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Research Article

Application of Remote Sensing in Analyzing Mangrove Forest Changes and Drivers in Mui Ca Mau National Park, Vietnam

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Abstract

Mangroves are vital in coastal ecology and for sustaining and securing coastal communities. However, several factors such as human activities and climate change have changed mangroves' quantity and quality. This research analyses land-use/land cover (LULC) changes focusing on mangroves in Mui Ca Mau National Park (MCMNP) from 1995-2022. Collected Landsat imagery in 1995, 2003, and 2022 were applied to perform this research. Overall accuracy and Kappa of land cover classification were 88.5% and 0.86 in 2003, and 87.6% and 0.85 in 2022, respectively. The classified results showed that the mangrove area had increased significantly from 4,316.1 hectares in 1995 to 8,741.3 and 10,764.1 hectares in 2003 and 2022, respectively. In addition, the drivers of mangrove change were identified and analyzed. This study showed the important role of policy in mangrove conservation and the sustainable use of natural resources. The study provided useful information for policy-making in terms of forest conservation and management.

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Introduction

Mangrove forests are vital to coastal zones and they provide numerous benefits to marine organisms and humans [1-3]. Unfortunately, they are one of the most threatened tropical ecosystems in the world due to human activities such as population growth, conversion to aquaculture ponds, and clear-cutting for timber, charcoal, and wood chip production [4-6]. Therefore, it is essential to collect and share ecological information to develop conservation and protection plans for mangrove ecosystems [7].

Before the Indochina war, it was estimated that mangrove forests in Vietnam covered an area of around 400,000 ha, of which approximately 200,000 ha were in Ca Mau Peninsula (mostly in Ngoc Hien, Nam Can, Dam Doi, and Phu Tan Districts) [8]. Unfortunately, during the Vietnam War (1962-1971), 40% of mangrove forests in Southern Vietnam were destroyed. Then, most of the remaining mangrove forest and wetland areas were converted to agricultural areas such as paddy fields and aquaculture. By the end of the 1990s, mangrove forests had been cleared for shrimp farming in many areas, leading to a decrease in mangrove and forest cover by about 50% over the past few decades [8]. Although mangrove forests rehabilitation efforts began in the late 1990s due to the decline in shrimp production and the establishment of Mui Ca Mau National Park (MCMNP) in 2003, the mangrove forest in the MCMNP is still affected by aquaculture activities, climate change, and economic development. This results in changes in land use and cover (LULC) and negative impacts on natural resource conservation [9].

Since the location, structure, and composition of a mangrove forest cause low accessibility, the task of collecting ecological information by ground inventory is extremely laborious [10]. In addition, field survey data might not cover broad areas especially when access to field sites is restricted or not available. On the other hand, previous studies have reported that remote sensing (RS) based approaches could be used for rapid mapping and long-term monitoring of large-scale mangrove systems [11-15]. RS has had a crucial role in land surface observation as it enables classification and tracks changes over large areas in a short time interval [16]. Also, RS and geographic information system (GIS) techniques have been widely used in mangrove forest studies such as mapping mangrove species [17], detecting the change of habitats, and assessing mangrove biomass carbon stock [18-21]. It is a cost-effective approach for monitoring and mapping forests across various spatial scales [22]. RS-based approaches provide information on the land's surface quickly and accurately [11, 23-25]. Outputs of RS imagery analysis give quick and accurate information for supporting conservation plans. Furthermore, the results help policy-makers in advanced stages [26]. In Ca Mau Province, some scientists used optical images for mapping mangrove forests. Son et al. (2015) tried to investigate the multi-decadal change in mangrove forests based on Landsat data from 1979 to 2013. According to this study, from 1979 to 2013, the area 75 mangrove forests in the study region had decreased by 74%, mainly due to the local aquaculture industry [27]. Besides that, Van et al. (2015) conducted research to monitor mangrove forest changes in Ca Mau Province over six decades. This study showed that forest areas declined drastically from 71,345 ha in 1953 to 6,968 ha in 1992 then rose to 20,501 ha in 2011 [28]. Similarly, another study conducted by Tran et al. (2015) demonstrated that mangrove forests decreased dramatically in Ca Mau Province, where it was reduced by nearly 90% from 1973 to 2011 [29]. In 2017, Tran and Fischer used Landsat images in 1989, 2000, and 2013 and classified mangroves in Ca Mau Province. Results showed that mangrove cover has declined by 24.6% in the province and fish diversity in the more highly fragmented mangrove area was 1.78 times lower than the less fragmented mangrove [30]. The previous studies all showed that RS technology has been an effective method in mangrove mapping. The previous studies focused on the changing of mangroves in some areas of Ca Mau Province but lack data on mangrove forests in the MCMNP. Given these considerations, this research was conducted 1) to generate LULC maps of the MCMNP at three periods including 1995, 2003, and 2022 by classification satellite images; 2) to analyze the distributions of mangroves and drivers of mangrove change in the MCMNP during the period 1995-2022. The results provided updated information about the mangrove forest of the MCMNP. This is useful information to support local government in terms of forest conservation and management.

Materials and methods

1) Study area

The MCMNP, located at the southernmost tip of Vietnam (Figure 1), was designated a national park in 2003 and has the highest priority among the four categories of national protected areas in Vietnam [31]. It was also recognized as one of the core zones of Ca Mau Biosphere Reserve by UNESCO in 2009 and the RAMSAR site in 2012. The park has a total area of 41,862 ha and is comprised of four functional zones, including Strictly Protected, Ecological Rehabilitation, Administration and Service, and Marine Protected. The study site is a plain with an average elevation of 1 meter above the mean sea level and is continuously expanding due to coastal accretion of up to 50 m per year [9, 32]. This characteristic gives typical features of the southernmost Mekong Delta to the MCMNP, where showed the continuous formation of lands by aggradation [33]. Therefore, the MCMNP, which has high ecological and economic values, was selected as a case study site for this research.

2) Data collection and processing

For assessing the changing of mangrove areas in the MCMNP, satellite images, and secondary data were collected and processed (Table 1). Landsat images were collected in 1995, 2003, and 2022 which characterized the period of shrimp farming expansion and the year that the MCMNP was established, respectively. Landsat images with the spatial resolution of 30 m are suitable for monitoring forest change. Besides, the secondary data were added to minimize the confusion classification. The collected secondary data were in several formats (e.g. MicroStation, Mapinfo) for GIS data. All the collected secondary data were converted to shapefile format which is a GIS data standard of Environmental Systems Research Institute (ESRI) [34]. Coordinate systems of all data were defined as WGS 84/UTM zone 48N. The data processing was performed in ArcGIS software version 10.1 [35].

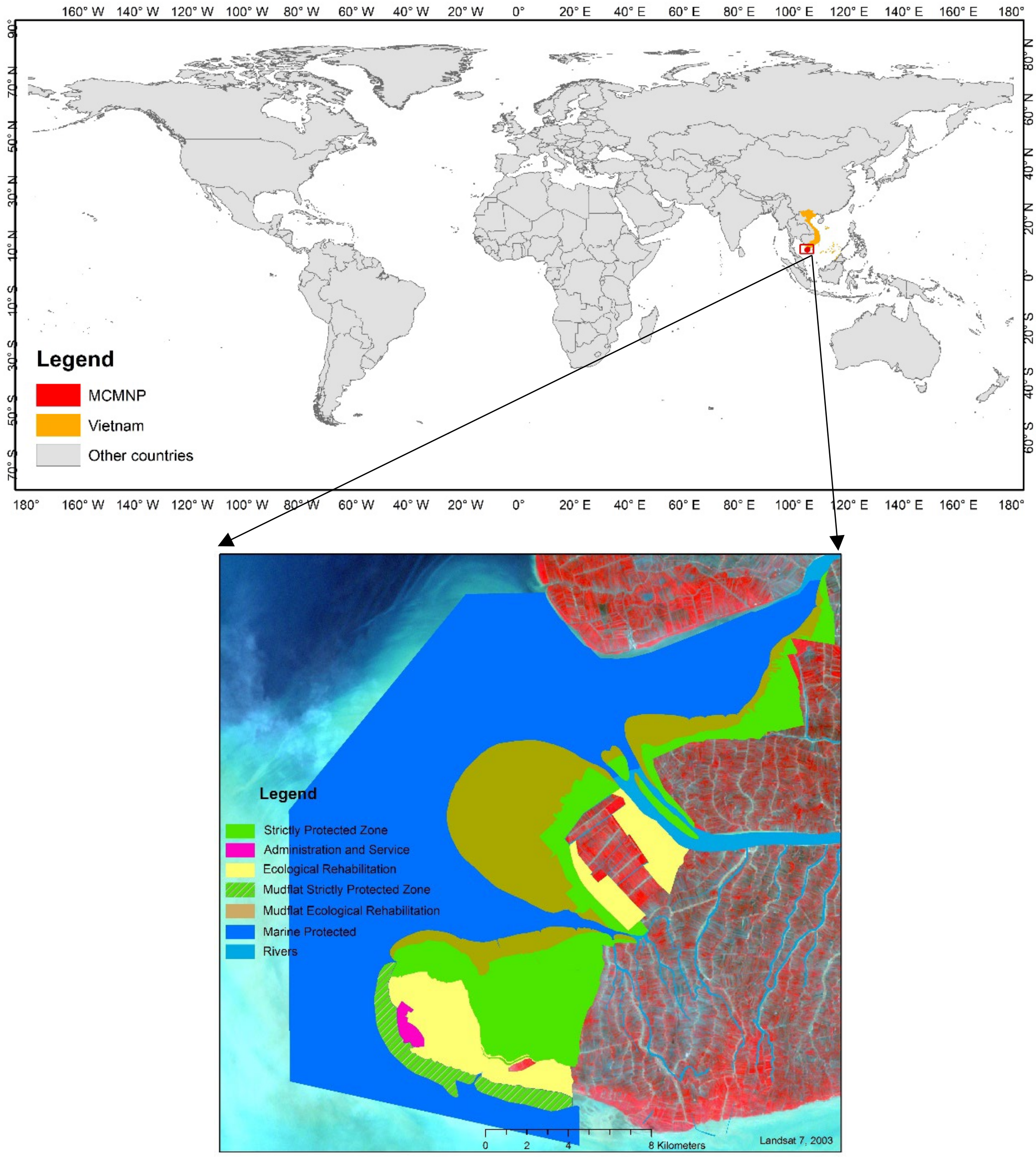

Figure 1 Location of the study area.

Table 1 Satellite imagery and the secondary data collection

Satellite imagery data			
Data	**Date**	**ID**	**Data source**
Landsat 5 (TM)	26/12/1995	LT05_L2SP_126054 _19951226_20200911_02_T1	The U.S. Geological Survey (https://earthexplorer.usgs.gov/)
Landsat 7 (ETM+)	06/01/2003	LE07_L2SP_126054 _20030106_20200916_02_T1	
Landsat 8 (OLI)	18/01/2022	LC08_L2SP_126054 _20220118_20220123_02_T1	
Secondary data			
Data	**Date**	**Data source**	
Administrative boundary	2018	The Department of Natural Resources and Environment of Ca Mau Province	
The MCMNP boundary	2003	The MCMNP management office	
Land use and vegetation maps	2003	The Southern Sub-Institute of Forest Inventory and Planning of Vietnam	
Inventory forest data and reports of the MCMNP	2007, 2010, 2014	The MCMNP management office and The Southern Sub-institute of Forest Inventory and Planning of Vietnam	
Report of planning the MCMNP	2018	The MCMNP management office	
Primary data	**Date**	**Types**	
Survey	8-10/2022	Dense mangroves, sparse mangroves, water, shrimp ponds, built-up areas, bare land	

3) Satellite image classification

For supporting the classification and accuracy assessment, ancillary data was combined with remotely sensed data. The reference data including land use and vegetation maps in 2003, 150 ground-trained points collected in 2022 by a field survey, and high spatial resolution images of Google Earth in 2022 were used to support the classification and accuracy assessment (Figure 2). The field points were taken by stratified random sampling using GPS Map78. The study aimed to classify mangrove areas, so the survey focused on gathering information about the mangroves. The survey routes were designed based on the convenient random. One trip was following the roads and trails, another using a boat and following the channels. The number of sampling points was collected as many as possible during the trip. These data provided the location of each land cover type in this area including dense mangroves, sparse mangroves, built-up areas, water surface, bare land, and shrimp ponds. Because the area of bare land was tiny, it was converted to shrimp pond area. Sparse mangrove is an area where mangroves cover less than 70% of the total area while dense mangrove is an area where mangrove coverage is higher than 70%. This is the ratio of mangrove forests to shrimp ponds in the ecological rehabilitation area designated by the Prime Minister in 2016 [36]. Farmers could only use 30% of the total area for shrimp production. The reference data were useful in estimating the current land covers in the research area. Then, the correlation between land cover types at the MCMNP and spectral reflectance values from satellite images was established. In the classification process, the vegetation map in 2003 was used in training for Landsat 2003. Besides, 70% of ground-trained points were used to train for the classification of Landsat image in 2022. This step provided the relationship between land cover types and their spectral reflectance. Then, the particular range of surface reflectance for each type of land cover was identified. Based on this signature, the Landsat in 1995 was trained and classified. In this step, a supervised method, maximum likelihood classifier (MLC) [37], was used. It is a pixel-based classification method that sets up a particular signature by combining the spectra of all training-set pixels for a given feature. All materials present in the training pixels influence the resulting signature. MLC has been widely used for mangrove classification because of its effectiveness and availability in many software for satellite image processing [11, 38].

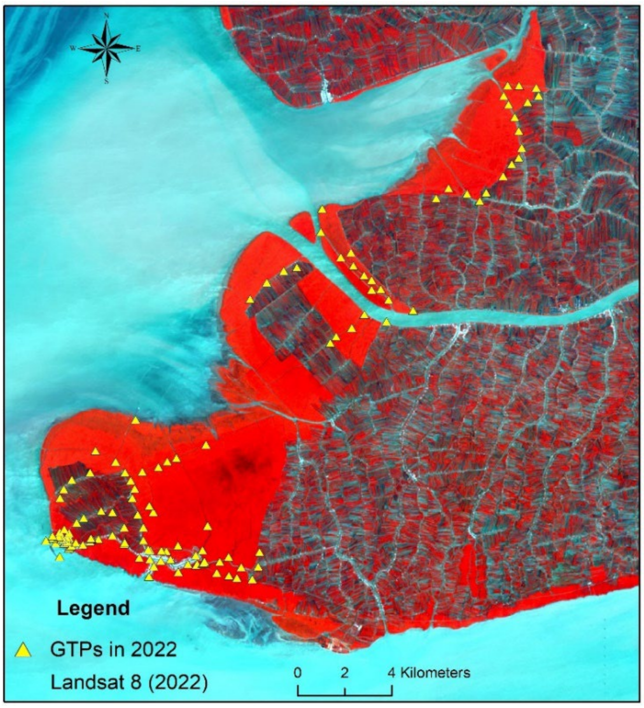

Figure 2 Ground trained points.

In 1995, there was no land use or vegetation map of CMCNP. In addition, there was no high-spatial-resolution images in Google Earth at that time. Due to the lack of data availability for the year of 1995, the accuracy assessment was conducted for 2003 and 2022 using an error matrix approach. It is one of the most common accuracy assessment methods in classification of remote sensing data [38]. Land use map in 2003 was used to assess the accuracy of Landsat classification in 2003. The 30% of ground-trained points in 2022 and the high spatial resolution images in Google Earth were used to identify the accuracy of image in 2022. The flowchart of mangrove change analysis using Landsat imagery was summarized in Figure 3. Landsat images in 1995, 2003, and 2022 were downloaded from https://earthexplorer.usgs.gov/. These images were processed through steps such as extraction of the study area, the normalized difference vegetation index (NDVI) analysis, and layer stacking. NDVI is one of the most widespread vegetation indices globally used for monitoring mangrove forests by remote sensing [39]. After data processing, Landsat images were classified and assessed accuracies using ancillary data. Next, the LULC data were transformed to shapefile and populated to a mangrove geodatabase of the MCMNP. Contemporaneous, the LULC maps in 1995, 2003, and 2022 were analyzed to assess the changing of mangrove areas in the MCMNP (Figure 3).

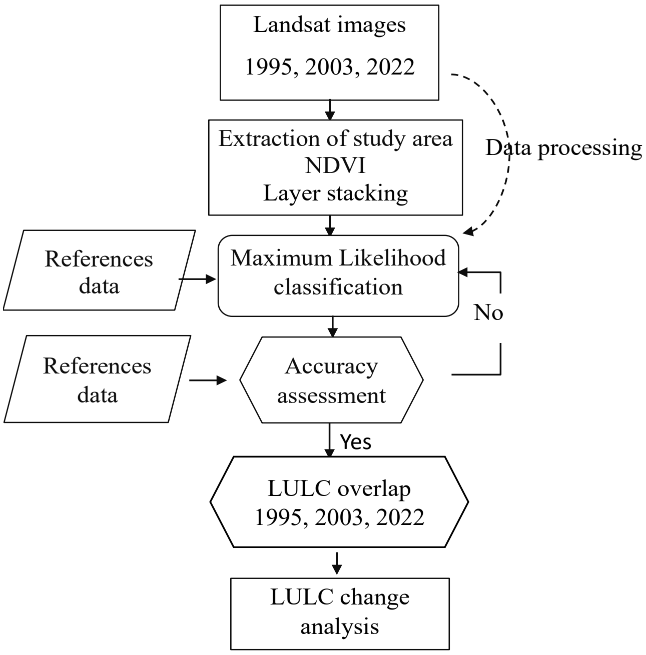

Figure 3 The framework of analysis mangrove area change.

Results and discussion

1) Satellite image classification and accuracy assessment

Satellite images were classified into five land cover types (dense mangroves, sparse mangroves, shrimp pond, water, and built-up areas) (Figure 4). The land cover classification in 2003 showed the overall accuracy of 88.5% and Kappa of 0.86 while the accuracy in 2022 was 87.6% and Kappa was 0.85. These accuracy values are comparable to the previous studies in Mekong Delta using satellite images to monitoring mangrove forest. For example, WorldView-2 and Sentinel-2 were used in classification mangrove in Mekong Delta with the overall accuracy higher than 90% and Kappa higher than 0.81 [3]. Another study in 2019 monitored mangrove forest areas using medium spatial resolution (Landsat) with accuracies higher than 78% [40]. The recently study in Ca Mau, Landsat images were classified for monitoring mangroves changes from 1973 to 2018 with accuracies ranging from 87 to 90% [10].

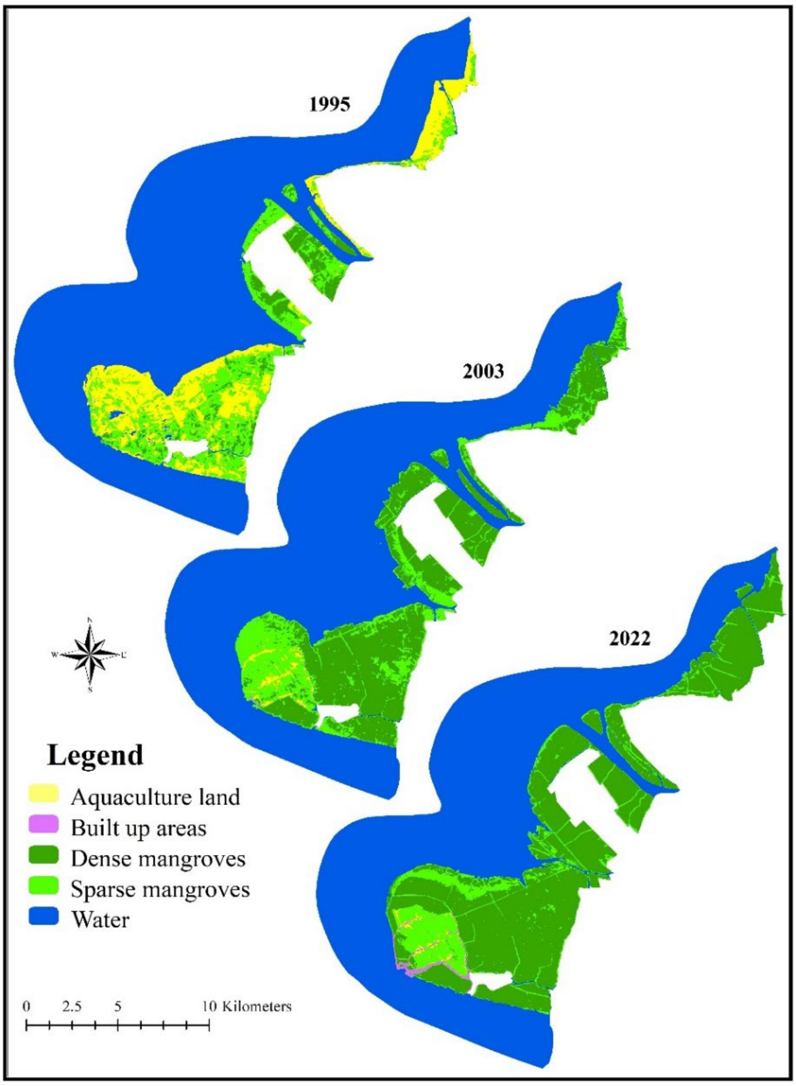

Figure 4 LULC in the MCMNP at the year of 1995, 2003 and 2022.

2) Analyzing mangrove area changes and the drivers

From the 1980s to the late 1990s, shrimp ponds rapidly expanded on the coastal Mekong Delta [8] because several policies have encouraged shrimp farming for the exportation of shrimp products. Minh Hai Province (including Ca Mau and Bac Lieu Provinces) in 1991 allowed farmers to use 70% mangrove cover for integrated mangrove-shrimp farming systems on their farms [41]. Besides that, in 1994, The Prime Minister designated that open coastal areas and water bodies could be used for aquaculture, and household contractors clearing mangrove forests were not supposed to pay tax for the first five years. Consequently, in 1995, aquaculture land accounted for 3,155 ha in 1995. Figure 4 showed that aquaculture covered the large areas of the MCMNP in 1995. Mangroves occupied 4,316.10 ha but they were fragmented, of which the areas of dense and sparse mangrove forests covered 1,011.4 ha and 3,304.7 ha, respectively (Figure 5). On another hand, the government enacted policies to establish and maintain mangrove forests [8]. In 1984, a technical procedure was issued for establishing and maintaining mangrove forests. The Vietnamese Ministry of Forestry promulgated decision in 1992, initiating a plantation program for 6,000 ha of the suitable area along the coast of Minh Hai [8]. The conflict of policies between mangrove conservation and forest exploitation for shrimp farming confused managers and local people.

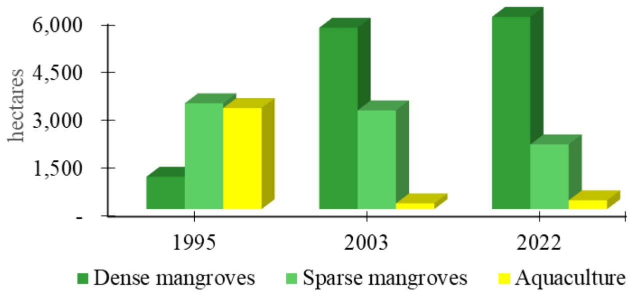

Figure 5 LULC change from 1995 to 2022.

In 1995, the shrimp disease outbreak occurred which led the aquaculture slowing down. Hence, the government issued the policies in 1997 and 1998 to enhance urgent measures to protect and develop forests [28]. In 2002, the local government enacted a decision that allowed shrimp ponds ranging from only 30-50% of the land [28]. In addition, the MCMNP was established in 2003. Hence, the apparent mangrove covering in the aquaculture regions of the study area increased significantly from 4,316.1 ha in 1995 to 8,741.3 ha in 2003 while aquaculture land notably decreased from 3,155 ha to 180.2 ha at the same period. In other words, for eight years, the area of aquaculture land decreased by approximately 94%, while the area of mangrove forests doubled. The area of densely vegetated mangroves significantly increased from 1,011.4 ha to 5,660.8 ha and the area of sparsely vegetated mangroves slightly decreased from 3,304.7 ha to 3,080.5 ha (Figure 5). These results reflected the afforestation efforts of the government in the early 1990s.

The established CMCNP comprised 4 ecological zones including (i) strictly protected (12,203 ha); (ii) ecological rehabilitation (2,859 ha); (iii) administration and service (200 ha); (iv) marine protected (26,600 ha) [31]. Under the strict protection of local government, mangroves rapidly regained within the MCMNP. In addition, mangroves developed on the accumulated land through the natural regeneration process. Besides that, Ca Mau Province planted 250 ha of mangroves in the protection zone from 2016 to 2020. Consequently, mangroves increased gradually after the establishment of the MCMNP. The most remarkable change was the increase of the area covered by mangroves from 8,741.3 ha in 2003 to 10,764.1 ha in 2022, mainly because the area of densely vegetated mangroves noticeably increased from 5,660.8 ha to 8,745.7 ha during the same period. On the other hand, sparsely vegetated mangroves occupied 2,018.4 ha in 2022, showing a decrease of 1,062.1 ha in their area. Besides, aquaculture land increased slightly from 180.16 ha in 2003 to 275.7 ha in 2022. The area covered by mangroves increased by only 2,022.8 ha from 2003 to 2022, indicating that the expansion rate of mangrove forests in 2003-2022 dropped compared to its expansion rate in 1995-2003. In summary, there were various factors affecting mangrove forest change, such as forest plantation, natural forest regeneration, policies, and regulations of government and local government. Mangrove reforestation and natural regeneration made a significant impact on increasing forestland and the constancy of forest coverage.

The information on mangrove forests is becoming very useful for supporting the conservation and protection of the environment [42-43]. The information may help to minimize impacts caused by human activities. Several researchers have concluded that insufficient information might limit the success of mangrove rehabilitation and conservation [7]. Thus, it is required to address this issue to enhance the rehabilitation and preservation of mangroves and their ecology in further studies. Remote sensing proved that satellite images are useful in collecting and analyzing mangrove forest data on a large scale and long term. It may help to improve decision-making reduce costs and increase efficiency in ecosystem services research in the study area.

Conclusions

The land cover maps of the study area in 1995, 2003, and 2022 were successfully created using GIS and RS techniques. The assessment of mangrove area change of the MCMNP during the 1995-2022 period was performed. Two main periods with different characteristics of mangrove management were analyzed. The mangroves in the period of 1995-2003 were affected by the policy conflict between mangrove conservation and shrimp farming development. That caused the more drastic mangrove area changes. The period of 2003-2022 was characterized by the policy in mangrove conservation due to the site being declared as the MCMNP. Mangroves increased the areas because of natural regeneration, forest plantation, and especially the Vietnamese Government's policies in forest conservation. The study showed that satellite imagery was successful in the classification and assessment of mangrove forest change. The main drivers causing mangrove changes in each period were analyzed which provided useful information for local government in sustainable forest use.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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