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Original Paper

Carbon Stock Calculating and Forest Change Assessment Toward REDD+ Activities for The Mangrove Forest in Vietnam

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Mangrove forests are one of the main forest types in Vietnam. However, during the last decades, a lot of mangrove forest area has been converted to other land-use types. The objectives of this study are to assess the changes that occurred in the mangrove forests from 1990 to 2010 and to determine a method for carbon-stock calculating for the forests that can be used as the input data for a Reference Emission Levels (REL) calculation. The study was conducted in two different research areas; one was the Quang Ninh province in the north of Vietnam, and the other took place in the Ca Mau and Kien Giang provinces in the south. In this research, the maps of mangrove forests for the periods of 1990, 2000, and 2010 were created by using optical satellite-imagery data. The change matrix was then calculated by overlaying maps of different periods in the forests for analyzing the changes and assessment. Field trips were also taken to each study area in order to verify/adjust the latest classified mangrove forest maps and interview/identify the main causes of land-use changes taking place during these periods. During the fieldwork, a number of sample points were surveyed to collect the number of parameters of mangrove trees. These data are then used for analyzing the relationship between tree height and the HH and HV values of ALOS PALSAR (Advanced Land Observing Satellite - Phased Array type L-band Synthetic Aperture Radar) data. An allometric relationship between biomass and tree height was also applied for investigating the relationship between aboveground biomass and ALOS PALSAR polarimetric data. Finally, the change in the carbon stock of the forests through all periods was estimated for living biomass, fuel-wood gathering, and other losses by applying the stock-change method. The results of this study were the mangrove forest maps and biomass maps for the years 1990, 2000, and 2010; the changes analysis showed that the forest area is decreasing and that the main cause is the conversion of the forests to aquaculture land, according to the equations/models of biomass estimation for biomass mapping based on ALOS PALSAR data.

Key Words: Mangrove, Carbon Stock, Forest Change, REDD+, Vietnam

1. Introduction

In Vietnam, assessing the forest value was first stated in the Law on Forest Protection and Development in the year 2004[1)]. However, this value was only assessed based on an economic factor in which wood and non-timber forest products were the most important based on their economic value. Unfortunately, the well-known environment value of the forest was not taken into account in this law. Recently, the decree No. 99/2010/ND-CP was issued by the Prime Minister of Vietnam, dated September 24th, 2012, regarding payment for forest environmental services[2)] and the circular No. 80/2011/TT-BNNPTNT was issued by the Minister of Agriculture and Rural Development (MARD) regarding the guidance of the method of determining payments for forest environmental services[3)]. The decision No. 799/QD-TTg was also issued by the Prime Minister, dated June 27th, 2012, regarding the approval of the national action plan for "Reducing greenhouse gas emissions through efforts to limit deforestation and forest degradation, increasing the absorption of greenhouse gases forests, sustainable management of forest resources and biodiversity conservation". This program was developed return to contribute to the successful implementation of the national strategy on climate change and achieve the objective of poverty alleviation, towards sustainable development. This is one of the important tasks of the national strategy on climate change, to show the goodwill and efforts of Vietnam, contributing to the international community in protecting the earth's climate system, contributing to the achievement of 20% reduction of greenhouse gas emissions in agriculture in 2020. One of the important contents of the program is under review, collection, evaluation and processing of data necessary to establish REL and initially identify trends of greenhouse gas emissions and after the implementation of Reducing Emissions from Deforestation and Forest Degradation - REDD + (RELs/FRLs) at national and provincial level (if necessary) in accordance with the United Nations Framework Convention on Climate Change (UNFCCC) and the technical guidance of the Intergovernmental Panel on Climate Change (IPCC)[4)]. In order to do so, there have been various reports and research assessing the value of environment services to the forest, with more of a focus on greenhouse gas emissions, watershed protection, and soil-erosion prevention[5-7)]. The conclusion was that forest change monitoring and assessment as well as forest carbon stock estimation has become the most important part of these activities.

Mangrove forests are one of the main forest types in Vietnam, and their distribution is mostly located along the coastal zone. Mangrove forests play many important roles to the overall ecosystem, including slowing down currents and spreading the tides wide; reducing the height of the waves during strong tides, storm, or high winds to protect sea dykes and other constructions; preventing bank erosion; contributing to the retention of nutrients and the production of biomass; maintaining natural ecological processes; and providing wood, fuel wood, non-timber forest products, medical herbs, and other wildlife resources and fishery resources[8]. Vietnam's 3200 km coastline and the Ca Mau Cape have the potential to support a substantial area of mangroves. Unfortunately, no exact records have been maintained on the area of mangrove forest existing in the entire country. Before the Indochina war (1962-1971), it is estimated that mangrove forest in Vietnam covered an area of about 400,000 ha. The use of herbicides and napalm during the Vietnam war (1962-1971) resulted in the destruction of nearly 40% of the mangrove forest in southern Vietnam. In other areas, mangroves were exploited for the resources or replaced by agricultural and shrimp farms[9]. For the last decades, mangrove forests have been significantly degraded in both quantity and quality as a result of major contributing factors such as overexploitation and its conversion to aquaculture land, agriculture land, and residential areas[10,11].The changes in the mangrove forests of Vietnam from 1943 to 2010 are shown in figure 1 [12].

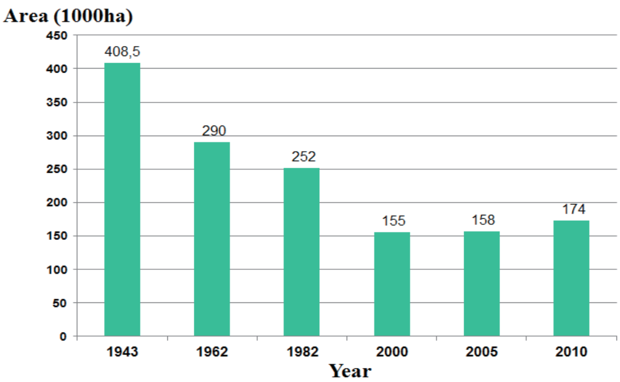

Fig. 1. Changes of mangrove forest in Vietnam.

Worldwide, the calculation of carbon stocks has been conducted by measuring the biomass of the field or by using remote-sensing data[13-15]. In forests, including mangroves, there is a positive relationship between measured backscattering coefficients σ0 (in decibels dB) and the aboveground biomass[16-18]. However, this relationship only exists up to a threshold biomass value, after which the backscattering coefficient saturates. The threshold is dependent on the polarization and wavelength of the radar signal. In mangroves, P-band frequency and HV polarization has been found to have the highest sensitivity to biomass, with a saturation level of 160 Mg ha [16].

At present, some research in Vietnam focuses on the forest carbon-stock estimation based on the field-measurement data for the main types of forest lands, such as evergreen forests, plantation forests, shrub land, and grass land, while there has been no research on mangrove forests [19,20], especially with the use of remote-sensing technology.

Consequently, research on the forest-change assessment and carbon stock estimation for this type of forest is urgently needed in order to provide basic data for assessing the full value of all of the main forest types in Vietnam, which will be used for establishing of regional and national reference levels.

2. Objectives

The objectives of this study are the following: (1) to produce and provide data on mangrove forests for the periods of 1990, 2000, and 2010; (2) to assess mangrove forest changes from 1990 to 2010; and (3) to develop a model for aboveground biomass (AGB) calculating and mapping in order to calculate mangrove forest carbon stock and its change, which will be used as the input data for REL calculations in Vietnam.

3. Study Area and Data

The four main areas of mangroves in Vietnam, based on the geographical location from north to south, are as follows: (1) from Mong Cai to Do Son, (2) from Do Son to Lach Truong (Thanh Hoa), (3) from Lach Truong to Vung Tau, and (4) from Vung Tau to Ha Tien[8,9]. The large areas of mangrove forest are mostly distributed in regions 1 and 4. There is a big difference regarding tree species, tree height, and stock volume in the mangrove forests in those two regions.

The study areas are the mangrove forests located in Quang Ninh province, representative of the mangrove forests distributed in region number 1 in the north of Vietnam, and Ca Mau and Kien Giang provinces, representative of the mangrove forests distributed in region number 4 in the south. Figure 2a shows the location of Quang Ninh, Ca Mau, and Kien Giang provinces of Vietnam. There are 5 main species of mangrove trees in the Quang Ninh province: Aygeceras Corniculatum, Kandelia Candel, Sonneratia Caseolaris, Bruguiera Gymnorrhiza, and Avicennia Marina. Figure 2b shows the mangrove forest in Quang Ninh province. There are 3 main species of mangrove trees in the Ca Mau and Kien Giang provinces: Rhizophoraceae, Bruguiera Gymnorrhiza, and Avicennia. Figure 2c shows the mangrove forest in Ca Mau province.

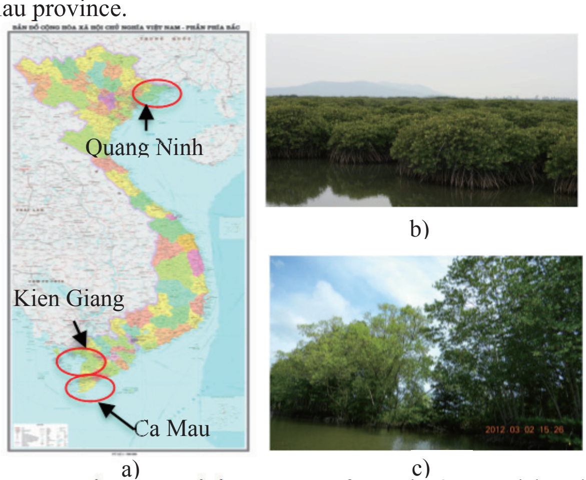

Fig. 2. Study areas and the mangrove forests in Quang Ninh and Ca Mau.

Various data types were used in this study, including satellite data. ALOS PALSAR and Shuttle Radar Topography Mission (SRTM) were used for biomass mapping in 2010 and 2000, respectively. Recently, radar data has been widely used for biomass mapping[21,22]. The longer radar wavelengths (L-band) are less affected by leaves and penetrate herbaceous biomass. Hence, the L-band is commonly used for mapping woody biomass[23]. ALOS PALSAR uses microwaves emitted by an instrument and reflected by the earth to form an image. Polarized microwave signals can be horizontally (H) or vertically (V) transmitted and received, resulting in co- (HH and VV) and cross- (HV or VH) polarized data. In polarimetric systems, the backscatter coefficient σ^0 and phase can be derived for each polarization. The backscatter coefficient of a forest canopy depends upon the interaction of microwaves with leaves, branches, trunks, and—in the case of mangroves—aboveground roots. On the other hand, to quantify forest structures (in terms of height and density) and make estimations of biomass in mangroves, the Digital Elevation Model (DEM) derived from the SRTM has been successfully used[24]. The result of the mangrove height map using SRTM has a mean tree-height error of 2.0 m root-mean-square error (RMSE) over a pixel of 30 m (SRTM) [25].

Integrated-remote sensing and GIS data to monitor and assess the changes of mangrove forest areas with high accuracy and identify the trend of changes allow decision makers to evaluate the ecologically sensitive areas and to analyze the driving forces of forest-cover changes and develop sustainable countermeasures[26]. For this purpose, ALOS AVNIR2 (Advanced Visible and Near Infrared Radiometer type 2) data were used for mangrove forest mapping in 2010; Landsat images were utilized for mangrove forest mapping in the years 1990 and 2000. On the other hand, topographical maps of the National Land use Inventory program conducted by Ministry of Natural Resources and Environment in 2010 at the scale of 1:100.000 in VN2000 projection were used as the base map in creating final maps of the mangrove forest for each study province. The other auxiliary data, such as the existing mangrove forest maps, sample plots, and the reports on mangrove forest changes from 1990 to 2010 in the study areas were used as the references for mangrove forest mapping, accuracy assessment, and their changes analysis as well. Those auxiliary data were mostly collected in the Forest Inventory and Planning Institute (FIPI) of Vietnam, which is responsible for national forest resources change monitoring and assessment for every 5 years, beginning in 1990.

4. Methodology

4.1. Mangrove forest mapping for the period 1990-2010

Figure 3 shows the framework of mangrove forest mapping and change assessment in Vietnam. The satellite images are pre-processed by using color composition, contrast enhancement, and geometric correction based on the topographical map in the VN2000 projection according to the circular No. 973/2001/TT-TCDC issued by the Cadastral Department, dated June 20th, 2001, on the Guideline for the application of national projection of VN2000[27].

The forest and land use status maps in the year 1990, 2000 and 2010 were produced using satellite data acquired during more or less the same year. First, the training-sample sets were established for each period based on the existing data, such as the sample plots, forest and land use maps, and aerial photos. The object-based classification method was then applied to classify the satellite images. By applying this method, the knowledge of the remote-sensing technique as well as the understanding/experiences of the distribution of forest in field will be incorporated into the classification process. The non-image features related to the mangrove forest (such as the characteristic of its distribution based on elevation, distance to the residential area, to the river, and to the dyke system, etc.) can also be used for classification. All of these features can be extracted based on the topographical map. The inputs-image index based on image features such as Normalized Difference Vegetation Index (NDVI), total of gray-value level index (TRRI), ratio-vegetation index (RVI), green-vegetation index (GVI), enhancement-vegetation index (EVI)[28], and some existing parameters were also used for image classification including mean value and standard deviation of each band.

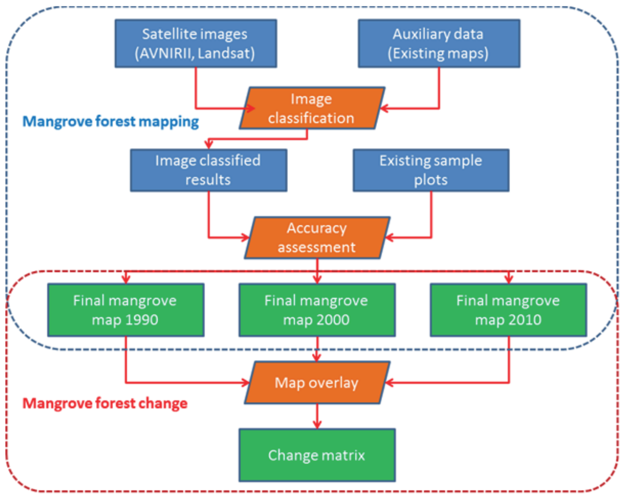

Fig. 3. Framework of mangrove forest mapping and change assessment in Vietnam.

The next step was the segmentation process based on the input parameters, including compactness, shape, and scale parameter. The threshold for each index above for mangrove forests was calculated based on the training areas that will be used for establishing the process tree and rule set for automatic image classification in order to execute the image classification. Classification results for each period have been rechecked by experienced and qualified interpreters for timely supplementary and adjustment. The method applied to check and adjust classification result is on-screen observation. During the checking process, both discussion and cross check were conducted in order to arrive to a common consensus on image-classification results. For the map of 2010, the field check was carried out in cooperation with local organizations such as the Department of Agriculture and Rural Development, Forest Rangers, and Forest Owners to rectify misclassifications and validate the outcome.

4.2. Accuracy assessment

The accuracy assessment for forest and land use maps in 1990 and 2000 was conducted after completing satellite data derived from mangrove forest maps. Ground truth points to assess the accuracy of these maps were identified using historical-inventory data (sample plots) or aerial photos when available. The ground truth points were mapped based on the coordinate of the center of the sample plots or representative area for mangrove forest and other land-use types in aerial photos. In order to calculate the overall accuracy of these mangrove forest maps, the map of ground truth points was overlaid with the generated forest map in the same period and compared. The accuracy assessment of the 2010 forest and land-use map was done by creating random ground truth points across the entire mangrove forest area. At least 30 ground truth points were assigned in this process. Coordinates for all ground truth points were recorded. A field survey for ground truth and accuracy assessment of the mangrove forest map in 2010 was conducted as well. The Overall Accuracy (OA) was calculated by using the formula:

$$OA=(Number\ of\ corrected\ points/Total\ number\ of\ points)*100 \quad (1)$$

The area data assessment and analysis was done using the GIS technique. The mangrove forest maps and the map containing administrative boundaries, forest blocks, and compartments were overlaid, then the attributes of the resulting Geographic Information System (GIS) data layers were used to create and compare extents of mangrove forest areas.

4.3. Assessment and analysis of the causes of mangrove forest and land use change for the period of 1990 to 2010

The mangrove forest maps over the periods were overlaid to build the maps of mangrove forest and land use change. These maps were used for fieldwork to interview, discuss, and meet with the provincial Forest Protection Department (FPD), district FPDs, forestry organizations, and forest owners to find the driving force and the trend of forest and land-use status changes.

The field surveys were conducted to collect information on forest and land use changes from 1990 to 2010. The surveys included an assessment of the impact of forestry policies, the socio-economic factors to the changes in forest resources, an evaluation of the impact of programs and projects of economic development to the changes in mangrove forests, and an assessment of the impact of social factors to the changes in mangrove forests.

Experts including forestry professionals, managers, and local people were consulted at provincial and district levels to gather more information. Survey information was collected from agencies and local people as well. This information was used for analyzing, synthesizing, comparing, and assessing the impact of each policy on forestry, socio-economic development, and other factors involved in the forest changes, as well as the combined effect of these factors to forest change, thereby determining the main factors.

4.4. Biomass mapping

Figure 4 shows the framework of biomass mapping of the mangrove forest in Vietnam[29].

It is mainly composed of two approaches, depicted as A and B in Figure 4. Approach A employs an allometric equation of biomass as a function of the diameter at breast height (DBH) [30] (or tree height[31]), which is estimated by in-situ measurements with Global Positioning System (GPS) location. ALOS PALSAR measurements with HH and HV polarization are downscaled to those match-up dataset, which enables the direct measurement of the AGB of mangrove trees. Approach B uses an optical sensor to classify data into ecosystems and to relate mangrove forest classification with a sample-plot biomass with species and tree ages.

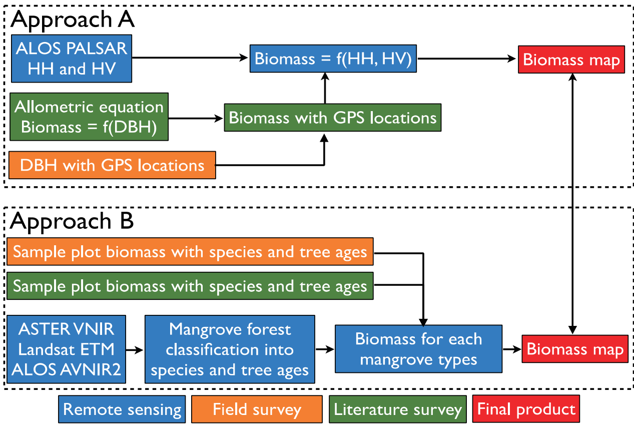

Fig. 4. Flowchart of a framework of above ground biomass mapping of the mangrove forest in Vietnam.

Field surveys were carried out from 2010 to 2012, and the in-situ data were collected at the sample plots with 30x30 meter size and 10 meters transecting at difficult-access areas in Quang Ninh, Ca Mau and Kien Giang provinces. The typical sampling method was applied to select the sample plots with the following criteria: (i) to spread over the area of mangrove distribution in the province, (ii) to represent for different coverage levels of mangrove forest (thick, medium, and open), and (iii) to be scattered in the area of distribution of different mangrove species. The measured parameters in sample plots include the number of trees in a plot, crown diameter (for large trees), tree height (TH), canopy height from the bottom, and GPS photos.

SRTM3 data were used to estimate the TH of the mangrove forest area, then the relationship between TH and AGB [31] was utilized to calculate AGB for the year 2000. The sample plots used for measuring biomass is available from the projects or research, which has been done in Quang Ninh, Ca Mau and Kien Giang provinces in the year 2000, such as the forest-changes monitoring and assessment program implemented by FIPI, and the research on mangrove biomass calculating based on the field measurement data conducted by Society for International Cooperation of Germany (GIZ) project [16]. The carbon stock was calculated by multiplying the biomass volume with 0.5. In this research, because there were no sample plots conducted during the 1990s in study provinces and the satellite data was not enough to calculate the carbon stock in 1990, the average value of carbon stock per hectare of the mangrove forests in 2000 and 2010 were calculated and the results was extrapolated to calculate the carbon stock of the mangrove forest in 1990.

5. Results and Discussion

5.1. Mangrove forest mapping

The mangrove forest maps of Quang Ninh, Ca Mau, and Kien Giang provinces in 1990, 2000, and 2010 are shown in figures 5, 6, and 7, where green represents a mangrove forest. Table 1 is the confusion matrix of Quang Ninh province for the years 1990, 2000, and 2010, where the land cover was classified as either mangrove forest or other. Table 1 is the ground truth for accuracy assessment for Quang Ninh, Ca Mau, and Kien Giang provinces. This table also shows the overall accuracy of the mangrove forest maps of 3 provinces in 1990, 2000, and 2010. The accuracy of mangrove forest mapping by using satellite images is around 90%, where Kien Giang province has the lowest value.

Table 1. Accuracy assessment.

Province	1990			2000			2010		
	Correct	Incorect	Accuracy %	Correct	Incorect	Accuracy %	Correct	Incorect	Accuracy %
Quang Ninh	21	2	91,3	27	3	90,0	42	4	91,3
Ca Mau	25	2	92,6	32	3	91,4	54	5	91,5
Kien Giang	16	2	88,9	26	4	86,7	37	5	88,1

The main cause of this result is that the mangrove forest is mostly distributed in a narrow segment along the coastline; there are some areas that are only about 100 meters wide, while the spatial resolution of the satellite images being used is 30 meters. This will lead to the confusion of classified results. Besides, the mangrove forests in Quang Ninh and Ca Mau provinces are distributed in a relatively large concentration; therefore, the classified result has less confusion.

5.2. Mangrove forest changes assessment

The change of mangrove forests in Quang Ninh, Ca Mau and Kien Giang provinces from 1990 to 2010 is shown in figure 5, 6 and 7.

Fig. 5. Mangrove forest change in Quang Ninh province.

Fig. 6. Mangrove forest change in Ca Mau province.

Fig. 7. Mangrove forest change in Kien Giang province.

In the red circles inside these maps, the area of mangrove forests had been decreased gradually in every 10-year period studied in this research work. This change can be seen definitively in figure 5, 6, and 7, which shows the decrease in area of the mangrove forest from 22,283.32 ha in 1990 to 17,353.73 ha in 2010. Tables 2, 3, and 4 show in greater detail how the mangrove forest area in Quang Ninh province changed from 1990 to 2010. It is easy to recognize that the rate of deforestation in the period of 2000–2010 is higher than the period of 1990–2000.

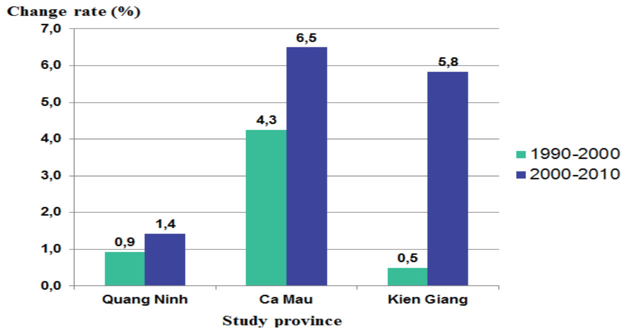

Fig. 8. Mangrove forest change rate per year.

The decreasing of the mangrove forest areas have taken place not only in Quang Ninh province in the north of Vietnam, but also in Ca Mau and Kien Giang provinces in the south of Vietnam. Figures 6 and 7 show the mangrove forest maps of Ca Mau and Kien Giang provinces, figures 8 show the annual mangrove forest change rate of these provinces in the period 1990 - 2000 and 2000 - 2010.

Table 2. Change matrix between 1990 and 2000 of Quang Ninh (unit:ha).

Year 1990	Year 2000		
	Other	Mangrove	Total
Other	6,694.0	6,517.6	**13,211.6**
Mangrove	8,577.3	13,706.0	**22,283.3**
Total	**15,271.3**	**20,223.6**	**35,494.9**

Table 3. Change matrix between 2000 and 2010 of Quang Ninh (unit:ha).

Year 2000	Year 2010		
	Other	Mangrove	Total
Other	6,872	8,399	**15,271**
Mangrove	11,269	8,954	**20,224**
Total	**18,141**	**17,354**	**35,495**

Table 4. Change matrix between 1990 and 2010 of Quang Ninh (unit:ha).

Year 1990	Year 2010		
	Other	Mangrove	Total
Other	6,518	6,694	**13,212**
Mangrove	11,624	10,660	**22,283**
Total	**18,141**	**17,354**	**35,495**

Similar to the mangrove forest areas in Quang Ninh, the mangrove forest areas in Ca Mau and Kien Giang were decreased (shown clearly in the red circles on these maps), especially from 2000 to 2010. Tables 5, 6, and 7 show the change matrices from 1990 to 2010 of the mangrove forest areas in Ca Mau, and tables 8, 9, and 10 show those of Kien Giang province in the same period.

Table 5. Change matrix between 1990 and 2000 of Ca Mau (unit:ha).

Year 1990	Year 2000		
	Other	Mangrove	**Total**
Other	1,906.11	24,721.22	**26,627.33**
Mangrove	64,025.29	28,334.45	**92,359.74**
Total	**65,931.40**	**53,055.67**	**118,987.07**

Table 6. Change matrix between 1990 and 2010 of Ca Mau (unit:ha).

Year 1990	Year 2010		
	Other	Mangrove	**Total**
Other	20,495.24	6,132.09	**26,627.33**
Mangrove	79,906.62	12,453.12	**92,359.74**
Total	**100,401.86**	**18,585.21**	**118,987.07**

Table 7. Change matrix between 2000 and 2010 of Ca Mau (unit:ha).

Year 2000	Year 2010		
	Other	Mangrove	**Total**
Other	58,980.86	6,950.54	**65,931.40**
Mangrove	41,421.00	11,634.67	**53,055.67**
Total	**100,401.86**	**18,585.21**	**118,987.07**

Table 8. Change matrix between 1990 and 2000 of Kien Giang (unit:ha).

Year 1990	Year 2000		
	Other	Mangrove	**Total**
Other	102.82	1,469.27	**1,572.09**
Mangrove	2,024.90	9,091.55	**11,116.45**
Total	**2,127.72**	**10,560.82**	**12,688.54**

Table 9. Change matrix between 1990 and 2010 of Kien Giang (unit:ha).

Year 1990	Year 2010		
	Other	Mangrove	**Total**
Other	1,415.78	156.31	**1,572.09**
Mangrove	6,876.58	4,239.87	**11,116.45**
Total	**8,292.36**	**4,396.18**	**12,688.54**

Table 10. Change matrix between 2000 and 2010 of Kien Giang (unit:ha).

Year 2000	Year 2010		
	Other	Mangrove	**Total**
Other	2,020.54	107.18	**2,127.72**
Mangrove	6,271.82	4,289.00	**10,560.82**
Total	**8,292.36**	**4,396.18**	**12,688.54**

The most apparent cause of deforestation is the conversion of mangrove forests to aquaculture land. On the other hand, during the past 20 years, the economy of Vietnam has been developing at a high rate; consequently, a part of mangrove forest area has been used to develop seaports, economic zones, and industrial parks[11]. In addition, because of the improvement in social life, the demand for housing, tourism, and coastal recreation has been increased. As a result, some areas of coastal wetlands, including mangrove forest areas, have been used to build new urban areas and in the development of tourism. The main driving force of forest degradation is aquaculture development in which areas with dense mangrove forest coverage need to be adjusted to create an optimal environment for aquaculture farming by reducing the canopy coverage by 40%–50%.

During the last decade, with the increasing awareness of the role of mangrove forests for environmental protection and the enhancement of social life, some projects have been started that invest in mangrove forest protection, rehabilitation, and development. Many low-quality mangrove areas have been renovated and large areas of wetland where mangrove forests formerly existed have been replanted through the national program, projects such as 327, 661, PAM, Red Cross etc., and programs developed by international organizations such as Japan International Cooperation Agency (JICA), World Bank, and Reconstruction Credit Institute of Germany (KfW)[11]. The achievements have contributed to increasing the area and improving the quality of mangrove forests.

5.3. AGB calculation

Figure 9 is the relationship between TH and backscatter coefficients σ^0 of HH and HV of ALOS PALSAR data in the mangrove forests in Quang Ninh, Ca Mau, and Kien Giang provinces.

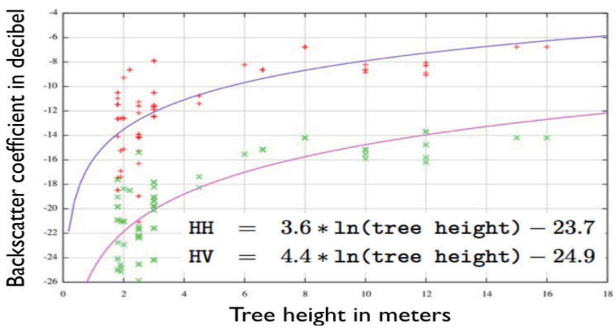

Fig. 9. Relationship between tree height and backscatter coefficients of HH and HV in the mangrove forest of Vietnam.

The results show that there is a positive relationship between σ^0 and tree height (TH), with the larger sensitivity to tree height found at HV. Moreover, strong differences are observed between polarizations at HH and HV.

A regression analysis was carried out between tree height and σ^0 at HH and HV polarizations, and it was characterized by Eq. (1) and Eq. (2) with root mean square errors of 2.2 and 2.0 (m), respectively.

$$HH = 3.6*\ln(TH) - 23.7 \quad (1)$$

$$HV = 4.1*\ln(TH) - 25.3 \quad (2)$$

Lefsky[31] reported the relationship between aboveground biomass (AGB) in kilograms and TH in meters as shown in Eq.

(3):

$$AGB = 0.098 * TH^2 + 20.7 \quad (3)$$

By solving Eq. (2) and Eq. (3), we estimated AGB from the HV image directly.

The relationship between aboveground tree weight (AGW) in kilograms and DBH in centimeters is shown in Eq. (4) [29].

$$AGW = 0.25 * DBH^{2.46} \quad (4)$$

This equation is suitable for the mangrove species in Vietnam[31]. Based on this relationship, AGW is calculated from DBH[29] which is the most suitable investigate factor of mangrove forest in Vietnam in comparing with other factors.

Figure 10 shows the PALSAR HV image and AGW map over the mangrove area of Quang Ninh province. Brighter color indicates higher values of AGW, which ranges from 6.4 (t/ha) to 16.0 (t/ha) [29].

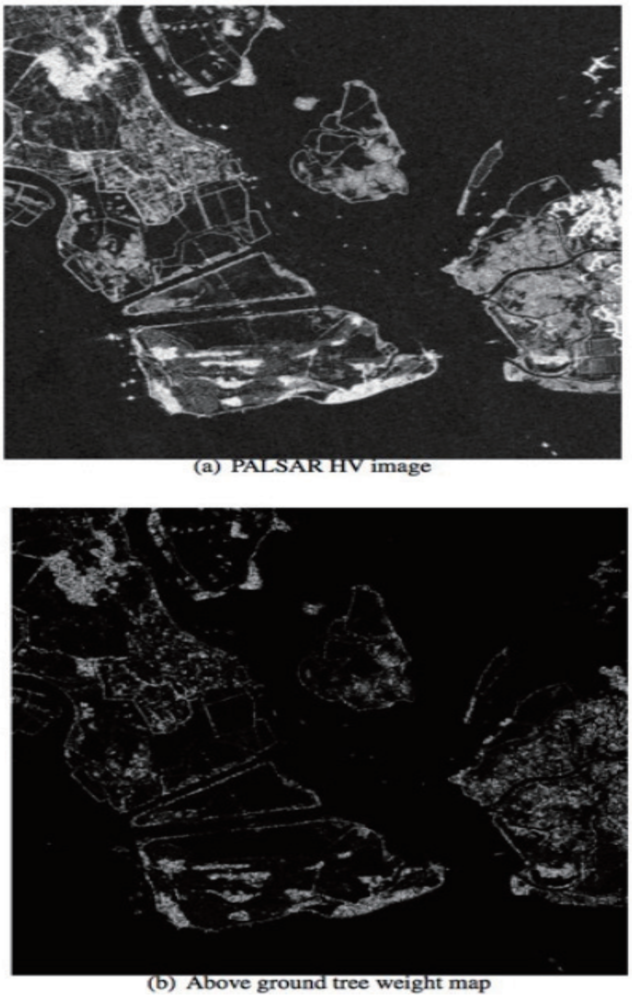

Fig. 10. PALSAR HV image and AGW map of an area in Quang Ninh province, Vietnam, in 2010 [29].

Figure 11 shows the AGB map over the mangrove area in 2009 of Ca Mau and Kien Giang provinces estimated from ALOS PALSAR 50 m mosaic dataset.

Table 11 is the result of an AGB estimation for Quang Ninh province in 1990, 2000, and 2010. Table 12 is the result of an AGB estimation for Ca Mau and Kien Giang provinces in 1990, 2000, and 2010.

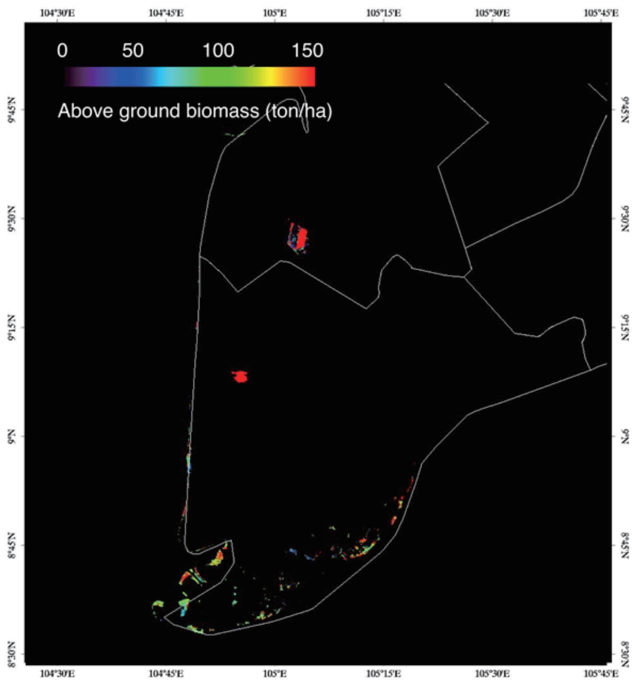

Fig. 11. AGB map of an area in Ca Mau and Kien Giang province, Vietnam, in 2009.

Table 11. AGB of Quang Ninh province in 1990, 2000 and 2010.

Year	1990	2000	2010
Area (ha)	22,283.32	20,223.57	17,353.73
(ton of Carbon)	687,848	550,476	460,967

Table 12. AGB of Ca Mau and Kien Giang provinces in 1990, 2000 and 2010.

Year	1990	2000	2010
Area (ha)	103,476	63,616	22,981
(ton of Carbon)	3,006,145	1,610,988	518,124

It revealed that the total carbon stocks volume of both study areas were dramatically decreased. In Quang Ninh Province, the total carbon stocks volume in 2010 is accounting for 67% compared with the year of 1990, the average decrease of 1.6%/year. Whereas in Ca Mau and Kien Giang Province, the total carbon stocks volume in 2010 is only accounting for 17.2% compared with the year of 1990, an average decrease of 4.1%/year.

6. Conclusions

Remote sensing technology was successfully used for forest status mapping, especially for mapping in the past. The method of automatic classification based on object-oriented approach with high applicability in the interpretation of satellite images, combined with the field survey to verify and additional updates the classified results was applied for forest status mapping with precision to meet the requirements, reduce costs and labor consuming.

Remote sensing and GIS technology was objectively and effectively applied in the mangroves changes monitoring and assessment in three study provinces. The causes and driving force of forest change were identified and analyzed. This is an important basis for determining the management and protection solutions in order to reduce the risk of forest degradation and deforestation in the future. In addition, the mangrove forest maps and data, as well as the driving force of forest changes, will also be used as references for the establishment of a forest protection and development plan for three study provinces, according to Decision No. 57/QD-TTg issued by the Prime Minister in 2012 on a forest protection and development plan[32].

The active remote sensing data are effectively used in the research of biomass mapping for mangrove forest by determining the correlation between SAR backscatters values on the image and investigate factors such as tree diameter, height to determine the biomass of mangroves, which will be used for calculating the carbon stocks of mangroves in 3 study provinces for each period. These studied methods will be applied for calculating carbon-stock volumes of mangrove forests throughout the country, which will be used as input data for establishing RELs/RLs for others provinces/bio-ecoregions (Decision No. 799/QD-TTg, 2012, on national action plan for REDD+ activity in Vietnam[4]).

In the future, further information on AGB as well as AGW is required to validate the results, either through field surveys or literature surveys. On the other hand, the other carbon pools, such as below ground biomass, soil carbon, and dead wood should also be investigated to understand the carbon sequestration over the entire mangrove ecosystem so that these methods will be fully applied for calculating the carbon stock of this forest type in Vietnam in particular, and in other countries in general.

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