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Application of remote sensing and GIS for detection of long-term mangrove shoreline changes in Ca Mau, Vietnam

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Abstract

Ca Mau at the southern tip of Vietnam supports a large area of mangroves and has a high value for biodiversity and scenic beauty. This area is affected by erosion along the East Sea and accretion along the Gulf of Thailand, leading to the loss of huge stretches of mangroves along the East Sea and, in some cases, loss of ecosystems services provided by mangroves. In this study, we used remotely sensed aerial (1953), Landsat (1979, 1988, and 2000) and SPOT (1992, 1995, 2004, 2008 and 2009, and 2011) images and the Digital Shoreline Analysis System (DSAS) to quantify the rate of mangrove shoreline change for a 58 yr period. There were 1129 transects sampled at 100 m intervals along the mangrove shoreline and two statistical methods, namely End Point Rate (EPR) and Linear Regression Rate (LRR), were used to calculate the rate of change of mangrove shorelines and distance from 1953 to 2011. The study confirms erosion and accretion respectively are significant at the Eastern and Western Sea sides of the Ca Mau tip. The East Sea side had a mean erosion LRR of 33.24 m yr^{-1}. For the accretion trend at the Gulf of Thailand side averaged at rate of 40.65 m yr^{-1}. The results are important in predicting changes of coastal ecosystem boundaries and enable advanced planning for specific sections of coastline, to minimize or neutralize losses, to inform provincial rehabilitation efforts and reduce threats to coastal development and human safety.

1 Introduction

Mangrove ecosystems occur in the transitional zone between marine and terrestrial environments. Mangrove morphology and sedimentation are good indicators of interactions between relative sea level changes, coastal processes and sediment supply (Filho et al., 2006; Gilman et al., 2007; McIvor et al., 2013). As emphasized by Filho et al. (2006), a mangrove shoreline is one of the best geo-indicators in global coastal change research.

Remote sensing and geographical information system (GIS) techniques have been used widely to assess changes in coastal shorelines (Chen and Rau, 1998; Ghosh et al., 2001; Lin et al., 2001; Wal et al., 2002; Ali, 2003; Vanderstraete et al., 2006; Genz et al., 2007; Maiti and Bhattacharya, 2009; Sesli et al., 2009; Rebelo et al., 2009; Kuleli, 2010; Kuleli et al., 2011; and Hai-Hoa et al., 2013) and the boundaries of mangrove forests and other habitats over time (Woodroffe, 1995; Solomon et al., 1997; El-Raey et al., 1999; Wilton and Saintilan, 2000; Saintilan and Wilton, 2001; Cohen and Lara, 2003; Dahdouh-Guebas et al., 2004; Fromard et al., 2004; Filho et al., 2006; Gilman et al., 2007; Satyanarayana et al., 2011; and Nfotabong-Atheull et al., 2013). The Digital Shoreline Analysis System (DSAS) is an extension to ArcMap and introduced to automatically or manually generate measurements of transects and metadata based on user-specified parameters, calculating rates of shoreline changes and to provide other statistical information (Thieler et al., 2009). It utilizes the Avenue code to develop transects and rates, and the Avenue programming environment to automate and customize the user interface (Morton et al., 2004). The DSAS has been used widely to calculate the rate of shoreline changes (Table 1).

Natural and anthropogenic factors in the mangroves around the Ca Mau tip have caused erosion along the East Sea coast and accretion along the West Sea shoreline. These changes have led to the loss of huge stretches of mangroves along East Sea resulting in the decrease and, in some cases, loss of mangrove ecosystem services. These effects include loss of spawning grounds for aquatic organisms (mangrove snappers and mullet) and the loss of the wave buffering and sheltering effect of mangroves, threatening residential areas and infrastructure behind the mangrove (Ca Mau Biosphere Reserve, 2013). In addition, by the end of the 21st century, average sea level in the study area is projected to rise 59–75 cm and 62–82 cm along the East Sea and the Gulf of Thailand respectively (MONRE, 2012). However the change in the mangrove shoreline due to accretion and erosion at the Ca Mau tip has not been quantified but merely observed. Key weaknesses in previous attempts at government mangrove rehabilitation have been uniform application of homogeneous monoculture plantations with little consideration for maintenance needs or coastal dynamics, which dictate suitability of mangrove rehabilitation at any given site (Mangroves for the Future, 2012). It is, therefore, very important to detect quantitatively the changes of mangrove shoreline. This will be used effectively to predict the changes of coastal ecosystem boundaries and enable advanced planning for specific sections of coastline, to minimize or neutralize losses, to inform provincial rehabilitation efforts and reduce threats to coastal development and human safety (Dahdouh-Guebas, 2002; Gilman et al., 2007; Mangrove for the Future, 2012).

In this research, we quantify the rate of mangrove shoreline change around the Ca Mau tip with remotely sensed images of aerial photographs, Landsat and SPOT data for a 58 yr period and applying DSAS.

2 Materials and methods

2.1 Study area

The study area is located at the southernmost point of Ca Mau Province between latitude 8°32′ N–8°49′ N and longitude 104°40′ E–105°19′ E (Fig. 1). It covers entirely Ngoc Hien District and partly Nam Can District of Ca Mau Province. We chose this area due to it is a lowland deltaic plain (0–3 m above mean sea level) and strongly divided by a system of natural rivers and a dense network of canals (Hong and San, 1993). The water flow regime in the area is under the influence of both the East Sea and the Gulf of Thailand with the eastern flow the stronger. The whole area is characterized by a soft muddy soil and influenced semidiurnal tidal originating from the East Sea (tidal amplitude 2–3 m) and the diurnal tides from the Gulf of Thailand (tidal amplitude 0.5–0.8 m) (Hong and San, 1993). More importantly, Ca Mau supports the most substantial area of mangroves (Hong and San, 1993) and is a natural mangrove ecosystem with high conservation value for its biodiversity and scenic beauty (Ca Mau Biosphere Reserve, 2013). There are 27 true mangrove species in Ca Mau, with *Avicennia alba*

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Blume, *Avicennia marina* (Forssk.) Vierh., *Avicennia officinalis* L., *Rhizophora apiculata* Bl., *Bruguiera parviflora* Wight and Arnold ex Griffith, *Ceriops zippeliana* Blume and *Nypa fruticans* (Thunb.) Wurmb. amongst the major species (Hung and Tan, 1999 and Massó i Alemán et al., 2010). But natural and anthropogenic factors in the mangroves around the Ca Mau tip have caused erosion along the East Sea and accretion along the Gulf of Thailand.

Our study area extended from Bo De river mouth on the east coast to Bay Hap estuary on the west coast of Ca Mau around the tip. Based on coastal characteristics (erosion and accretion) and availability of remotely sensed data, this area was divided into eight zones for the purpose of the study (Fig. 1 and Table 2).

2.2 Data sources and geo-referencing

Aerial photographs from 1953 and remotely sensed image data of Landsat (1979, 1988, and 2000) and SPOT (1992, 1995, 2004, 2008 and 2009, and 2011) images were used to analyse the change rate of mangrove shorelines over 58 yr (specifications of remotely sensed data used in this study is given in Table 3). The Landsat images were freely downloaded from the US Geological Survey (USGS) at level 1T which has processed to standard terrain correction. Other images was purchased by the Laboratory of Plant Biology and Nature Management, Vrije Universiteit Brussel and the Institute of Meteorology, Hydrology and Environment. The SPOTs were procesed at level of orthorectified using ground control points and a digital elevation model. All these data were geo-referenced to the UTM WGS-1984 Zone 48N projection and coordinate system with further geometric correction using ENVI 4.7 software.

2.3 Mangrove shoreline digitization and detection

The mangrove forest edge was used as the shoreline indicator to derive historical rates of mangrove shoreline change in the study area. For the eroding east side, mangrove trees occur as far seaward as there is soil to remain stable, with no mud flats beyond them. For the prograding west side, the first occurrence of a closed mangrove canopy was used as a border. Long intertidal mudflats extend beyond the mangrove vegetation in these areas, but are not yet suitable for mangrove propagules to establish as the water depth over time is still too deep. Using the closed canopy mangrove forests as border of the land area is an acceptable solution to distinguish the mudflats from the land area, although single mangrove individuals and young plants colonizing the newest areas are excluded from the analysis. ArcGIS 9.3 was used to manually digitize mangrove shoreline position in 1953.

Normalized Difference Vegetation Index (NDVI) is one of the most successful and widely used ways to simply and quickly identify vegetated areas by detecting living green plant canopies in multispectral remote sensing data (Seto and Fragkias, 2007; Vo et al., 2013). In this study, NDVI was used to distinguish vegetated areas from other surface types, especially for the purpose of this study between water or land and mangrove. In order to improve the accuracy of mangrove shoreline detection, the clustering threshold technique of Otsu (1979) was used. This detects an optimum threshold by minimizing weighted sum of within-class variances of the foreground and background pixels and gives satisfactory results when the numbers of pixels in each class are close to each other. The Otsu method remains one of the most cited thresholding methods (Sezgin and Sankur, 2004; Kuleli, 2010; Kuleli et al., 2011). The border pixels between segmented vegetation/water or land regions can be delineated as mangrove shorelines. These are delineated using binarized images produced from a thresholding based segmentation algorithm. As a result, images were divided into two major segments, mangrove and water or land. After this process, the boundaries of the classified regions were vectorized by using the raster to vector conversion application of ENVI 4.7. Next, the conversion accuracy was evaluated by overlaying the extracted mangrove shorelines with the original Landsat and SPOT images.

2.4 Mangrove shoreline rate calculation

Calculating mangrove shoreline movement and changes were formalized into DSAS version 4.2, an extension to ArcMap developed by the USGS. DSAS computes rate-of-change statistics from multiple historic shoreline positions residing in a GIS (Thieler et al., 2009). DSAS generates transects that are cast perpendicular to the baseline at a user-specified spacing alongshore. The intersections of transects and the mangrove shorelines along this baseline are then used to calculate the rate-of-change statistics. In this study, a total of 1129 transects were regularly placed at a spacing of 100 m by applying DSAS software. To assess the spatial and temporal movement trend of mangrove shoreline positions, a hypothetical baseline was constructed offshore and parallel to the general orientation of the mangrove shoreline. The generated transects together with the extracted mangrove shorelines are graphically shown in Figs. 2–5.

In order to calculate erosion/accretion rates, many statistical methods have been applied, such as end point rate (EPR), average of rates (AOR), minimum description length (MDL), jackknifing (JK), linear regression rate (LRR), reweighted least squares (RLS), weighted least squares (WLS), reweighted weighted least squares (RWLS), least absolute deviation (LAD), and weighted least absolute deviation (WLAD) (Dolan et al., 1991; Thieler et al., 1995; Crowell et al., 1997; Coyne et al., 1999; Honeycutt et al., 2001; Genz et al., 2007; Kuleli, 2010; Kuleli et al., 2011; Sheik and Chandrasekar, 2011). The two most frequently cited methods are EPR and LRR. In this study, two comparative statistical methods of EPR and LRR were used to calculate the change in rates of mangrove shorelines in Ca Mau tip. The EPR is simply the rate determined by the changes in position between the oldest and most recent shorelines in a given dataset. As it only considers the earliest and the latest shoreline position, it was suitable for the short term mangrove shoreline change analysis of zone 6 (Con Moi) with only two mangrove shorelines of 2009 and 2011 available. The LRR is the result of estimating the average rate of change using a number of shoreline positions over time, with the change statistic of fitting a least-squared regression line to all shoreline points for each transect. The linear regression rate is the slope of the line. Therefore, LRR was used to analyze the long term mangrove shoreline change (from 1953 to 2011) of the other study zones. In this study, data uncertainty was ±5 m and confidence interval was 90 % determined as a weighted linear rate parameter.

2.5 Ground truth and social survey

Field ground truth was carried out in 2006, 2007, 2010 and 2011. A total of 150 GPS points collected in the field with attribute information on location of the seaward edge of the mangroves and households in and around the mangroves area. These points were imported to ArcGIS 9.3 for analysis.

Social surveys in households close to the mangrove area were conducted using interviews. The target group was the population with experiences of the region. In 1980s, there was unauthorized influx of people from other provinces migrated to Ngoc Hien District (Hong and San, 1993). Therefore, the people with ages ranging from 45 to 65 yr old were chosen for the interviews. The major objectives regarding changes they had observed in the mangrove area over time. Collected information is used in the discussions.

3 Results

Table 4 summarizes rates of mangrove shoreline change as averages of the erosion or accretion values on the transects in each zone, along with maximum and minimum values. Positive EPR and LRR values represent mangrove shoreline movement towards the sea (accretion rate) and negative values indicate movement inland (erosion rate). Mangrove shoreline changes emphasize erosion along the East Sea and accretion along the Gulf of Thailand, as observed previously. It is also clear that the islands in the Cua Lon estuary are recently formed.

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Along the East Sea, mangrove shoreline of zone 1 is located between Bo De and O Ro river mouths. Over 49 km, there were 489 transects used to intersect the base line and nine mangrove shorelines of 1953, 1979, 1988, 1992, 1995, 2000, 2004, 2008 and 2011 (Table 2 and Fig. 2). The rate of change varied from $-12.61\,\mathrm{m\,yr^{-1}}$ to $-71.54\,\mathrm{m\,yr^{-1}}$ with a mean rate of $-38.31 \pm 14.26\,\mathrm{m\,yr^{-1}}$ (Table 4). The maximum erosion rate was near to Bo De river mouth, $-71.54\,\mathrm{m\,yr^{-1}}$ (Fig. 2).

The mangrove shoreline of zone 2, from Vam Xoay to Rach Tau river mouth, recorded dominant erosion. Similar to zone 1, nine mangrove shorelines were observed in zone 2, but mangrove shoreline 2008 was replaced by the one in 2009 (Fig. 3). Along the 11.1 km, 111 transects were generated (Table 4 and Fig. 3). Over the period 1953–2011, the change rate of the shorelines ranged from $-2.54\,\mathrm{m\,yr^{-1}}$ to $-13.73\,\mathrm{m\,yr^{-1}}$, with an average of $-10.28 \pm 2.64\,\mathrm{m\,yr^{-1}}$ (Table 4).

On the other hand, mangrove accretion is significant along the Gulf of Thailand. A time series of nine mangrove shorelines was extracted. Along the 22 km of mangrove shoreline of zone 3 from Ca Mau tip (Hai Thien canal) to Cua Lon estuary, the rate of accretion averaged over 219 transects was $44.74 \pm 24.36\,\mathrm{m\,yr^{-1}}$. Maximum accretion rate in this zone was $95.67\,\mathrm{m\,yr^{-1}}$ at the transect between Nam Khoi and Ba Mang canals (Table 4 and Fig. 3).

Further, in the Cua Lon estuary, three newly formed islands of Con Trong (zone 4), Con Ngoai (zone 5) and Con Moi (zone 6) continue to be accreted (Fig. 4). Con Trong Island (zone 4) was formed during the 1960s and is located in the middle of the estuary. Therefore, there was no mangrove shoreline in 1953 to be observed (Fig. 4). A total of 74 transects were extracted in zone 4 (Table 4 and Fig. 4). Maximum accretion rate was observed at the north eastern tip of the island. Hence, zone 4 was divided into two subzones 4A and 4B. During 1979–2011, 72 transects of subzone 4A were evidenced average accretion rate of $1.31 \pm 1.46\,\mathrm{m\,yr^{-1}}$ that was much lower than the 2 transects of subzone 4B ($48.69 \pm 3.01\,\mathrm{m\,yr^{-1}}$) (Table 4).

Located further offshore, Con Ngoai (zone 5) was formed during the 1980s. Hence, mangrove shorelines of 1953, 1979 and 1988 are not available. It is clearly seen that this island is expanding at the northeast tip. For 16 transects there, the average accretion rate was $7.38 \pm 7.61\,\mathrm{m\,yr^{-1}}$ over the period 1992–2011 (Table 4 and Fig. 4). For the other parts of the island, the mangrove shoreline was stable, no change observed (Fig. 4).

Con Moi (zone 6) is a newly formed island during the 2000s and only two mangrove shorelines available (2009 and 2011) (Fig. 4). The EPR was applied and showed accretion dominated the eastern bank of the island (subzone 6A), whereas erosion dominated the western bank (subzone 6B) (Table 4 and Fig. 4). Over the 22 transects of subzone 6A, the mean accretion rate was $9.59 \pm 6.99\,\mathrm{m\,yr^{-1}}$. The mean erosion rate was $-5.80 \pm 3.69\,\mathrm{m\,yr^{-1}}$ for the 22 transects of subzone 6B.

Located on the western bank of the Cua Lon river, zone 7 is also a sediment receiver. Over the period 1953–2011, nine mangrove shorelines were reported. There were 62 transects generated in zone 7 (Fig. 5). Change rate of mangrove shorelines ranged from $6.40\,\mathrm{m\,yr^{-1}}$ to $47.03\,\mathrm{m\,yr^{-1}}$ with mean accretion rate of $23.00 \pm 11.26\,\mathrm{m\,yr^{-1}}$ (Table 4).

Next to zone 7, zone 8 remained six mangrove shorelines of 1979, 1988, 1992, 2000, 2004, and 2011. Over 11.8 km of zone 8, 117 transects was recorded (Fig. 5). The mean accretion rate was $65.00 \pm 46.61\,\mathrm{m\,yr^{-1}}$ (Table 4).

4 Discussion

4.1 Erosion along the East Sea

Analysis from a time series of mangrove shorline along the East Sea shows average erosion rate varying from $10.28\,\mathrm{m\,yr^{-1}}$ (zone 2) to $38.31\,\mathrm{m\,yr^{-1}}$ (zone 1) (Table 4). As compared with the studies at other sites, these are much higher. In Doula Estuary, Cameroon, results showed the seaward edge of mangroves had over two thirds of the shoreline experienced dieback at up to $3\,\mathrm{m\,yr^{-1}}$ over the period 1975–2007 (Ellison and Zouh, 2012). Gilman et al. (2007) observed mean landward migration of American

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Samoa mangroves over four decades was from 6.39 cm yr^{-1} to 3.27 m yr^{-1}. Recently, Hai-Hoa et al. (2013) found the width of fringe mangroves has been significantly reduced in Kien Giang coast, Vietnam, with average rates of width reduction from 3 m yr^{-1} to 7 m yr^{-1} over the period 2003–2009. It has been discussed on roots of change which were reduction in sediment supply and mangroves overexplotation (Ellison and Zouh, 2012), shrimp farm expansion (Hai-Hoa et al., 2013) and climate change, especially, sea level rise (Gilman et al., 2007).

Because of the specific history of the study area, it is very difficult to compare the mangroves in the study area to mangrove systems elsewhere (Koedam et al., 2007). This constitutes an added value to performing this research. Indeed, it is clear that the coast of the Ca Mau tip is strongly dynamic. Mangrove loss on the eastern side is arising primarily because of natural changes in the coastal system and the impact of the north east monsoon, plus as a consequence of human activities such as herbicide application during the Vietnam war, deforestation, and the reduction of sediment supply from the Mekong mouths by rapidly increasing the number of dams on the Mekong system.

During the Vietnam war (1961–1971), herbicides were sprayed by the United States forces for military purposes at a rate more than an order of magnitude greater than for similar domestic weed control (Stellman et al., 2003). The tip of Ca Mau was one of the two heavily sprayed regions in the south of Vietnam (Hong and San, 1993). Ross (1975) reported from 1966 to 1970 the tip of Ca Mau received 1.027 kg of Agent Orange from 55 missions and 285 kg of Agent White. As a result, 52 % of dense mangroves at the tip of Ca Mau were destroyed (Hong and San, 1993). In the study area, bare waste land area increased about ten times from 2003 ha in 1953 to 21 964 ha in 1975 (Van et al., 2013), with a similarity to the flight paths of spray missions delivering Agents Orange and White during the war (Stellman et al., 2003). After this time, forests in the affected areas consist mainly of secondary growth, much of it scrubby, and plantations (FAO, 2007).

In Ca Mau tip, *Rhizophora* spp has value for timber and poles, firewood and charcoal (Hong and San, 1993). After the war, rapid population growth in the study area and resulted in increased demand from mature forests remaining in Ca Mau. Exploitation was indiscriminate despite regulation of the utilization of mangrove forests. From 1975 to 1983, there was 207 798.4 m^3 of timber, 686 961.6 m^3 of firewood, and 23 030.19 tons of charcoal exploited from the mangrove forests of the former Minh Hai Province (Ca Mau and Bac Lieu Provinces) (Hong and San, 1993). In addition, conversion to brackish water aquaculture is a major agent of mangrove change in Vietnam (Giesen et al., 2006). Extensive expansion of aquaculture in the 1980s and 1990s resulted in the loss of about two-thirds of Vietnam's mangroves by 2000 (Hashimoto, 2001). At initial stage, extensive tidal areas in Ca Mau converted for agriculture. Although initially yields were high, crops eventually failed. The reclaimed land was rapidly converted to aquaculture (Hong and San, 1993; Binh et al., 2005). In 1980s, most of forestry aquaculture enterprises in Ca Mau cleared mangrove forest for the expansion of shrimp farming area and this lead to the further deterioration of mangrove forests (Hong and San, 1993).

Upstream hydrological engineering (hydroelectric dams and irrigation canals) contribute an additional layer of complexity by modifying local coastal dynamics, which can impact mangrove ecosystem permanence by altering rates of erosion or accretion (Hashimoto, 2001). Dam construction on rivers reduces the volume of water and riverine sediment supply to the sea and coastal mangroves (Ellison and Zouh, 2012). The Mekong River is likely to already have lower sediment loads due to damming of the main stream and tributaries, and this be exacerbated in the future with more dam construction. Long-shore drift from the Mekong River mouths is southwards towards Ca Mau. Monthly suspended sediment concentration decreased about 20–30 % at the Vietnamese stations of Tan Chau, My Thuan and Can Tho (Lu and Siew, 2006), but the impacts particularly on the erosion of the eastern coast is unpredictable.

4.2 Accretion along the Gulf of Thailand

The strong longshore drift associated with the wave action eroding the East Sea shoreline transfers sediment to the Gulf of Thailand (Ca Mau Biosphere Reserve, 2013). Huge amount of sediment in the East Sea is transported to the Gulf or Thailand by Cua Lon River, then accumulates at the Cua Lon estuary at average rate of 70–80 $mg L^{-1}$ (November–April) and 30 $mg L^{-1}$ (May–October). It is estimated Cua Lon River transfers about 1 030 000 tons yr^{-1} of sediment from the East Sea to the Gulf of Thailand (Ca Mau Biosphere Reserve, 2013). As a consequence, this study shows accretion is dominant along the Gulf of Thailand (Table 4, Figs. 3, 4 and 5). Especially, three islands of Con Trong (zone 4), Con Ngoai (zone 5) and Con Moi (zone 6) were newly formed in 1960s, 1980s, and 2000s respectively.

The mangrove shoreline of zone 3, from Rach Tau to the Cua Lon estuary, is considered an important spawning ground for valuable aquatic organisms (mangrove snapper and mullet). There are about 8 billion breeding shrimps generated per year in the tip of Ca Mau (Ca Mau Biosphere Reserve, 2013). From interviews, it is noted local people usually use rakes to illegally collect breeding animals for livelihood. This technique threatens the aerial root system and propagules of pioneer mangrove species, especially *Avicennia* spp. Therefore, the issue of over-capacity in aquaculture and capture fisheries needs to be addressed, and national policy is required to move a significant proportion of coastal livelihoods to non-marine livelihood alternatives (Mangroves for the Future, 2012). In addition, public awareness should be raised.

Figure 6 clearly shows Con Trong (zone 4) is continuing to advance seaward to meet Con Ngoai (zone 5) at the northeast tip and Con Moi (zone 6) on the western bank. Geographically, sediment from the Cua Lon river and from the East Sea (transported by rivers, canals and shore drift) is intrerpreted as the main sediment source (Ca Mau Biosphere Reserve, 2013). Mangroves on these three newly formed islands have been growing naturally. These can potentially be open laboratories for scientific activities on mangrove ecosystems and should be strictly protected.

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4.3 Implication for mangroves management and conservation

The shoreline of the Ca Mau tip is characterized by river alluvium and is a "soft shoreline" where the mangrove forest plays a vital important role in the erosion and accretion process of the coast (Ca Mau Biosphere Reserve, 2013). The results show the mangrove shoreline is changing dynamically with erosion and accretion dominating along the East Sea and Gulf of Thailand respectively.

Along the East Sea coastline, sections of the Ho Chi Minh road are being built about 1 km inland from the mangrove shoreline (Detail plan of Ho Chi Minh road, 2013). If erosion persists along the East Sea, mangrove at some parts will be lost leading the loss of their wave buffering and sheltering effect. This will threaten residential areas and infrastructure behind the mangrove, such as the Ho Chi Minh road. Therefore, adaptation measures should combine "soft" and "hard" solutions focusing on wave reduction, accretion creating, and mangrove reforestation are needed. This is not only for the purpose of existing coastal protection but also long term coastal engineering to take advantage of alluvium from the rivers in the Mekong Delta to advance the shoreline to the sea. In order to achieve success in these combined measures, the following recommenations should be considered by mangroves managers in the study area. Firstly, measures for accretion combining mangrove reforestation should be implemented seaward progressively. Secondly, infrastructure for wave reduction should be considered in short term, simpleness and local-used material terms. For mangrove growth, these measures should aim to ensure the accretion rate is not too fast with too small-grained alluvium only. Thirdly, advanced techniques for mangrove reforestation and protection should be considered.

However, the capacity to implement any measures is not yet present. The staff of the Mui Ca Mau National Park lack the numbers for functional operation. In order to be able to enlarge the mangrove protection zone and to maintain the present status of the forest, more staff are needed. It could be that volunteering co-workers will come forward after awareness has risen but still encouragement by higher authorities is necessary (Tamara, 2010).

Furthermore, there is a need for solutions concerning the lack of interaction between the different agencies responsible for the protection of certain aspects of mangrove management. Policies, laws and regulations governing mangroves in Vietnam are incoherent, incomplete and inconsistent. Consequently, attempts to manage mangrove ecosystems are frustrated by policy, legislative and regulatory complexity, confusion, contradiction and conflict. A root cause is that administrative responsibility for mangroves and the coastal area is shared among multiple government institutions within two ministries: the Ministry of Natural Resources and Environment, which is responsible for coastal planning, land allocation, biodiversity conservation, aquatic ecosystem management and protection, and climate change; and the Ministry of Agriculture and Rural Development, which is responsible for the management of forests, terrestrial and marine protected areas, capture fisheries, aquaculture, sea dykes, storm and flood control (Mangroves for the Future, 2012). Even at a local scale there is a poor communication between the monitoring, managing and exploiting authorities. The contact of these groups with provincial authorities is hardly present (Tamara, 2010).

5 Conclusions

The study on mangrove shoreline changes in Ca Mau tip between 1953 and 2011 confirms that erosion and accretion respectively are significant along the East Sea and the Thailand Gulf. Along 60 km of mangrove shoreline at the East Sea side, the mean LRR of erosion was found as 33.24 $m\,yr^{-1}$. For the accretion trend along the Thailand Gulf, the LRR rate was 40.65 $m\,yr^{-1}$.

The combination of remote sensing and GIS techniques is a helpful tool to detect mangrove shoreline movement changes over time in response to both natural and anthropogenic forces. The method should be good for application in other Mekong Delta areas where there has been erosion or where the situation is complex. Understand-

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ing the nature of changes, either natural or human, is a basic knowledge to facilitate suitable planning, management, and regulation of coastal wetland.

The results obtained from the study will aid the scientists in predicting the areas most at risk of erosion/or advance of accretion in the future. Furthermore, it will facilitate the managers and decision makers to propose adaptation measures as well as to incorporate wetland management plans into plans and strategies at both provincial and national levels. Especially, it will contribute to a provincial effective coastal zone management plan to respond to climate change and sea level rise in Ca Mau.

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Table 1. History of universal DSAS application.

No.	Purpose of DSAS application	Country	Period	References
1	Estimating rates of change of mangrove seaward edges and landward margins in Doula Estuary	Cameroon	1975–2007	Ellison and Zouh (2012)
2	Calculating shoreline change rates in Accra	Ghana	1904–2002	Appeaningaddo et al. (2008)
3	Finding out the change rate of shoreline along the coast of Bhitarkanika Wildlife sanctuary, Orissa	India	1973–2009	Chand and Acharya (2010)
4	Analysing shoreline changes along the coast between Kanyakumari and Tuticorin	India	1999–2009	Sheik and Chandrasekar (2011)
5	Analysing shoreline change of Vedaranyam coast, Tamil Nadu	India	1930–2005	Natesan et al. (2013)
6	Consistently estimating the spatiotemporal dynamics of erosion and accretion of the Sundarbans coastline	India and Bangladesh	1973–2010	Rahman et al. (2011)
7	Detecting the shorelines of the Sele Plain coastline between the towns of Salerno and Agropoli and define its change	Italy	1870–2009	Alberico et al. (2011)
8	Quantitatively analysing shoreline changes at the Mediterranean Coast in Turkey	Turkey	1972–2002	Kuleli (2010)
9	Detecting shoreline change on coastal Ramsar wetlands of Turkey	Turkey	1972–2009	Kuleli et al. (2011)
10	Quantifying shoreline changes along the Sefton Coast	UK	1955–2005	Esteves et al. (2009)
11	Mapping shoreline change in Puerto-Rico	USA	36 yr	Thieler and Danforth (1994)
12	Analysing historical shoreline changes and associated coastal land loss along the US Gulf of Mexico	USA	1800s-2002	Morton et al. (2004)
13	Analysing shoreline changes and associated coastal land loss along the US Southeast Atlantic Coast	USA	1800s-2000	Morton and Miller (2005)
14	Analysing historical shoreline change and associated coastal land loss along sandy shorelines of the California Coast	USA	1800s-2002	Hapke et al. (2006)
15	Analysing shoreline change at Mad Island Marsh Preserve, Matagorda County, Texas	USA	1995–2005	Mangham and Williams (2007)
16	Rates and trends of coastal change in California	USA	1800s-2001	Beach et al. (2009)
17	Estimating historical coastal cliff along the California Coast	USA	1920–2002	Hapke and Reid (2007)
18	Analyzing estuarine shoreline change: a case study of Cedar Island, North Carolina	USA	1958–1998	Lisa et al. (2010)
19	Analysing historical shoreline change along the New England and Mid-Atlantic coasts	USA	1800s-2000s	Hapke et al. (2010)
20	Determining shoreline change along sheltered coastlines in Neuse River Estuary	USA	1958–1998	Cowart et al. (2011)
21	Calculating shoreline change in Phan Thiet coastal area	Vietnam	1973–2002	Thao et al. (2008)
22	Examining the rates of change in width and the associated changes in adjacent shoreline land-use in Kien Giang coast, Vietnam	Vietnam	2003–2009	Hai-Hoa et al. (2013)

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Table 2. Eight zones of study area divided basing on coastal characteristics and availability of remotely sensed data.

Zone	Length (km)	Direction	Description Position	Accretion/ Erosion	Time series
1	49.0	Northeast	From Bo De river mouth to O Ro river mouth	High erosion	1953, 1979, 1988, 1992, 1995, 2000, 2004, 2008, 2011
2	11.1	Southeast	From Vam Xoay to Rach Tau river mouth	Erosion	1953, 1979, 1988, 1992, 1995, 2000, 2004, 2009, 2011
3	22.0	Southwest	From Hai Thien canal to Cua Lon estuary	Accretion	1953, 1979, 1988, 1992, 1995, 2000, 2004, 2009, 2011
4	7.5	West	Con Trong island, formed in 1960s, at Cua Lon estuary	Accretion	1979, 1988, 1992, 1995, 2000, 2004, 2009, 2011
5	1.7	West	Con Ngoai island, formed in 1980s, at Cua Lon estuary	Accretion	1992, 1995, 2000, 2004, 2009, 2011
6	4.5	West	Con Moi island, newly formed in 2000s, at Cua Lon estuary	Accretion and erosion	2009, 2011
7	6.3	West	On right bank of Cua Lon river	Accretion	1953, 1979, 1988, 1992, 1995, 2000, 2004, 2009, 2011
8	11.8	Northwest	From Cua Lon to Bay Hap estuaries	Accretion	1979, 1988, 1992, 2000, 2004, 2011

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Table 3. Specifications of image data.

No.	Name	Path/row	Acquired date	Resolution (m)	Study area
1	Aerial photos		1 Jan 1953	20	1,2,3,7
2	Landsat 3 MSS	135/054	13 Feb 1979	79	1,2,3,4,7,8
3	Landsat 5 TM	125 and 126/054	31 Jul 1988	30	1,2,3,4,7,8
4	Landsat ETM	125 and 126/054	22 Jun 2000	30	1,2,3,4,5,7,8
5	SPOT 2	273/332	3 Jan 1992	20	1,2,3,4,5,7,8
	SPOT 2	273/333	3 Jan 1992	20	
	SPOT 2	274/333	3 Jan 1992	20	
6	SPOT 2	273/333	12 Dec 1995	20	1,2,3,4,5,7
	SPOT 2	274/333	12 Dec 1995	20	
7	SPOT 5	273/332	7 Jan 2004	10	1,2,3,4,5,7,8
	SPOT 5	273/333	7 Jan 2004	10	
	SPOT 5	274/333	7 Jan 2004	10	
8	SPOT 4	274/333	8 Sep 2008	10	1
9	SPOT 2	273/333	19 Jan 2009	20	2,3,4,5,6,7
10	SPOT 5	273/332	19 Feb 2011	10	1,2,3,4,5,6,7,8
	SPOT 5	273/333	19 Feb 2011	10	
	SPOT 5	274/333	19 Feb 2011	10	

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Table 4. Change rate of mangrove shoreline in 8 zones of the study area. For zone 6, there are only two mangrove shorelines of 2009 and 2011, no linear regression statistic was run, and hence end point rate is used. For the rest, mangrove shoreline change was derived from linear regression rates. Each of zones 4 and 6 occurs different statistical numbers of mean that stand for different dynamic subzones.

Items	Zones 1	2	3	4 A	4 B	5	6 A	6 B	7	8
Number of transects	489	108	219	72	2	16	22	22	62	117
Transect length (m)	5500	1050	1100 2000 5600 3700 2700	300 170	1900	500	90	90	1900 3700	1800 4500 2000
Mean of mangrove shoreline change ($\mathrm{m\,yr^{-1}}$)	−38.31 ±14.26	−10.28 ±2.64	+44.74 ±24.36	+1.31 ±1.46	+48.69 ±3.01	+7.38 ±7.61	+9.59 ±6.99	−5.80 ±3.69	+23.00 ±11.26	+65.00 ±46.61
Maximum of mangrove shoreline change ($\mathrm{m\,yr^{-1}}$)	−71.54	−13.73	95.67	5.52	50.82	20.07	20.38	0.94	47.03	133.41
Minimum mangrove shoreline change ($\mathrm{m\,yr^{-1}}$)	−12.61	−2.54	1.14	0	46.56	0.25	1.16	−11.17	6.40	0.62

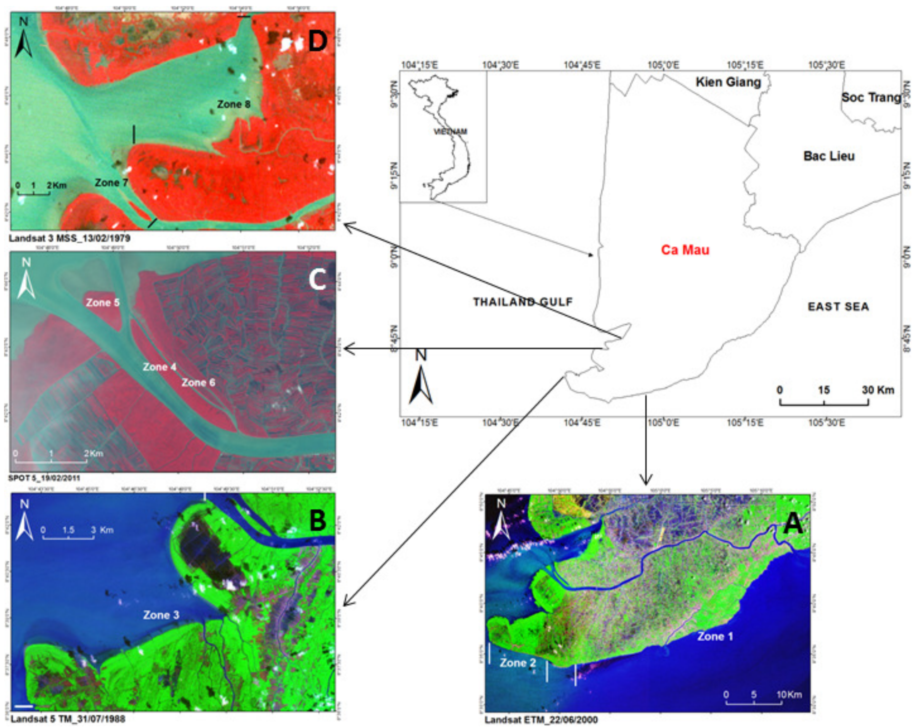

Fig. 1. Map of study area. It is divided into 8 zones that belong to coastal characteristics and remote sensed data availability. **(A)** Zones 1 and 2; **(B)** zone 3; **(C)** zones 4, 5 and 6; and **(D)** zones 7 and 8.

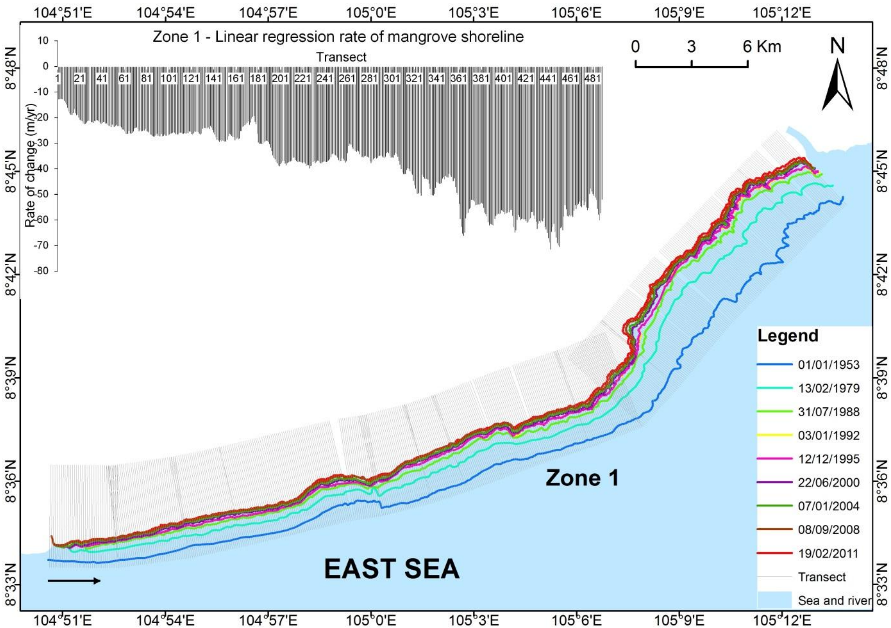

Fig. 2. Mangrove shoreline changes in zone 1 which locates from Bo De to O Ro river mouths, along the East Sea. There are 489 transects were generated by DSAS software. The arrow shows the direction of transects from 1 to 489 which have linear regression rate illustrated in the graph at the top left corner.

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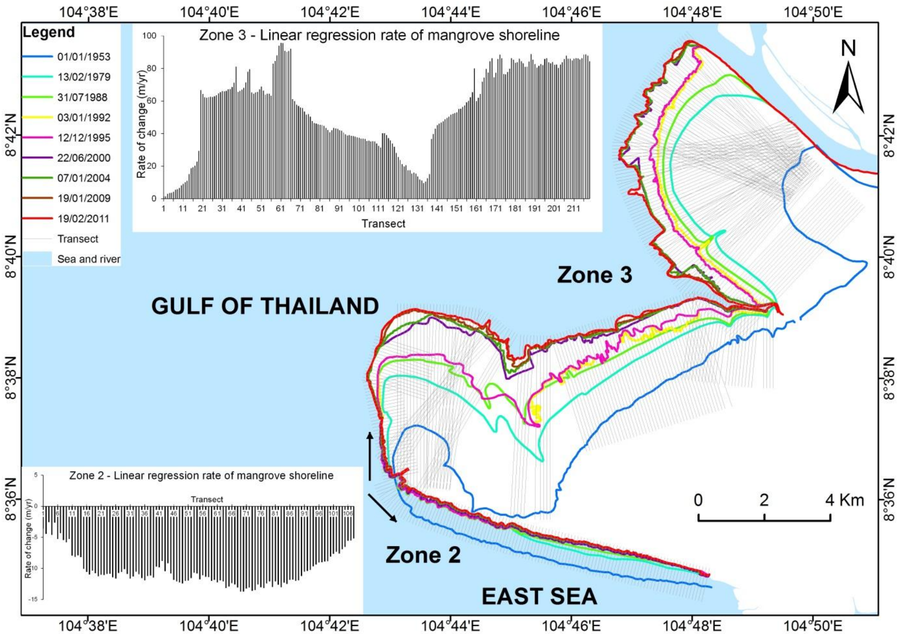

Fig. 3. Mangrove shoreline change in zones 2 and 3. Zone 2 is located on the East Sea coast and zone 3 on the Gulf of Thailand. There are 108 and 219 transects are generated for zones 2 and 3 respectively. The arrow shows the direction of transects from 1 to 108 for zone 2 and from 1 to 219 for zone 3.

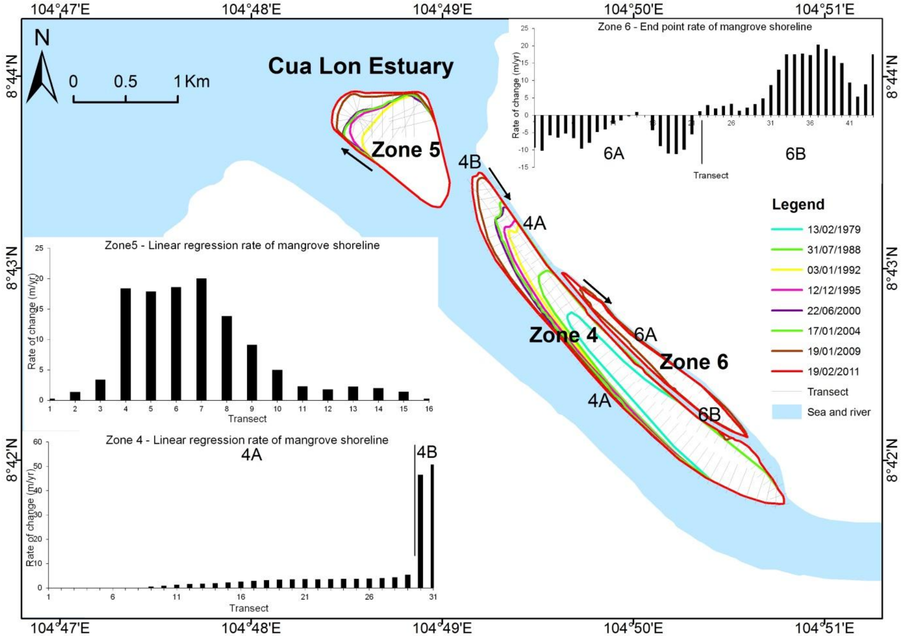

Fig. 4. Mangrove shoreline change in zone 4 (Con Trong), zone 5 (Con Ngoai) and zone 6 (Con Moi) in the Cua Lon Estuary. These are new islands were formed in 1960s, 1980s, and 2000s respectively. Therefore, there are 8, 5 and only 2 mangrove shorelines generated for zone 4, zone 5 and zone 6 respectively. There are 74, 16 and 44 transects are generated for zone 4, zone 5 and zone 6 respectively. Each of zone 4 and zone 6 is divided into two dynamic regions, A and B. The arrows show the direction of transects from 1 to 74 for zone 4, from 1 to 16 for zone 5 and from 1 to 44 for zone 6.

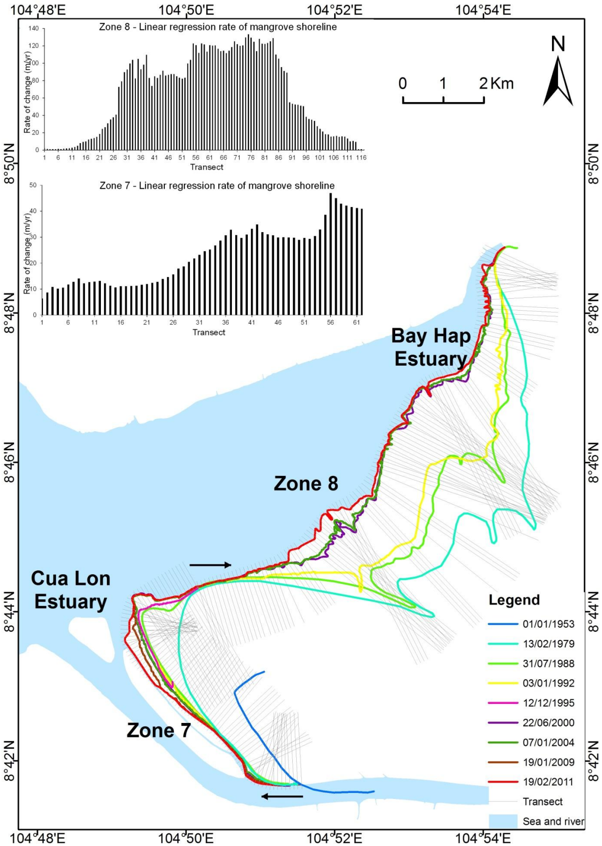

Fig. 5. Mangrove shoreline change in zones 7 and 8. Mangrove shoreline 1953 is not observed in zone 8. There are 62 and 117 transects are generated for zone 7 and zone 8 respectively. The arrows show the direction of transects from 1 to 62 for zone 7 and from 1 to 117 for zone 8.

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