USING SENTINEL-2 DATA FOR ABOVE-GROUND MANGROVE BIOMASS AND CARBON STOCKS MAPPING OVER 7 YEARS (2016-2022) IN TIEN YEN, QUANG NINH PROVINCE

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SUMMARY

Mangrove forests are found along tropical and subtropical coastlines. They have vital functions in preventing coastal erosion, mitigating effects of wave actions, and protecting coastal habitats. This study used the Sentinel-2-derived CMRI thresholds for coastal land covers (CMRI > 0.47 for mangrove forests, -0.25 < CMRI ≤ 0.47 for non-mangrove forests, and CMRI ≤ -0.25 for water bodies). The CMRI is suitable for detecting mangrove cover along the coast of Tien Yen district with overall accuracy over 90.5% and Kappa coefficient greater than 0.85 for the whole selected years. Overall, the extent of coastal mangrove forests along the coast of Tien Yen, Quang Ninh province increased by 792.7 ha in 2022 compared to 2016. Moreover, the total AGB and AGC of mangrove forests were estimated at 2,761,533 tons and 1,311,728 tons in 2022, respectively. The total CO_2 sequestration was estimated at 4,814,042 tons in 2022, an increase of 1,212,632 tons compared to 2016. The study assumed the constant carbon price of US$5 ton^{-1} CO_2, US$11 ton^{-1} CO_2, and US$15 ton^{-1} CO_2, the total amount of CO_2 paid for Tien Yen district would be about US$6,063,160, US$13,338,952, and US$18,189,480, respectively. The study highly suggests that mangrove blue carbon should be adopted and implemented toward sustainable mangrove management in Tien Yen district, including mangrove PES schemes. However, some key factors should be clearly addressed to ensure the success of mangrove blue carbon option in Tien Yen district, including an increased awareness of the value of mangrove ecosystem promoted; the involvement of local communities encouraged; other issues in relation to PES policy revised.

Keywords: AGB, AGC, CMRI, NDVI, Sentinel-2A, Tien Yen.

1. INTRODUCTION

Mangrove forests are known as salt tolerant trees and shrubs that grow in the intertidal regions of the tropical and subtropical coastlines (Kathiresan and Bingham, 2001; Duke et al., 2007). They have been considered as a key marine biome for providing valuable ecosystem goods and services, including water quality control, fisheries production, nursery habitats, and storm prevention (e.g. Albert et al., 2012; Hai-Hoa and Hien, 2021; Hai-Hoa et al., 2022b). Like other forests, mangrove forests are one of the most productive and efficient carbon dioxide sinks, along with other marine ecosystems, including sea-grasses and tidal salt marshes, recognized as 'blue carbon' ecosystems (Donato et al., 2011). As blue carbon accounts for nearly 55% of the biological carbon on earth, the conservation and restoration of such 'blue carbon' habitats are crucial for climate change mitigation (Albert et al., 2012). Globally, mangrove forests have been being deforested at an alarming rate (Duke et al., 2007; Hai-Hoa, 2014). The main drivers of mangrove deforestation have been blamed for aquaculture expansion, coastal development and land use clearing, pollution, natural disasters, and climate change impacts (e.g. Valiela et al., 2001; Taillardat et al., 2018; Hai-Hoa et al., 2022a). One of possible mechanisms may contribute to reduce the loss of mangrove forests is the use of payments for ecosystem services (PES). The ability of terrestrial and marine forests to remove and store carbon from the atmosphere has led to quantification, and trade of this ecosystem service by 'carbon credit' scheme (Friess et al., 2020). Recently, this has occurred within international and national programs to Reduce Emissions from Deforestation and Degradation known as REDD+, where developing countries have been

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compensated for maintaining carbon sequestration functions of their forests (Albert et al., 2012). This can be achieved through quantifiable activities and conservation. More interestingly, recent studies indicate that rich-carbon mangrove forests in the tropics through PES and carbon credit systems highly offer the opportunity to achieve dual goals of poverty reduction and protection of global marine carbon sinks (Albert et al., 2012).

In Vietnam, mangrove ecosystems have been well-recognized as highly valuable resources for local people, who are living nearby the coastal regions (e.g. Hai-Hoa, 2014; Hai-Hoa and Hien, 2021). They have not only provided the shelter for highly economic values of marine species, but also offered the local people for sustainable livelihoods (Hai-Hoa et al., 2013; Hai-Hoa, 2014). However, the extent of mangrove forests have experienced significant losses over the last decades due to the expansion of agriculture, the economic development and the pressure from the growth of population to satisfy the major demand for aquaculture and fishing production (e.g. Hai-Hoa et al., 2013; Hai-Hoa, 2014). Mangrove forests in Tien Yen district have suffered the same fate as others in Vietnam where are being under the pressure of the growth of population and socio-economic development (Quyet et al., 2020).

Although remote sensing technology has been globally applied to monitor and detect the mangrove deforestation and degradation, its application has not been well-documented or limited to monitor and evaluate the success of mangrove afforestation projects or detect the changes in the extent of mangrove forests in Vietnam, including Tien Yen coast, Quang Ninh province (Hai-Hoa et al., 2022a and 2022b). Notably, although recent efforts from national and international programs have been paid in mangrove restoration and rehabilitation in Tien Yen district, Quang Ninh province, some parts along the coast of Tien Yen have been witnessed a decline of the extent of mangrove forests as they are being under increasing threats from aquaculture expansion, coastal high population growth, timber cutting, and other human activities (Hai-Hoa, 2014; Hai-Hoa et al., 2022a). Loss of mangrove resources might increase the threats to the local livelihoods as increased vulnerability of coastal communities to storm surges with large typhoons (Duke et al., 2007; Hai-Hoa et al., 2018). Fewer studies have been conducted to quantify the changes in the spatial-temporal mangrove and identified their drivers of change in Tien Yen district over the last decades (Quyet et al., 2020), thus causing a lack of sound science-based mangrove management solutions. The questions of how the spatial-temporal mangrove cover, their associated biomass and carbon stocks have been changed over the last decades; and what solutions can be applied to sustainable management of mangrove forests in Tien Yen district remain unanswered. This study addressed three main questions: (1) How have the spatial-temporal extent of mangrove forests been changed along the coast of Tien Yen district, Quang Ninh province over 7 years (2016-2022); (2) What are the total above-ground biomass (AGB) and carbon stocks (AGC) held in mangrove forests, and how have AGB and AGC been changed over 7 years in Tien Yen district; (3) Is mangrove blue carbon approach a feasible option for Tien Yen to alleviate poverty, reduce mangrove deforestation and contribute to climate change adaptation and mitigation.

2. RESEARCH METHODOLOGY

2.1. Study site

Tien Yen is a coastal district of Quang Ninh province, with an area of 3,900 ha of mangrove forests, of which Dong Rui has over 1,800 ha, accounting for nearly 50% of the natural area of the commune (Quyet et al., 2020) (Fig. 1).

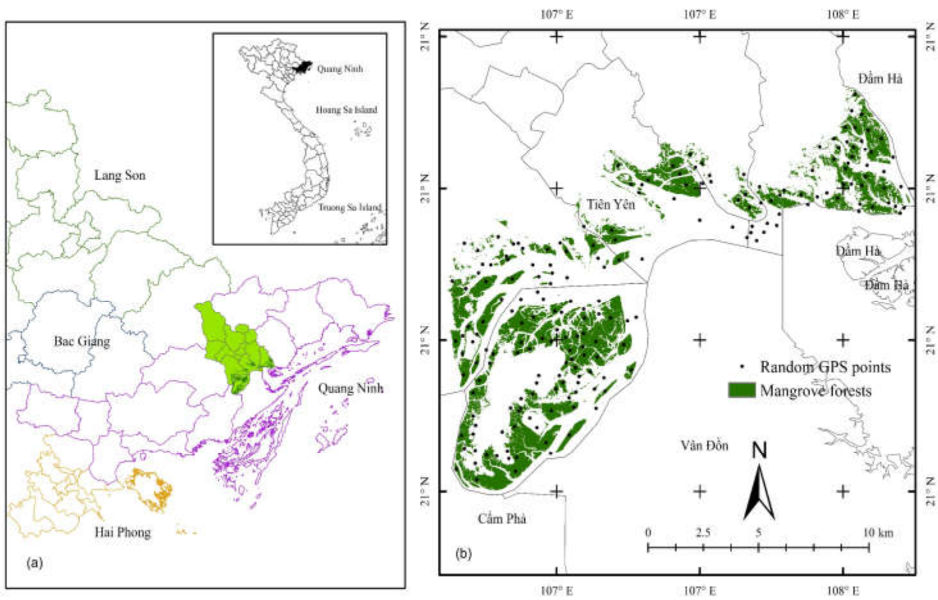

Fig. 1. Study site (a) Geographical location of Quang Ninh province in Vietnam, (b) Mangrove forests distributing along the coast of Tien Yen town, Quang Ninh province

Tien Yen is the center of the crossroads of the Eastern districts of Quang Ninh province, the traffic hub connecting the major economic, commercial, and tourist service centers of Quang Ninh province. As a coastal district, it has diverse soil-climate conditions that are suitable for the development of diversified ecological agriculture, forestry, and fishery. The district is adjacent to the Gulf of Tonkin with a 35 km long coastline, which is a favorable condition for economic exchanges and marine economic development.

2.2. Remote sensing data collection

In this study, multiple-temporal Sentinel-2A images were used to classify the extent of mangrove forests in different periods (Table 1).

Table 1. Remotely sensed data used for mangrove cover mapping over 7 years

ID	Image codes	Date	Spatial resolution (m)	Remarks
1	S2A_ MSIL1C_20161202T033827	02/12/2016	10	T48QYJ
2	S2A_MSIL1C_20171217T032131	12/17/2017	10	T48QYJ
3	S2B_MSIL1C_20181217T032129	12/17/2018	10	T48QYJ
4	S2A_MSIL1C_20191107T031931	11/07/2019	10	T48QYJ
5	S2A_MSIL1C_20201022T031801	10/22/2020	10	T48QYJ
6	S2A_MSIL1C_20211206T032121	12/06/2021	10	T48QYJ
7	S2A_MSIL1C_20220224T031731	02/24/2022	10	T48QYJ

Source: http://earthexplorer.usgs.gov

2.3. Study methods

To quantity spatial-temporal extent of mangrove forests and detect its changes in this study, five steps were proceeded as the following:

Sentinel-2A pre-processing: In this study, the available time series of Sentinel-2A data (from 2016 to 2022), covering the whole coast of Tien Yen town with cloud-free cover selected in Quang Ninh province, were freely downloaded from the USGS as indicated in Table 1. They were then used to quantify the spatial-temporal changes in mangrove forests along the coast of Tien Yen town during the period of 2016-2022. Prior to the interpretation and classification of land covers and mangrove forests, the semi-automatic classification plugin (SCP) in QGIS Version 3.16 (Congedo, 2020), which provides a full suite of processing tools that facilitate the pre-processing phases for image classification. The acquired Level-1C orthorectified, top-of-atmosphere optical Sentinel-2A data were atmospherically corrected and further processed to Level-2A product to obtain bottom-of-atmosphere corrected reflectance image (Castillo et al., 2017; Hai-Hoa and Hien, 2021).

Visual Interpretation: This study used the visual interpretation approach to separate the extent of mangrove cover from other land covers using a band combination (Hai-Hoa et al., 2022a; 2022b). The visual interpretation was based on either the true color image (RED, BLUE and GREEN) or other band combination, such as (RED, GREEN and NIR) (Pavlovic et al., 1997; Ye et al., 2021). In this study, visual image interpretation was adopted to observe the presence or absence of mangrove forests (Asrat et al., 2018).

Mangrove classification: NDWI is also useful to delineate open water features (McFeeters, 1996). It has also been developed to discriminate the mangrove cover, which has higher water content (Teng et al., 2021). Therefore, the combination of the two vegetation indices (NDVI and NDWI) would be very effective to classify mangrove cover from non-mangrove covers and water bodies along the coast of Tien Yen town (Veettil and Quang, 2019; Hai-Hoa et al., 2022a). This combination is created the CMRI (Combined Mangrove Recognition Index), which has been widely used in recent years (Gupta et al, 2018; Hai-Hoa et al., 2022a) for distinguishing mangrove covers from other features. This CMRI has been considered as a useful tool and selected to determine the presence of mangrove forests (Baloloy et al., 2020; Yancho et al., 2020). The calculation of NDVI, NDWI and CMRI was summarized in Table 2.

This study adopted the thresholds of Sentinel-2-derived CMRI from the study of Hai-Hoa et al., (2022a) for distinguishing mangrove cover from other land covers. The thresholds for mangrove cover are greater than 0.47 (CMRI > 0.47), while areas with frequent presence of water surface are defined with a threshold of less than -0.25 (CMRI < -0.25), a range from -0.25 to 0.47 (-0.25 < CMRI ≤ 0.47) is identified as non-mangrove covers (Hai-Hoa et al., 2022a).

Table 2. Equations of vegetation indices used for mangrove cover mapping

Vegetation indices	Equations	References
NDVI Normalized Difference Vegetation Index	$(Band_{NIR} – Band_{RED})/(Band_{NIR} + Band_{RED})$	Rouse et al., (1974); Thu and Populus, (2007)
NDWI Normalized Difference Water Index	$(Band_{GREEN} – Band_{NIR})/(Band_{GREEN} + Band_{NIR})$	Du et al., (2016); Kaplan and Avdan, (2017)
CMRI Combined Mangrove Recognition Index	(NDVI–NDWI)	Gupta et al., (2018); Jamaluddin et al., (2021)

Where: $Band_{NIR}$ is Near Infrared Band (Band 8 in Sentinel-2); $Band_{RED}$ is RED Band (Band 4 in Sentinel-2); $Band_{GREEN}$ is GREEN Band (Band 3 in Sentinel-2).

Accuracy assessments: Thematic mangrove cover map derived from Sentinel-2-based CMRI was required to assess the accuracy of classified images (Ghorbanian et al, 2021). For accuracy assessments, this study used high-resolution satellite images offered by Google Earth images (2016, 2017, 2018, 2019, 2020, and 2021) in combination with GPS points collected from the field investigation in 2020 and 2022 to assess the accuracy of classified images. A total of 200 GPS sampling points (including 100 GPS points for mangrove cover; 60 points for non-mangrove covers, 40 points for water bodies) selected for each single year of Sentinel-2A data. These random points were used for accuracy assessments of each thematic mangrove cover map.

The classification and control matrices were constructed to cross-tabulate the observed data with the reference data using the Kappa coefficient (Congalton, 1991). The Kappa coefficient is a measure of the consistency between two maps, considering all the elements of the error matrix (Stehman, 1997). A Kappa with value of 0 is inconsistent; from 0.41 to 0.6 refers as moderately consistent; 0.61–0.8 is remarkably homogeneous; and 0.81–1.0 is almost perfect homogeneity (Conchedda et al., 2008; Dat and Yoshino, 2016).

Post-classification: The filtering process was applied to remove isolated pixels or noise or the "salt-and-pepper" effects in the land cover map. The filtered classified image was then used as the final forest cover map each year.

Estimation of mangrove AGB: To calculate the above-ground biomass (AGB) of mangrove forests, this study adopted the regression model developed from by Hoa and Hien (2021) in Quang Ninh province and other coastal regions in the North of Vietnam.

$$AGB = -179.1 + 13243.6*NDVI$$

Estimation of mangrove AGC: Carbon stocks of mangrove forests were obtained by multiplying the total AGB with a conversion factor of 0.475 (47.5 % of biomass) known as above-ground carbon of mangrove forests (AGC) (Howard et al., 2014).

$$AGC = AGB * 0.475$$

Amount of CO_2 sequestration (ACS): This study calculated the total CO_2 absorbed by mangrove forests using the formula (Eggleston et al., 2006)

$$ACS = AGC * 3.67$$

3. RESULTS AND DISCUSSION

3.1. Multi-temporal extent of mangrove forests in Tien Yen district

Accuracy assessments of land cover and mangrove cover mapping:

All the Sentinel-2 images were used to produce the CMRI-based land cover classification maps for the whole coast of Tien Yen. The error matrices indicated that accuracy assessments of each selected year (from 2016 to 2022) have high accuracies with user's accuracies, as follow: mangrove cover (from 93.0% to 98.0%), non-mangrove covers (from 78.3% to 95.0%), and water bodies (from 90.0% to 100%), giving overall accuracies of 91.5%, 96.0%, 93.5%, 90.5%, 94.5%, 95.0% and 96.5% in 2016, 2017, 2018, 2019, 2020, 2021 and 2022, respectively (Table 3).

Table 3. Summary of accuracy assessments of land covers/mangrove cover in Quang Yen

	2022	2021	2020	2019	2018	2017	2016
UA (%) for Man	98.0	97.0	93.0	93.0	95.0	95.0	98.0
UA (%) for Non-	78.3	91.7	90.0	86.7	95.0	91.7	95.0
PA (%) for Man	100	100	93.9	98.9	96.9	96.9	97.0
PA (%) for Non-	92.2	94.8	88.5	86.7	85.1	91.7	93.4
OA (%)	91.5	96.0	93.5	90.5	94.5	95.0	96.5
KC	0.86	0.94	0.90	0.85	0.91	0.92	0.94

Man (mangrove forests); Non- (Non-Mangrove forests); UA (User's accuracy), PA (Producer's accuracy), OA (Overall accuracy), KC (Kappa coefficient)

Accuracy assessment results from verified data show that the CMRI index is a good classifier with overall classification accuracy (> 90.5%) and Kappa coefficient (> 0.85). This confirms that using CMRI for mangrove cover mapping is reliable with Sentinel-2 data. The kappa coefficients also indicate that there are very high agreements between the classified maps and the reference data, thus implying that the Sentinel-2-derived CMRI has a great potential for mangrove monitoring and mapping in the study area.

Coastal land use and land cover mapping:

As the thresholds have been determined for classifying mangrove forests, non-mangrove forests, and water bodies, the thematic maps of coastal land covers/mangrove cover are then constructed as indicated in Figs. 2 and 3. As indicated in Table 4 and Fig. 3, there was an increase of 792.7 ha of mangrove forests during the period of 2016-2022. Indeed, there was 2,699.5 ha of mangrove forests estimated in 2016 for the whole coast of Tien Yen, Quang Ninh province, it sharply increased to 3,491.1 ha in 2017, but decreased to 3021.1 ha, 2,640.9 ha and 2,282.5 ha in 2018, 2019, and 2020, respectively. Conversely, the total extent of mangrove forests dramatically increased to 3,662.4 ha in 2021, it kept slightly increasing to 3,492.2 ha in 2022 (Table 4 and Fig. 3).

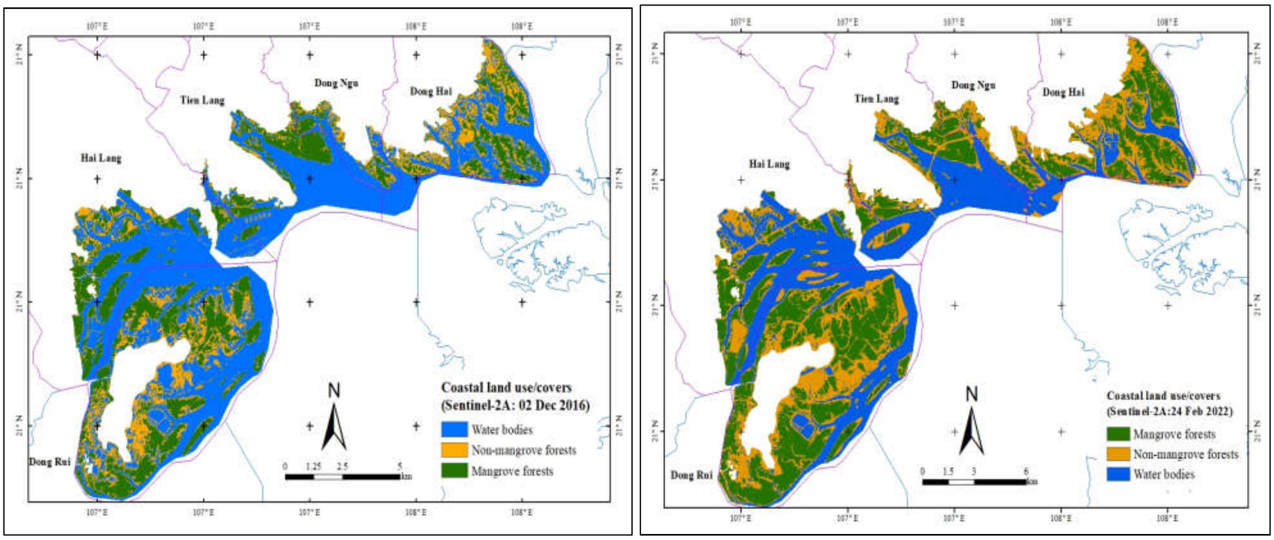

Fig. 2. Land covers and mangrove covers along the coast of Tien Yen in 2016 and 2022

Table 4. Extent of coastal land covers along the coast of Tien Yen in selected years (ha)

	2016	2017	2018	2019	2020	2021	2022
Mangrove	2699.5	3491.1	3021.2	2640.9	2282.5	3462.4	3492.2
Non-mangrove forests	1905.9	1785.1	1966.2	2480.3	1879.6	1660.8	3033.9
Water	5361.5	4690.7	4979.5	4845.7	5804.8	4843.7	3440.8
Total	**9966.9**	**9966.9**	**9966.9**	**9966.9**	**9966.9**	**9966.9**	**9966.9**

Non-mangrove forests include Rice paddy field/agriculture, residential areas/built-up areas, muddy flats; Water bodies refer to areas covered by water, including shrimp ponds, rivers, and open sea water.

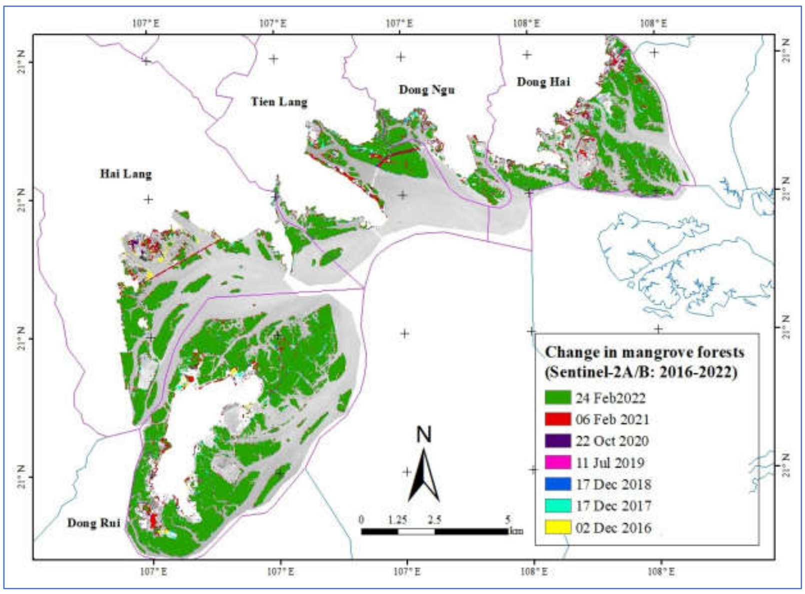

Fig. 3. Changes in land covers, mangrove cover along the coast of Tien Yen in 2016 and 2022

3.2. Above-ground biomass and carbon stocks of mangrove forests in Tien Yen district

Above-ground biomass of mangrove forests in Tien Yen district during 2016-2022:

As indicated in Table 5 and Fig. 4, there was 1,774,204 tons ha^{-1} of AGB estimated in 2016 for the whole coast of Tien Yen, Quang Ninh province, it increased to 2,173,985 tons, 2,407,805 tons of AGB in 2017 and 2018, respectively, but decreased to 1,794,393 tons in 2019. However, the total AGB of mangrove forests increased to 1,900,081 tons in 2020, it kept sharply increasing to 2,469,819 tons in 2021 and to 2,761,533 tons in 2022 (Table 5 and Fig. 4).

Table 5. Estimation of mangrove AGB accumulation in over 7 years of study

Years	2016	2017	2018	2019	2020	2021	2022
AGB (tons)	1,774,204	2,173,985	2,407,805	1,794,393	1,900,081	2,469,819	2,761,533

AGB: Above-ground biomass of mangrove forests

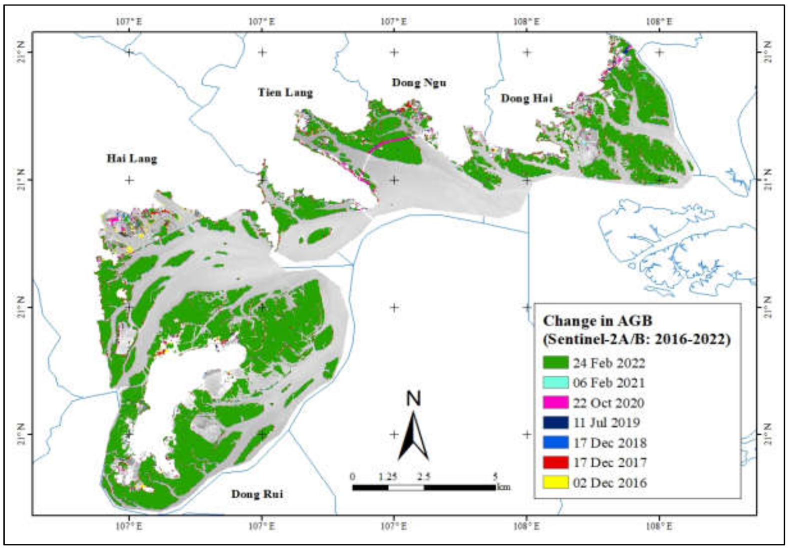

Fig. 4. Changes in AGB along the coast of Tien Yen during 2016-2022

Above-ground carbon stocks of mangrove forests in Tien Yen district during 2016-2022:

As can be seen from Table 6, there is a changes in amount of CO_2 sequestration from 2016 to 2022. The change has been observed across all coastal communes of Tien Yen. In this study, the main drivers of changes in ACS was due to an increase of mangrove extent from the afforestation projects.

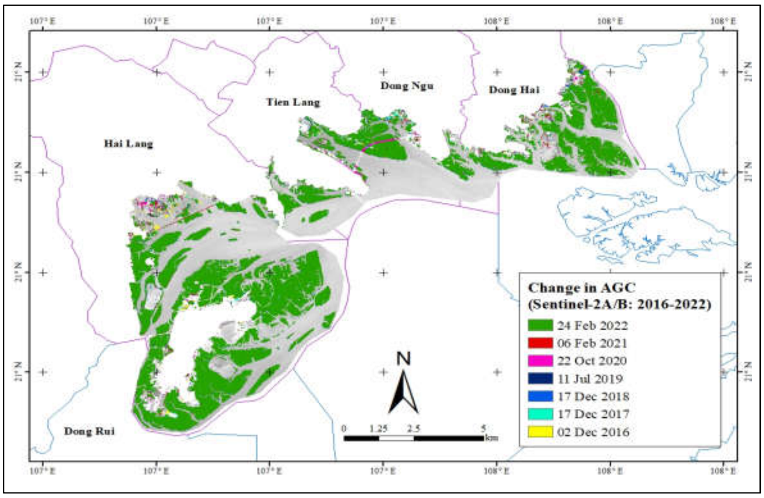

Fig. 5. Changes in AGC along the coast of Tien Yen during 2016-2022

The total CO_2 of mangrove forests in Tien Yen district was estimated at 4,814,042 tons in 2022, an increase of 1,212,632 tons compared to 2016, which has provided strong evidence for registration of carbon credit market (C-PFES) (Hai-Hoa et al., 2021). The higher the value of carbon stocks, the greater the commercial value that mangrove forests are likely to bring to local people that is the basis for the implementation of C-PFES or mangrove blue carbon payment scheme at the study site (Hai-Hoa et al., 2021; Hai-Hoa et al., 2022c). The estimation of AGC was illustrated in Fig. 5 and Table 6.

Table 6. Estimation of mangrove AGC accumulation (tons) in over 7 years of study

Years	2016	2017	2018	2019	2020	2021	2022
AGC (tons)	842,747	1,032,643	1,143,707	852,336.67	902,538	1,173,164	1,311,728
ACS (tons)	3,092,881	3,789,799	4,197,405	3,128,076	3,312,316	4,305,513	4,814,042

This study assumed that the carbon price would be followed one of three options:
Option 1: US$ 5/ton of CO_2: 563,242,914,000 VND (equivalent to $24,070,210 USD)
Option 2: US$ 11/ton of CO_2: 1,239,134,410,800 VND (equivalent to $52,954,462 USD)
Option 3: US$ 15/ton of CO_2: 1,689,728,742,000 VND (equivalent to $72,210,630 USD)
Current exchange rate: 1 USD= 23,400 VND (updated: 14th July 2022)

AGC: Above-ground carbon stocks of mangrove forests; ACS (Amount of CO_2 sequestration)

3.3. Mangrove blue carbon toward sustainable management and climate change mitigation

Drivers of mangrove deforestation and mangrove blue carbon:

Carbon-rich mangrove forests have been being deforested and degraded due to land use and land cover change (LULC); cutting for timber, fuel, and charcoal; and other additional drivers (e.g. Hai-Hoa et al., 2013; Hai-Hoa, 2014; Adenan, 2018). Natural disturbances also have mixed impacts on mangrove carbon stocks, sea-level rise is more likely to drown mangrove forests and their carbon stocks but offer opportunities for new carbon sequestration (Friess et al., 2020). Mangrove rehabilitation practices intend to actively enhance carbon stocks stored and reduce greenhouse gases emissions from LULC (Friess et al., 2020).

In Vietnam, the main drivers of mangrove deforestation and degradation are aquaculture development, agricultural land uses, and infrastructure development. In fact, aquaculture and agriculture have been keys for national economic and food security in Vietnam Nam since 1980s (Hai-Hoa, 2104; Hai-Hoa et al., 2022a). Up to date, the rehabilitation of degraded mangrove forests has reinstated carbon lost during LULC change. However, most mangrove projects have focused on low-diversity planting projects, with mixed success despite significant investments (Primavera and Esteban, 2008). Many efforts have been failed completely because of planting inappropriate species in environmental settings that is not suitable for their establishment (Bayraktarov et al., 2016; Wodehouse and Rayment, 2019). Mangrove blue carbon may apply at the site-scale through payments for ecosystem services (PES), where either donors or investors pay custodians to change land-use practices or protect mangrove forest resources. Similarly, blue carbon conservation can implement at the national scale, as incorporated into national-level carbon accounting system as a part of country's obligations to international climate change agreements (Friess et al., 2020).

Blue carbon may incentivize mangrove conservation and restoration between ecosystem service buyers and providers to change land use practices or otherwise prevent deforestation through PES mechanism. PES would provide a financial incentive to reduce the anthropogenic drivers of mangrove loss by using the potential financing mechanisms as mandatory carbon credit schemes under the

Kyoto Protocol of the United National Framework Convention on Climate Change or voluntary carbon credit markets (Friess et al., 2020). Mangrove forests can be influenced by along the coastal management decisions that potentially change local hydrodynamics and increase erosion (Friess et al., 2020). 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 spatially large-scale threat assessed (Friess et al., 2015; 2020).

Barriers to mangrove blue carbon and its implications to Vietnam:

Although there has been a strong interest in mangrove blue carbon from the international donor community over the last decades, mangrove PES in Vietnam remains at an embryonic stage (Hai-Hoa et al., 2022a). Like other countries, mangrove PES requires the carbon stocks gained to be permanent in Vietnam, but the dynamics in biological setting where mangrove forests are found has been challenged to the permanence of carbon stocks. Mangrove forests and their carbon have been integrated into the PFES policy (Payments for Forest Environmental Services), clearly stated in the Decree 156/2018/NĐ-CP, and dated 16th October 2018. Under this Decree, mangrove conservation has been folded into national discussions on biodiversity conservation and a reduction of carbon emissions as well as a justification for mangrove rehabilitation projects. To achieve mangrove blue carbon, key barriers should be clearly addressed, including unclear and insecure tenure, inequitable benefit sharing, misalignment between small-scale blue carbon projects and national REDD+ frameworks, and complexities for blue carbon in the Paris agreement and NDCs (Nationally Determined Contributions) (Schneider et al., 2021; Hai-Hoa and Hien, 2021; Hai-Hoa et al., 2021).

Mangrove blue carbon also can be achieved through carbon stock of community-managed mangroves (Gevana et al., 2018). Development of mangrove PES schemes would provide a sustainable income source for local communities to engage in mangrove restoration and protection (Locatelli et al., 2014; Gevana et al., 2018). It will greatly benefit to coastal communities whose survival and livelihoods are heavily dependent on mangrove resources. However, empowerment of local communities and livelihood improvement are very important elements for PES schemes to succeed (Fisher, 2014). Notwithstanding the increasing appreciation of the effectiveness of community-based model in mangrove management, a number of challenges should be addressed and overcome, including unclear tenure rights, poor ecological consideration in mangrove reforestation, and poor coastal management planning (Locatelli et al., 2014; Friess et al., 2015; Wylie et al., 2015; Gevana et al., 2018). To establish effective community-based mangrove PES platform in Vietnam, it is suggested that a stronger incorporation of mangrove forests into marine protected areas would assist in resolving some policy and resource management conflicts in declaring mangrove forests exclusive for protection purpose (Friess et al., 2016). In addition, either community-based or co-management practice should be encouraged to effectively reconcile various interests of local stakeholders and address conflicting policy objectives on the use of mangrove resources.

Recently, a number of REDD+ projects have implemented in relation to mangrove forests. REDD+ projects in Asia and Vietnam have planned to include mangrove restoration for carbon offset (USAID, 2010). The purpose of REDD+ is to conserve mangrove forests as an alternative shrimp farming. To get wider benefits from mangrove ecosystems, an increased awareness of the value of mangrove ecosystem should be developed and promoted among coastal communities to create a more solid basis for mangrove conservation (FAO, 2007; Ahmed and Glaser, 2016). In addition, involvement of local communities is significant for the conservation of mangrove forests for a better understanding of local incentives.

4. CONCLUSION

Remote sensing technology offers an effective tool to monitor and detect changes in coastal changes in LULC over the time. This study used the Sentinel-2 derived CMRI thresholds for coastal land covers (CMRI> 0.47 for mangrove forests, –0.25 <CMRI ≤0.47 for non-mangrove forests, and CMRI ≤-0.25 for water bodies). The CMRI is suitable for detecting and monitoring mangrove cover change along the coast of Tien Yen with overall accuracies over 90.5% and Kappa coefficient greater than 0.85 for whole selected years. Overall, the extent of coastal mangrove forests along the coast of Tien Yen town, Quang Ninh province increased by 792.7 ha in 2022 compared to 2016. In addition, the total AGB and AGC of mangrove forests were estimated at 2,761,533 tons and 1,311,728 tons in 2022, respectively.

The total CO_2 sequestration was estimated at 4,814,042 tons in 2022, an increase of 1,212,632 tons compared to 2016. This study assumed that the carbon price would be either US$5 ton^{-1} CO_2, or $11 ton^{-1} CO_2, or US$15 ton^{-1} CO_2, then the total amount of CO_2 paid would be US$6,063,160, US$13,338,952, and US$18,189,480, respectively. The study highly suggests that mangrove blue carbon should be adopted and implemented toward sustainable mangrove management in Tien Yen district, including mangrove PES schemes. However, some key factors should be clearly addressed to ensure the success of mangrove blue carbon option in Tien Yen district, including an increased awareness of the value of mangrove ecosystem promoted; the involvement of local communities encouraged; other issues related to PES policy revised.

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SỬ DỤNG ẢNH SENTINEL-2 XÂY DỰNG BẢN ĐỒ SINH KHỐI VÀ TRỮ LƯỢNG CÁC-BON RỪNG NGẬP MẶN GIAI ĐOẠN 2016-2022 TẠI HUYỆN TIÊN YÊN, TỈNH QUẢNG NINH

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TÓM TẮT

Rừng ngập mặn phân bố dọc theo các đường bờ biển nhiệt đới và cận nhiệt đới. Rừng ngập mặn có chức năng quan trọng trong việc ngăn chặn xói mòn bờ biển, giảm thiểu tác động của sóng và bảo vệ môi trường sống ven biển. Nghiên cứu đã sử dụng các ngưỡng chỉ số CMRI được tính toán từ ảnh Sentinel-2 cho các đối tượng che phủ mặt đất ven biển (CMRI > 0,47 đối với rừng ngập mặn, -0,25 < CMRI ≤ 0,47 cho đối tượng không là ngập mặn và CMRI ≤ -0,25 là đối tượng che phủ bởi nước). CMRI phù hợp để phát hiện độ che phủ bởi rừng ngập mặn dọc theo bờ biển huyện Tiên Yên với độ chính xác tổng thể trên 90,5% và hệ số Kappa lớn hơn 0,85. Nhìn chung, diện tích rừng ngập mặn ven biển ven biển huyện Tiên Yên, tỉnh Quảng Ninh tăng 792,7 ha vào năm 2022 so với năm 2016. Đặc biệt, tổng sinh khối trên mặt đất (AGB) và trữ lượng các bon trên mặt đất (AGC) của rừng ngập mặn ước tính lần lượt là 2.761.533 tấn và 1.311.728 tấn vào năm 2022. Tổng lượng CO_2 hấp thụ năm 2022 ước tính là 4.814.042 tấn, tăng 1.212.632 tấn so với năm 2016. Nếu việc chi trả tín chỉ các-bon được thực hiện với mức giá 5 USD, 11 USD và 15 USD cho mỗi tấn CO_2, thì tổng số tiền có thể nhận được lần lượt là 6.063.160 USD, 13.338.952 USD và 18.189.480 USD. Nghiên cứu đề xuất sáng kiến các-bon xanh nên được áp dụng cho rừng ngập mặn theo hướng quản lý bền vững tại huyện Tiên Yên, bao gồm chi trả dịch vụ môi trường rừng ngập mặn (PES). Tuy nhiên, một số yếu tố chính cần được xác định rõ ràng để đảm bảo sự thành công việc thực hiện sáng kiến các-bon xanh rừng ngập mặn ở huyện Tiên Yên, bao gồm nâng cao nhận thức về giá trị của hệ sinh thái rừng ngập mặn; khuyến kích sự tham gia của cộng đồng địa phương trong các hoạt động quản lý rừng ngập mặn; các vấn đề khác liên quan đến chính sách PES nên được xem xét và sửa đổi.

Từ khóa: Chỉ số nhận biết rừng ngập mặn kết hợp, chỉ số thực vật khác biệt chuẩn hóa, sinh khối trên mặt đất, Sentinel-2A, Tiên Yên, trữ lượng các bon trên mặt đất.

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