquaculture

☐ 2. 50% mangrove, 50% aquaculture

☐ 3. 30% mangrove, 70% aquaculture

☐ 4. 100% aquaculture

☐ 5. 100% mangrove

☐ 6. Other ratio…………………………….

4.2.3 How is your income base on your total area?

☐ 1.………………m² for aquaculture

☐ 2.………………m² for mangrove

4.2.4 Income from aquaculture productions/year

Species(*)	Quantity (kg)	Location (**)	How long (moth)	For what purpose (***)	Market prices (VND/kg)

Note: (*): 1- Fish; 2- Shrimp; 3- Crab; 4- Others……………

(**): 1- Inside your land; 2- Outside;

(***): 1- Personal and family consumption; 2- Sold; 3- Others …………..

4.2.5 Has the fishing pattern (species and quantity) changed over time?

☐ 1. Increase ☐ 2. Decrease ☐ 3. No change

4.2.6 Do you think this change is related to a change of mangrove?

☐ 1. No; ☐ 2. Yes,

How? ....
....

5. Resources fisheries and activities

5.1 How long have you been fishing?

☐ 1. < 1 year ☐ 4. 5-10 years

☐ 2. 1-3 years ☐ 5. >10 years

☐ 3. 3-5 years

5.2. Do you fish individually or with a group of fishermen? (If in a group, how many people are in a group?)

☐ 1. Individually

☐ 2. In a group; member in group…………people

5.3. Are the fishermen fishing with your family members?

☐ 1. Yes ☐ 2. No

5.4. What kind of boat do you use?

☐ 1. Fiberglass ☐ 2. Wooden ☐ 3. Other: ……………

5.5. Beside the types of transportation, what are the type of primary equipment which you use to catch fish?

Type	Total kg fish/month (kg) in last year		Estimate income (VNĐ)	
	Lowest/month	Highest/month	Last year	Average 3 recent years
☐ 1. Hook and line	……..kg/….....	……..kg/….....	…………….	…………… ………….
☐ 2. Gill net				
☐ 3. Trap				
☐ 4. Trawl				
☐ 5. Other:………				

5.6. In the last 12 months, in what areas (location) have you been fishing?

☐ 1. Offshore

☐ 2. Shore/coastal (no mangrove areas)

☐ 3. Mangrove forests

☐ 4. Others: ……………………………………………

6. Impact of coastal erosion/flooding

6.1. What do you think which problem is the most serious for environments in your community?

☐ 1. Coastal erosion

☐ 2. Flooding

☐ 3. Salinization

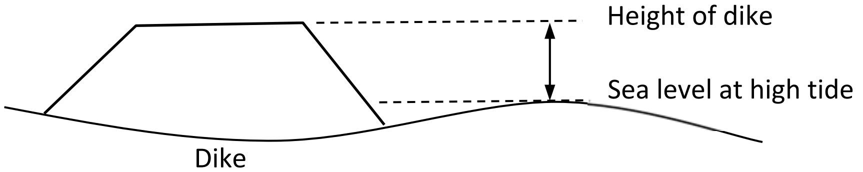
☐ 3. Water pollution

☐ 4. Solid wastes

☐ 5. Others: ....

6.2. How many meters of difference in height between your farm dike and sea level at the high tide is the threshold level that you have decided to cope with coastal erosion/flooding?

.....................meters.



6.3 What are the positive aspects of dike?

………………………………………………………………………………………

………………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

6.4 What are the negative aspects of dike?

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

7. Overall assessment:

7.1 In your opinion, how the following aspects have changed in your locality in the last 5 years?

No.		☐1. Better	☐ 2. Similar	☐3. Worse	☐ 4. No idea
1	Infrastructures (electricity, road, school, clinic, water supply and sewage, communication)				
2	Transportation services				
3	Agricultural extension (agricultural advisory services)				
4	Employment opportunity				
5	Ability to access to credit (preferential loans)				
6	Income and living conditions				
7	Irrigation and drainage system (canals)				
8	Natural benefits (fish, shrimp etc.)				

9	Sanitation and environment				
10	Other: …………………………………				

7.2. What areas do you want the government to invest in the coming years? (*Select 3 options in priority order, 1 is the first priority*)

No.	Area	Priority
1	Roads	
2	Irrigation and drainage system	
3	Electric supply	
4	Bridges	
5	Domestic water supply	
6	Sewage	
7	School	
8	Kindergarten, pre-school	
9	Clinic, healthcare centre	
10	Agricultural extension	
11	Recreation and entertainment	
12	Other (specify): ………………………….	

7.3. Social activities:

Which association do you or any member of your family member participate in?

No.	Order member in list of HHs	Association participated	Benefits gained from participating in such association?			
			Association 1	Association 2	Association 3	Association 4
1						
2						
3						
4						
5						

Code of association:

1. Women's union
2. Youth's union
3. Veteran's association
4. Farmers' association
5. Aged people's association
6. Horticulture's association
7. Religious group
8. Communist party
9. Other association (specify)
10. No participation in any association or union

Code of benefits gained:

1. Advice, spiritual and emotional benefits
2. Material, financial supports
3. Social intercourse
4. Obtaining credit
5. Learn to earn money

8. Process of coastal protection (CP) by mangrove forests and sea dikes

8.1 When did you hear about CP by mangrove forests for the first time (d/m/y)? …………………………………………………………………………………………..

8.2 From which sources (choose the most appropriate)?

☐ 1. Village leader ☐ 4. Provincial leader

☐ 2. Commune leader ☐ 5. Mass media

☐ 3. District leader ☐ 6. Friends

☐ 7. Others: …………………..…………

8.3 Did you have sufficient information about CP by mangrove forests, sea dikes or both?

CP by	Very positive	Positive	Neutral	Negative	Very negative
Mangrove forests (1)					
Sea dikes (2)					
Both (1+2)					
Others: …………..					

8.4 Change in water quality, ecosystem (biodiversity), and livelihood

	Current (2018)	**2018-2008**	**Before 2008**
Water quality ([1])	☐1. ☐2. ☐3. ☐4. ☐5.	☐1. ☐2. ☐3. ☐4. ☐5.	☐1. ☐2. ☐3. ☐4. ☐5.
Ecosystem ([2])	☐1. ☐2. ☐3	☐1. ☐2. ☐3	☐1. ☐2. ☐3
Livelihood ([3])	………………… ………………….	…………………… …………………….	………………… ………………….

	………………… ………………….	…………………… ……………………	………………… ………………….

(1) ☐ 1. Very good, ☐ 2. Good, ☐ 3. Medium,

☐ 4. Bad, ☐ 5. very bad

(2) ☐ 1. Increase ☐ 2. Decrease ☐ 3. No change

(3) Main occupation?

8.5 Change in flood, salinization, erosion/subsidence, and accretion/sedimentation

	Current (2018)	2018-2008	Before 2008
Salinization	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..…………….. (month/year) (3) …………..…… (VNĐ) (4) ……………….. (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..…………….. (month/year) (3) …………..…… (VNĐ) (4) ……………….. (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..…………….. (month/year) (3) …………..…… (VNĐ) (4) ……………….. (VNĐ)
Flood	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..……………. (month/year) (3) …………..…… (VNĐ) (4) ………..…… (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..……………. (month/year) (3) …………..…… (VNĐ) (4) ………..……… (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..……………. (month/year) (3) …………..…… (VNĐ) (4) ………..……… (VNĐ)

Erosion/ subsidence	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..……………. (month/year) (3) …………..…… (VNĐ) (4) ………..……… (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..………..…… (month/year) (3) ………….. (VNĐ) (4) ……………….. (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..………..…… (month/year) (3) …………..… (VNĐ) (4) ……………. (VNĐ)
Accretion/ sedimentation	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..……………. (month/year) (3) …………..…… (VNĐ) (4) ………..……… (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..……………. (month/year) (3) …………..…… (VNĐ) (4) ………..……… (VNĐ)	(1)☐1. ☐2. ☐3. ☐4. ☐5. ☐6. (2) ..……………. (month/year) (3) …………..…… (VNĐ) (4) ………..……… (VNĐ)

(1) ☐1. None, ☐2.Very low, ☐3. Low,

☐4. Medium, ☐5. High, ☐6. Very high

(2) When?

(3) How much damages?

(4) Any help from local authorities?

9. Recommendations

Please list down your recommendations for the use of mangroves and dikes in coastal protection (adaptation and reducing costs)

No	Mangrove forests	Dikes
1		
2		
3		

For interviewer: Please write down the most important notes, raising issues from this household

Thank you for your kind collaboration!