https://doi.org/10.25686/foreco.2023.92.18.001

CARBON STOCK CHANGES IN MANGROVE OVER PERIODS IN QUANG YEN TOWN, QUANG NINH PROVINCE

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Mangrove forests are often located in estuaries and tropical and subtropical coastal areas, where the tides come in and out every day. Mangroves play a significant role in human life in these areas. The study used PlanetScope images in 2017, 2020 and 2023 combined with the NDVI index to build the maps of mangrove area and determine biomass and carbon stocks for Quang Yen town. The results showed that the area of mangrove forests in Quang Yen town acconted for 3470.026, 3358.81 and 3418.10 ha in 2017, 2020, and 2023, respectively. The accuracy of the mangrove forest map between the years was 88 %, 88 % and 88 %, respectively. The total aboveground biomass (AGB) reserves acconted for 18,302,976 t (tonnes), 94,104,161 t and 145,035,226 t. The total bove ground carbon stock (AGC) was 8,693,913 t, 44,699,477 t and 68,891,730 t for 2017, 2020 and 2023. The use of remote sensing technology to build carbon stock maps for mangrove forests in Quang Yen town can be applied to other provinces. These findings are essential for sustainable mangrove management in the study area and finding suitable solutions. Blue Carbon and Payment for Ecosystem Services are effective solutions that can be applied here to minimise risks and enhance the effectiveness of mangrove forests in the future.

Keywords: *biomass, carbon stocks, PlannetScope, mangrove.*

Introduction

Mangroves play a vital role in maintaining the ecological balance of the coastal environment (Rahmadi et al., 2023). Not only do they protect and regenerate coastlines but also provide habitat for many animal and plant species (Widayanti et al., 2023). In Vietnam, mangrove forests are considered an important natural resource (Veettil et al., 2019). However, these mangrove forests are facing many challenges due to human activities, including habitat loss, resource depletion, and ecosystem degradation (Onyena and Sam, 2020; Son et al., 2023). These issues require attention and solutions to protect and sustainably develop this valuable ecosystem.

Nowadays, remote sensing technology has emerged as an important tool of forest management (Son et al., 2023). In particular, remote sensing technology has revolutionized the forestry sector, specifically in monitoring and managing mangrove forests. This advanced technology helps collecting data across large areas, including inaccessible ecosystems, providing a comprehensive view of the change, health, and carbon storage capacity of ecosystems (Zhu et al., 2021). Through satellite imagery from such systems as PlanetScope, Landsat and Sentinel, changes in mangroves can be monitored over time periods (Hoa et al., 2023; Quang, Hoa, 2022; Narayani, Nagalakshmi, 2023). This allows the detection of degraded or restored areas and provides incentives for conservation and effective management policies (Hoa et al., 2023; Nguyen et al., 2022). Furthermore, remote sensing technology plays an important role in monitoring and assessing carbon storage fluctuations in mangrove forests (Hoa et al., 2023; Zahra Safira Aulia, 2022). By combining remote sensing data with field measurements, accurate and reliable information on carbon stocks can be obtained (Hoa et al., 2023; Nguyen et al., 2022). This information is essential to better understand and effectively apply mangrove protection and management solutions, such as Blue Carbon, Carbon Payments for Environmental Services (C-PFES), and reduce emissions from deforestation and forest degradation (REDD+) (Friess, 2023; Hilmi et al., 2017; Nguyen et al., 2022).

Quang Yen town in Quang Ninh province has a relatively large area of mangrove forests, which play a key role in the ecosystems of Northern Vietnam. However, the issue of applying remote sensing technology in mangrove ecosystem is currently understudied. In particular, there have been no studies on the changes in mangrove areas, forest reserves, or carbon stocks. Therefore, this study focuses on mangrove forests in this region. The research aimed: 1) to build maps of mangrove forests and analyze mangrove area changes in Quang Yen town in 2017, 2020 and 2023; 2) to calculate carbon stocks for each year and analyse the dynamics of change. These research results will play a very important role in providing solutions for sustainable management and protection of mangrove forests in Quang Yen town in particular and in areas with similar ecological conditions in general. The results of this study will significantly contribute to elucidating the importance of mangrove ecosystems and pave the way for future conservation efforts.

Material and methods

Study site

Quang Yen is a coastal town located in the south-west of Quang Ninh province (Figure 1). Quang Yen town has a tropical monsoon climate. Therefore, the climate is hot, humid, and rainy. The average temperature in 2023 was 24ºC. The average annual rainfall is about 1,444 mm (Quang, Hoa, 2022). The amount of precipitation in Quang Yen town varies throughout the year, dipending by season. Thus, there are two distinct seasons: the rainy season and the dry season. This has a great impact on agriculture, forestry and fishery production in the area. In Quang Yen, there are two main types of seasonal winds: the northeast wind and the southeast wind. The town borders the sea, so it is often affected by storms. Storms often happen from May to October. July and August have the highest number of storms. The network of rivers in Quang Yen is quite well-developed, most of them flow in the northwest - southeast direction and then into the sea through estuaries. The coast of Quang Yen town is located in Ha Long Bay, the seabed is shallow, and the average depth of the bay is from 4 - 6 m (Quang, Hoa, 2022).

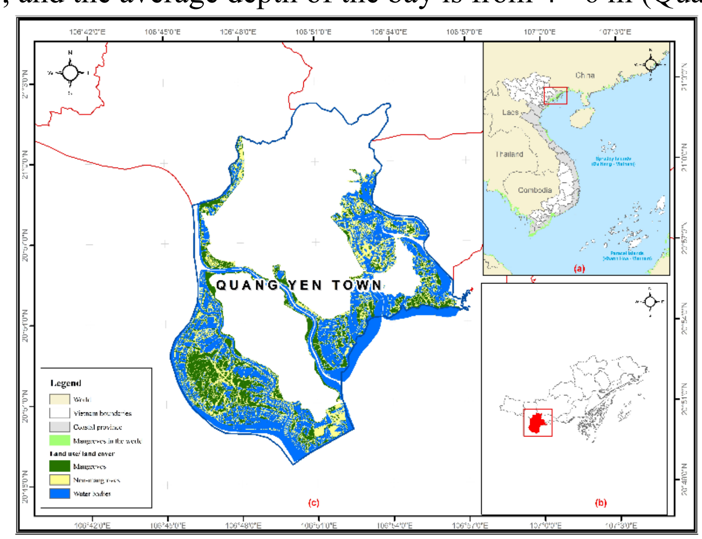


Figure 1. Study area. Vietnam map (*right*), Quang Yen town (*left*)

Research methodology
The figure below illustrated the materials and methods used in the research.

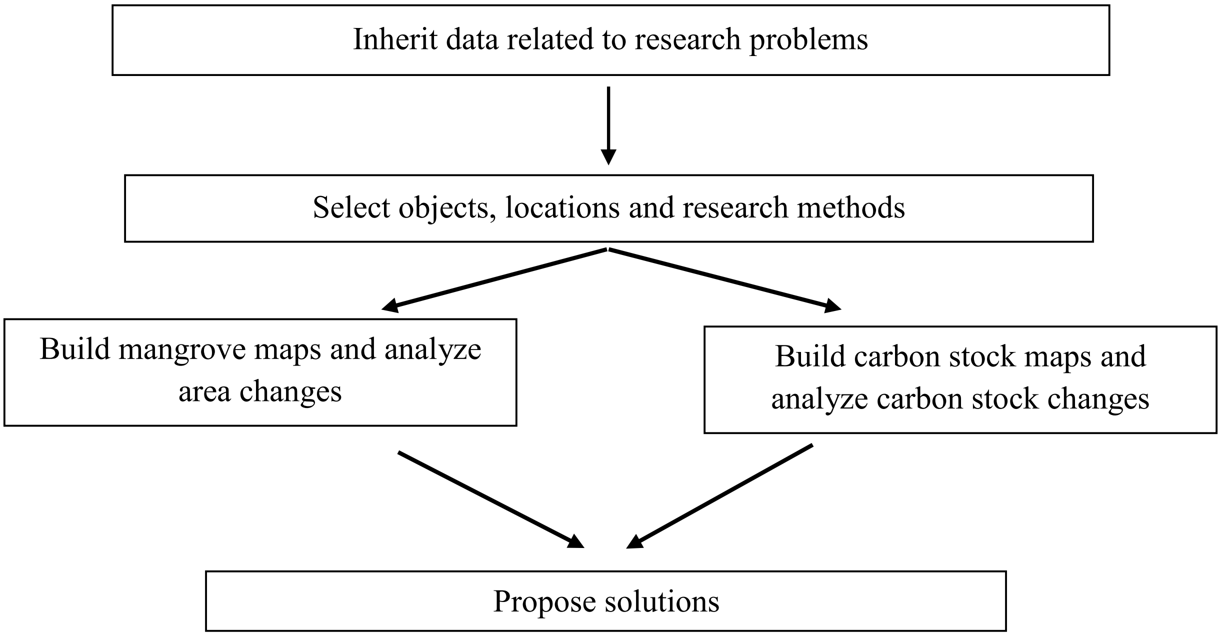


Figure 2. Diagram of research steps: from data collection to solution proposal

Data collection methods

The study relied on the annual socio-economic reports of Quang Ninh province and forest maps from the Quang Ninh forest protection department. Project reports have been conducted in Quang Ninh Province.

In oreder to build a current status map and estimate above-ground carbon stocks for mangrove forests in Quang Yen town, the study used PlannetScope images (Table 01) (www.planet.com).

Table 1. **Remote sensing images used in this research**

No.	Image	Date	Resolution
1	20171219_024815_1006_3B_AnalyticMS_SR	19/12/2017	3m x 3m
	20171219_024814_1006_3B_AnalyticMS_SR		
	20171219_024816_1006_3B_AnalyticMS_SR		
	20171219_024816_1006_3B_AnalyticMS_SR		
2	20201129_023936_222b_3B_AnalyticMS_SR	29/11/2020	3m x 3m
	20201129_023934_222b_3B_AnalyticMS_SR		
	20201129_023931_222b_3B_AnalyticMS_SR		
3	20230531_030857_2473_3B_AnalyticMS_SR	31/05/2023	3m x 3m
	20230531_030857_2473_3B_AnalyticMS_SR		

Data processing methods

Building mangrove forest maps in Quang Yen town

To build the mangrove forest map, the study used the normalized difference vegetation index (NDVI) combined with field survey results. The formula of NDVI was as follows:

$$NDVI = \frac{Band_{NIR} - Band_{RED}}{Band_{NIR} + Band_{RED}} \quad (1)$$

in which: $Band_{NIR}$ was Band 4 and $Band_{RED}$ was Band 3.

Each value range of NDVI corresponded to each type of land use. These were then used to construct landuse and landcover maps for each selected year. The study used Google Earth Pro and GPS checking points to accurately determine NDVI thresholds for each landuse type: mangrove, non-mangrove, and water surface (Rahman et al., 2022; Son et al., 2022). Finally, the study used ArcGIS 10.4.1 software to classify into three landcover types: mangrove, non-mangrove, and water areas through the reclassify tool (Ormsby et al., 2010).

Accuracy assessment for mangrove maps

To evaluate the accuracy of mangrove maps, the study established survey points for different landuse types. For 2017 and 2020, the study used high-resolution satellite imagery provided by Google Earth Pro (a total of 200 sampling points, including 100 points for mangroves; 60 points for non-mangrove areas and 40 points for water bodies) combined with 200 GPS points randomly collected from fieldwork in 2023 to evaluate the accuracy of landuse classification.

The study used following indicators: overall accuracy, Kappa coefficient and User's/Producer's accuracy in order to assess the accuracy of land use classification. Overall accuracy shows the number of correctly classified pixels. The Kappa coefficient is a statistical model that is used to eveluate the level of agreement between the two raster layers: observed and expected layers. User's/Producer's accuracy is the degree to which classified map is accurate on the ground (Ormsby et al., 2010; Skidmore, 2017).

Estimating biomass and carbon stocks of mangrove forests based on remote sensing images

The study used a regression equation developed for the independent variable (NDVI) by (Myeong et al., 2006) to calculate above-ground biomass combined with field surveys to estimate biomass values and carbon stocks more accurately.

$$AGB = 0.507 * e^{(NDVI*9.933)} \quad (2)$$

The carbon content could be obtained by multiplying the total biomass by a conversion factor of 0.475 (47.5 % biomass).

$$AGC = AGB * 0.475 \quad (3)$$

Then build biomass and carbon stocks maps using tools in ArcGIS as follows: Arctoolbox => Spatial Analyst tools => Raster Calculator (Son et al., 2023; Son et al., 2022).

Results and discussion

Maps and area changes in mangrove forests in Quang Yen town

Current status of mangrove forests over the years

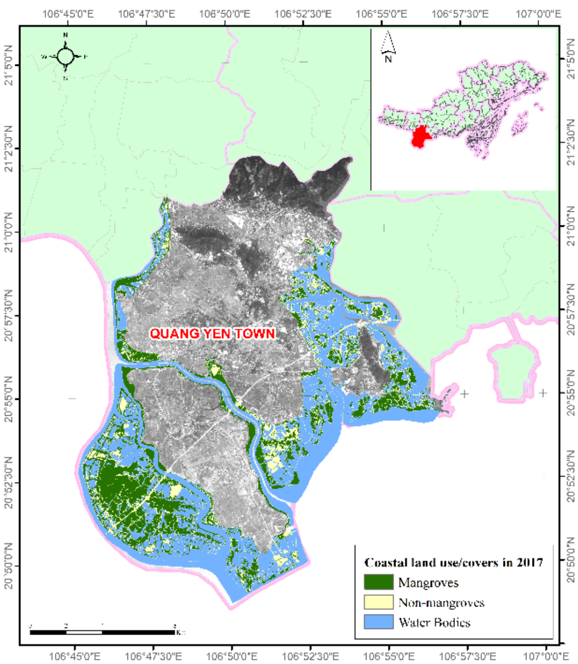
Table 2 provides data on the estimated area of landuse types in Quang Yen town, Quang Ninh province through analysis of PlanetScope images. Calculation results showed that the town had the least mangrove forests in 2017 and the most mangrove forests in 2023.

In 2017, the estimated area of mangrove forests was 3,470.03 ha, the non-mangrove area was 1,992.52 ha and the water surface area was 7,375.31 ha. In 2020, the estimated area of mangrove forests decreased to 3,358.81 ha. By 2023, the estimated area of mangrove forests increased to 3,418.1 ha, the non-mangrove area increased to 2,793.18 ha, and the water surface area decreased, reaching 6,626.57 ha. The location and area of landuse types over years are presented in Figure 3.

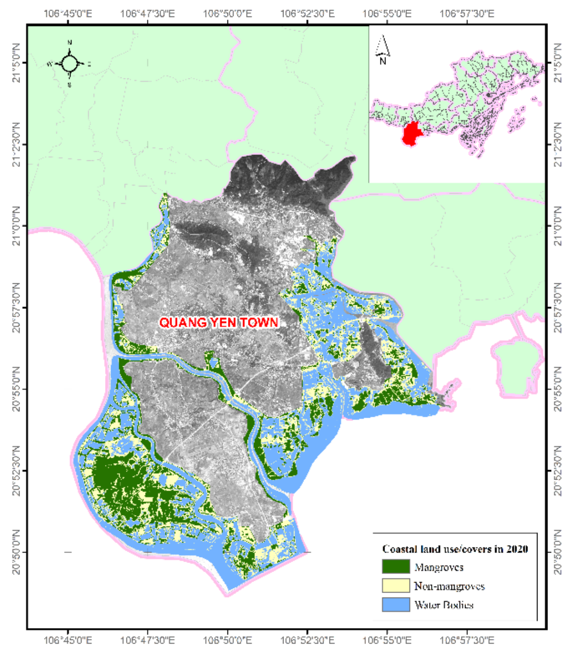
Table 2. **Estimated area of each landuse type in Quang Yen town**

No.	Landuse	2017	2020	2023
1	Mangrove	3470.03	3358.81	3418.10
2	Non-Mangrove	1992.52	3466.40	2793.18
3	Water bodies	7375.31	6012.64	6626.57
	Total	**12837.85**	**12837.85**	**12837.85**

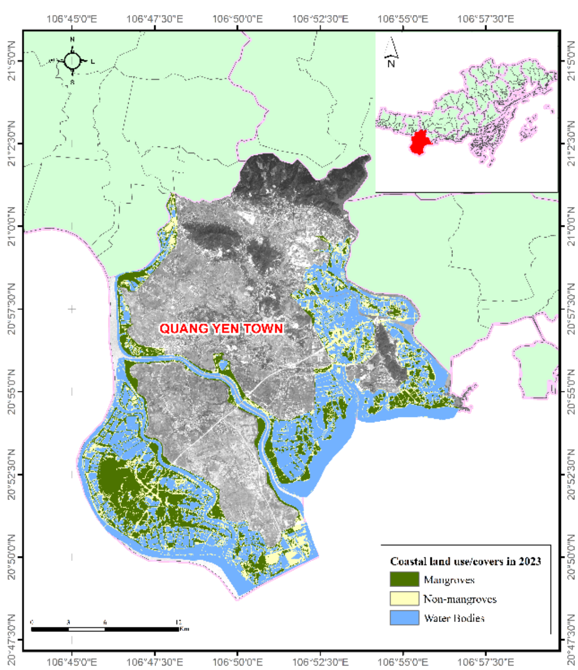
Note: Non-mangroves: Rice paddy field/agriculture, residential areas/built-up areas, and muddy flats; water body: shrimp ponds, rivers, and open sea water



a)



b)



c)

Figure 3. Landuse maps in different years: a) 2017, b) 2020 and c) 2023

Accuracy assesment for landuse maps in Quang Yen town

The NDVI values between 2017, 2020, and 2023 had slight changes. The average value of NDVI ranged from 0.17 to 0.32. For non-mangrove areas, NDVI values decreased from 0.01 to -0.03 and then stabilized. In water bodies, NDVI values fluctuated strongly decreasing from -0.35 to -1. These variations may reflect wide variations in the structure and quality of mangrove forests and water bodies. Besides, NDVI values can be affected by many different factors, including weather, tides, environmental factors, and limitations of remote sensing data.

Table 3 shows the classification accuracy and variations across landuse types over the period of tume under study. In 2017, the User Accuracy for mangroves was 89 % and the Producer's Accuracy was 85 %. In 2020, the User's Accuracy was the same as in 2017: 89 %, while the Producer's Accuracy decreased slightly to 87 %. In 2023, the User's Accuracy for mangroves was 87 %, while the Producer's Accuracy decreased to 83 %. This result is similar to some previous studies for mangrove forests in Vietnam (Hoa et al., 2023; Son et al., 2023; Son et al., 2022).

Table 3. **Accuracy assessment for each cover class in Quang Yen town**

No.	LULC	2017				2020				2023			
		UA %	PA %	OV %	KC	UA %	PA %	OV %	KC	UA %	PA %	OV %	KC
1	Mangroves	89	85	88	0.79	89	87	88	0.82	87	83	88	0.80
2	Non-mangroves	76	89			88	83			83	86		
3	Water bodies	90	88			88	92			90	92		

Note: UA: User's accuracy; PA: Producer's Accuracy; OA: Overall Accuracy; KC: Kappa coefficient.

Changes in the area of landuse types in Quang Yen town over the period 2017-2023

Figure 4 indicates the area change of landuse types in Quang Yen town, Quang Ninh province, between 2017 and 2023. During the period 2017-2020, the area of mangrove forests decreased by 111,215 ha, while the area of other land covers increased by 1473.88 ha and the area of water bodies decreased by 1362.67 ha. From 2020 to 2023, the area of mangroves increased by 59.29 ha, while the estimated area of non-mangroves decreased by 673.22 ha and the area of water bodies increased by 613.93 ha. Overall, from 2017 to 2023, the estimated area of mangroves was reduced by 51.93 ha, the area of non-mangroves increased by 800.66 ha and the area of water bodies decreased by 748.74 ha. Therefore, attention should be paid to developing and planting more mangrove forests in the study area. However, these results still have certain limitations, such as the lighting and weather conditions.

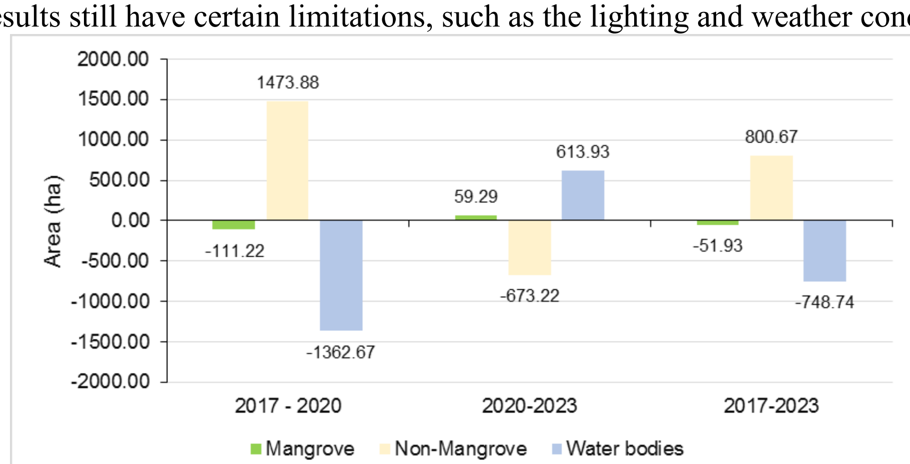


Figure 4. Area changes of mangroves over periods. (-) represents a decrease, (+) represents an increase.

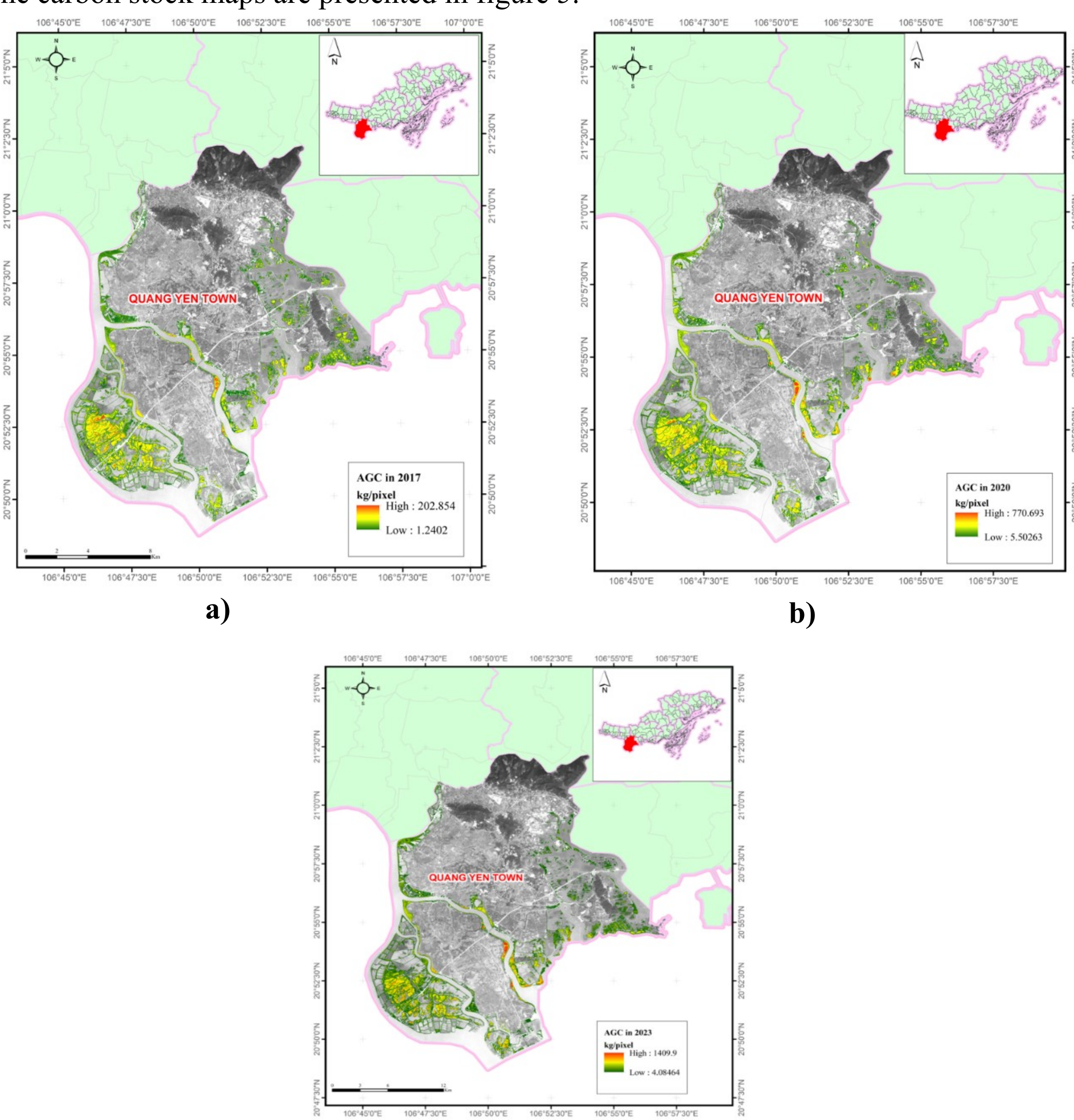
Maps and carbon stocks changes of mangrove forests in Quang Yen town

Carbon stock maps in Quang Yen town. The regression models presented in the method section were used to estimate biomass and carbon stocks of mangrove forests in Quang Yen town, Quang Ninh province. The results of AGB and AGC are shown in table 5 below.

Table 5. **AGB and AGC of mangrove forests in Quang Yen town**

No	**AGB/AGC (*ton/ha*)**	**2017**		**2020**		**2023**	
		AGB	**AGC**	**AGB**	**AGC**	**AGB**	**AGC**
1	Min	2.61	1.24	11.58	5.5	8.6	4.08
2	Max	427.06	202,85	1,622.51	770.69	2.968.21	1,409.90
3	Mean	47.47	22.55	252.15	119.77	381.88	181.39
4	SD	48.48	23.03	246.65	117.16	436.26	207.22
5	**Total**	**183,029,764**	**86,939,135**	**941,041,6133**	**446,994.765**	**1,450,352,259**	**688,917,299**

The carbon stock maps are presented in figure 5.



a) b)

c)

Figure 5. Carbon stock maps in different years: a) 2017, b) 2020 and c) 2023

Changes in carbon stocks of mangrove forests in Quang Yen town

The results showed that biomass and carbon stocks in the study area both increased gradually from 2017 to 2023. Biomass increased by 126,732,250 t/ha and carbon stocks increased by 60,197,817 t/ha. Although the area of mangrove forests has decreased slightly, the quality of the forests has improved significantly due to local forest protection and tending measures. Therefore, biomass and carbon stocks have increased.

If carbon is sold at different prices, this will be a significant source of income for households and agencies from protecting and developing mangroves. Particularly, with a carbon price of 5 USD/t CO_2, the total accumulated carbon value will be 30,782,374,987,711 VND. If the carbon price is increased to 11 USD/t CO_2, the total accumulated carbon value will increase to 67,721,224,972,964 VND. And finally, if the carbon price is 15 USD/t CO_2, the total accumulated carbon value will be 92,347,124,963,133 VND. However, the specific carbon price depends on a variety of factors, including national and international policies as well as economic and environmental factors. Currently, 27 countries have applied carbon taxes, but it is unclear how many countries apply specific prices such as $5, $10, or $15. For Vietnam, considering a specific carbon price will require more careful research on the country's specific economic, political, and environmental factors. This may include considering the potential consequences of introducing a specific carbon price, as well as the opportunities and challenges associated with implementing carbon pricing policies.

Table 6. **Estimated biomass and carbon stocks of mangrove forests in Quang Yen town**

No.	Years	2017	2020	2023
1	ΣAGB (*t/ha*)	18,302,976	94,104,161	145,035,226
2	ΣAGC (*t/ha*)	8,693,913	44,699,477	68,891,730
3	ΣACS (*t/ha*)	31,906,662.54	164,047,078.87	252,832,648.77

Note: AGB: Above-Ground Biomass; AGC: Above-Ground Carbon Stock; ACS: Amount of Carbon Sequestration (https://wise.com/).

Proposing some potential solutions for sustainable mangrove management

Blue Carbon – a natural climate solution

Blue Carbon (BC) is the term used to describe organic carbon that is accumulated and sequestrated by the oceans and coastal ecosystems, especially by vegetated coastal ecosystems including seagrass meadows, tidal marshes, and mangrove forests (Macreadie et al., 2019).

Blue carbon may incentivize mangrove conservation and restoration between ecosystem service buyers and providers to change land use practices or otherwise prevent deforestation through the PES mechanism. PES would provide a financial incentive to reduce the anthropogenic drivers of mangrove loss by using potential financing mechanisms like mandatory carbon credit schemes like the Clean Development Mechanism under the Kyoto Protocol of the United Nations Framework Convention on Climate Change or voluntary carbon credit markets (Friess, 2023). Key lessons learnt in PES implementation can be drawn from various projects in terms of substantial upscaling and investments to reach appreciable impacts on a significant reduction of GHG emissions and local livelihood improvements. Mangrove forests can be influenced the coastal management decisions that potentially change local hydrodynamics and increase erosion (Friess et al., 2020). Furthermore, anthropogenic intervention in upstream catchments may influence the health of mangrove forests through an increase in fluvial pollution or a reduction in the sediment budget. More importantly, non-anthropogenic influences, including tropical storms/cyclones may cause the loss of carbon, but cannot be controlled. These factors are external to the PES site, they should be considered outside of the control of a PES site manager (Friess et al., 2015). Therefore, mangrove PES projects should be framed against the levels of risk that can affect carbon gains. This risk also needs to be assessed, mitigated, or accommodated and requires management actions like credit buffers where more credits are generated than sold to compensate for losses or a spatially large-scale threat assessment (Friess et al., 2015; Friess et al., 2020).

Blue Carbon and REDD+

REDD+ implementation would improve the ecosystem services of mangrove forests, including biodiversity conservation, nutrient cycling, pest control, pollination, production, and water quality improvements (Ahmed, Glaser, 2016). Mangrove restoration through REDD+ is very important for sustainable coastal aquaculture to provide socio-economic benefits among farming communities (Ahmed, Glaser, 2016). Recently, a number of REDD+ projects have been implemented in relation to mangrove forests. REDD+ projects in Asia and Vietnam have been planned to include mangrove restoration for carbon offset. The purpose of REDD+ is to conserve mangrove forests as an alternative to shrimp farming. To get wider benefits from mangrove ecosystems, increased awareness of the value of mangrove ecosystems should be developed and promoted among coastal communities to create a more solid basis for mangroves conservation (Ahmed and Glaser, 2016). In addition, the involvement of local communities is significant for the conservation of mangrove forests and a better understanding of local incentives. In short, mangrove restoration through REDD+ is more likely to be effectively linked with sustainable coastal aquaculture practices. Coastal aquaculture can be managed so that the ecological functions of mangrove forests are not affected and mangrove blue carbon can be achieved (Ahmed, Glaser, 2016). This model can be applicable in Quang Yen town, Quang Ninh Province.

Conclusion

Research showed that the area of mangrove forests in Quang Yen town is accounted for 3470,026, 3358.81, and 3418.10 ha for in 2017, 2020, and 2023, respectively. In addition, the use of remote sensing technology combined with the NDVI index to build mangrove maps has obtained an overall accuracy of 88 %, 88 %, and 88 %, respectively. In addition, total AGB was 18,302,976 t, 94,104,161 t and 145,035,226 t, and AGC was 8,693,913 t, 44,699,477 t and 68,891,730 t in 2017, 2020, and 2023, respectively. Although the area of mangrove forests has decreased slightly, the quality of the forests has improved significantly. Therefore, the biomass and carbon stocks of mangrove forests both increased from 2017 to 2023. The use of remote sensing technology and methodology in this research can be applied to other provinces. Blue Carbon and REDD+ can be applied in the study area to improve the effectiveness of mangrove protection and development activities. In the future, higher-resolution images should be used. At the same time, the research period could be longer to obtain more accurate results on changes in area and carbon stocks in mangroves, this providing better grounds for sustainable mangrove management.

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