USING PLANETSCOPE DATA TO ESTIMATE CARBON SEQUESTRATION OF MANGROVE FORESTS: A CASE STUDY IN TIEN YEN DISTRICT, QUANG NINH PROVINCE

Nguyen Hai Hoa[1], Ha Tri Son[1], Nghiem Thi Linh[1], Daniel Ojeda de Vicent[2], Nguyen Ngoc Linh[1]
[1]*Vietnam National University of Forestry*
[2]*Eberswalde University for Sustainable Development (HNEE), Germany*

https://doi.org/10.55250/jo.vnuf.2023.15.087-099

ABSTRACT

Mangrove forests, typically found along tropical and subtropical coastlines, have a crucial role in preventing coastal erosion, mitigating the effects of wave actions, and safeguarding coastal habitats. This study utilized PlanetScope mangrove forests and a Combined Mangrove Recognition Index (CMRI), which was suitable for detecting mangrove cover along the coast of Tien Yen district with an overall accuracy of over 93.0% and a Kappa coefficient greater than 0.90 for the selected years. The total area of coastal mangrove forests along the coast of Tien Yen, Quang Ninh province has increased by 137.7 ha in 2023 compared to 2020. The total AGB and AGC of mangrove forests were estimated at 241,730,970 tons and 114,822,211 tons in 2023, respectively. The total CO_2 sequestration was estimated at 421,397,514 tons in 2023, which represents a decrease of 17,813,872.1 tons compared to 2020. The study highly suggests the adoption of blue carbon approach for sustainable mangrove management in Tien Yen district, including Payment for Ecosystem Services (PES) schemes. However, certain key factors, such as increasing awareness of the value of the mangrove ecosystem, promoting the involvement of local communities, and revising policy issues related to PES, need to be addressed to ensure the success of the mangrove blue carbon option in Tien Yen district.

Keywords: AGB (Above-ground Biomass), AGC (Above-ground Carbon), CMRI (Combined Mangrove Recognition Index), NDVI (Normalized Difference Vegetation Index), PlanetScope, Tien Yen.

1. INTRODUCTION

Mangrove forests are considered a highly important ecosystem in coastal environments worldwide and provide significant cultural, economic, and ecological values for humans [1]. Located in tropical and subtropical regions, these forests are seen as a crucial marine biome that provides essential ecosystem services, such as water quality control [2], nursery habitats [3], fisheries production [4], coastal protection [5], and storm mitigation [6]. Moreover, mangrove forests are highly effective at sequestering carbon dioxide, making them important carbon sinks [7]. Despite its invaluable value, mangrove forests have regressed significantly. The Global Mangrove Alliance have announced an estimated net loss of 5,245 km^2 of mangrove forest since 1996 (about 3.56% of their current area), which is likely due to direct and indirect anthropogenic factors [8]. In Vietnam, mangrove loss is mainly driven by non-sustainable aquaculture and timber extraction, urban and agricultural pollution, population growth, and urban expansion [9].

Mangrove monitoring and evaluation can help to halt mangrove loss, impulse restoration and grant long-term protection. In recent years, calculating the carbon sequestration ability of mangroves has become one of the various approaches to protecting and developing this type of ecosystem. This activity can be conducted by using satellite imagery and field-based models to estimate carbon storage [10]. It is worth noting that remote sensing techniques are considered less intrusive ways of extracting bountiful data about this structurally complex environment.

Mangrove forests are incredibly important carbon sinks, which are responsible for absorbing and storing more carbon that the forests release through the process of photosynthesis. Recent studies have shown that coastal and marine ecosystems, including mangroves, can rival terrestrial ecosystems in their ability to mitigate climate change through carbon sequestration and storage [11]. However, these "blue carbon" sinks are often not taken into consideration in climate change policies and payment schemes [12]. The emergence of carbon markets and the implementation of Reducing Emissions from Deforestation and Forest Degradation-Plus (REDD+) can provide economic incentives for mangrove conservation by funding carbon projects that prevent the release of greenhouse gases stored in their biomass [13]. It is crucial that people understand the dynamics of carbon storage and cycling in these blue carbon sinks so as to assess their potential for carbon payments and promote their conservation.

Market-based solutions, such as Payments For Ecosystem Services (PFES), have been proposed as a way to protect mangrove ecosystems by providing economic incentives to local communities [14]. PFES is a mechanism by which those who provide ecosystem services, such as carbon sequestration or water filtration are compensated by those who benefit from these services [15]. PFES has been implemented in several countries, including the Solomon Islands, and Vietnam, where it has been used to conserve mangrove forests [14]. However, PFES has also been criticized for its potential risk of further marginalizing vulnerable populations and for its emphasis on commodifying nature [16]. For example, there is a possibility that PFES programs may lead to the displacement of local communities who depend on the forests for their livelihoods, or that the market-based approach may display a bias towards the interests of powerful actors over those of marginalized communities.

Traditional methods of estimating carbon storage in mangrove forests can be labor-intensive, and time-consuming, however, they may not provide a complete picture of the forest's carbon sequestration potential [17, 18]. In recent years, the use of remote sensing technologies has emerged as a promising alternative for accurate estimation of carbon storage in these ecosystems [19]. In particular, the use of PlanetScope data to estimate carbon storage in mangrove forests has shown great potential [20]. PlanetScope data are acquired from a constellation of low-cost satellites to provide 3-m Red (590 - 670 nm), Green (500-590 nm), Blue (455-515 nm), and near-infrared (NIR, 780-860 nm) spatial resolution data with near-daily global coverage [21, 22]. In addition, PlanetScope captures high-resolution images of the Earth's surface using a network of small satellites, which provide rapid and frequent global coverage that can be accessed through an easy-to-use interface [23]. This satellite imagery can provide detailed information on the growing area and density of forest cover, making it possible for more accurate calculations of carbon storage potential [24]. However, there are still relatively limited studies that have utilized PlanetScope data to estimate carbon sequestration in mangrove forests. In order to understand the potential of this technology in a more proper way, it is important that one conduct case studies in different ecosystems and regions. Therefore, in this study, we selected a coastal area to estimate the area of mangrove forest and the amount of above-ground biomass (AGB) and above-ground carbon (AGC) of mangrove forests in the region based on 2 selectd indices, namely NDVI and CMRI [25]. In a study by Veettil [9], it is asserted that Vietnam benefits from a long coastline where mangrove forest can grow, albeit limited by environmental conditions like rocky topography or varying climate conditions between North and South Vietnam among other factors [9]. Furthermore, US Army chemical warfare is also believed to have caused the abrupt loss of a quarter of Vietnam mangroves.

Veettil estimates the country to have 252,500 remaining ha of Mangrove, mainly concentrated in four areas.

The results of the study "Using PlanetScope data to estimate carbon storage of mangrove forests in Tien Yen district, Quang Ninh province" intend to answer three questions: (1) What and where is a spatial distribution of the mangrove cover in Tien Yen district, Quang Ninh province. (2) How much are AGB and AGC sequestration of mangrove forests in Tien Yen district, Quang Ninh province (3). What solutions should be applied to the mangrove forest management towards carbon credit payments? These findings are expected to provide an accurate and reliable approach for the estimation of carbon sequestration of mangrove forests and suggest a good way of sustainable mangrove forest management.

2. RESEARCH METHODOLOGY

2.1. Study site

Tien Yen, a coastal district in Northern Vietnam located in Quang Ninh province, is an area that houses one of the largest and the most important mangrove forests in the North. Tien Yen district is bordered by the East Sea to the East, the Ba Che district to the West, and Ha Long city to the South. The district's economy relies mainly on agriculture and forestry, with main products, such as pepper, fruit trees, sugarcane, vegetables, and timber. In addition, tourism and mining are also evolving industries there.

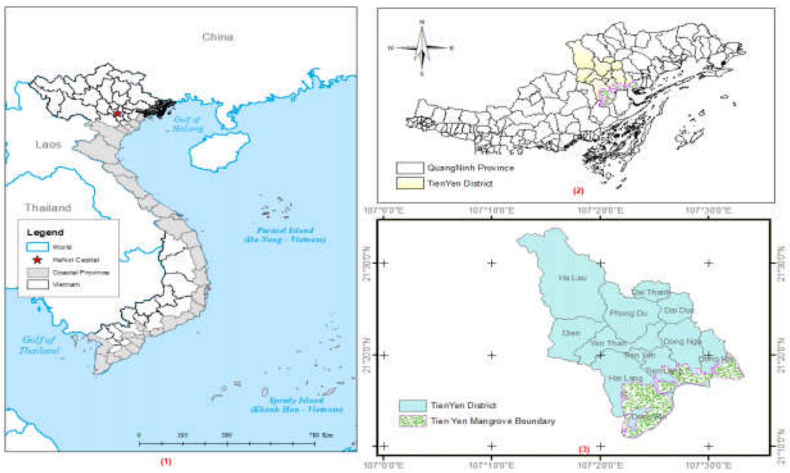


Fig. 1. Study site: (1) Geographical location of Quang Ninh province in Vietnam, (2) The location of Tien Yen district, (3) Mangrove forests spatially distribute in Tien Yen coast

As for climate, Tien Yen belongs to the tropical monsoon region with an average temperature ranging from 15 to 25 degrees Celsius, which has hot and humid summers, and cool and dry winters. Its terrain is mostly hilly with an elevation ranging from 100 to 300 meters above sea level, along with valleys, plains, and a coastline of about 12 km. Mangrove forest covers nearly 4,000 ha in the eastern coastal area of the district, comprising 5 communes, namely Hai Lang, Dong Ngu, Dong Hai, Dong Rui, and Tien Lang. Mangrove forests play a vital role in protecting and promoting the development of rare and valuable wildlife and plant species, as well as providing significant economic, social, and environmental values to the surrounding area.

Remote sensing data collection

In this study, the area of mangrove cover is calculated for each year and changes over each period are quantified using multi-temporal PlanetScope data from 2021 to 2023. The PlanetScope image used in this study is an atmospheric corrected image available on https://www.planet.com/explorer/.

Table 1. Remotely sensed PlanetScope was used for this research over 4 years

ID	Image codes	Date	Resolution (m)	Remarks
1	20201113_024357_91_227e_3B_AnalyticMS	13November2020	3 x 3	PlanetScope
	20200428_023713_44_2259_3B_AnalyticMS	28April2020	3 x 3	PlanetScope
	20200428_023715_66_2259_3B_AnalyticMS	28April2020	3 x 3	PlanetScope
2	20210606_024518_94_2276_3B_AnalyticMS	06June2021	3 x 3	PlanetScope
	20210606_024521_23_2276_3B_AnalyticMS 20210606_024521_23_2276_3B_udm2_clip	06June2021	3 x 3	PlanetScope
3	20220407_022712_02_2463_3B_AnalyticMS	07April2022	3 x 3	PlanetScope
	20220407_022714_32_2463_3B_AnalyticMS	07April2022	3 x 3	PlanetScope
	20220407_022716_62_2463_3B_AnalyticMS	07April2022	3 x 3	PlanetScope
	20220407_030042_32_2461_3B_AnalyticMS	07April2022	3 x 3	PlanetScope
	20220407_030044_63_2461_3B_AnalyticMS	07April2022	3 x 3	PlanetScope
4	20230130_024551_06_225a_3B_AnalyticMS	30January2023	3 x 3	PlanetScope
	20230130_024548_87_225a_3B_AnalyticMS	30January2023	3 x 3	PlanetScope

Source: http://planetscope.com

2.2. Study methods

The PlanetScope images from 2020 to 2023 have been geo-referenced and geometrically improved. This geometric correction was necessary to improve the geographic location to a root mean square error smaller than a pixel and the accuracy of subsequent change analysis [26, 27, 28]. In this study, we examined the data to ensure that all images were properly geo-referenced to the WGS 1984 UTM Zone 48N projection. Using the Mosaic to New Raster tool in ArcMap 10.4.1, all scenes each year were mosaicked to obtain a full coverage of the study area in the Tien Yen district. This product was then clipped along the boundary of potential mangrove forests. The detailed steps as follows:

Visual Interpretation: This study employed visual interpretation as a method to distinguish the mangrove cover extent from other land covers. This was achieved through a band combination approach using either true color imagery (RED, BLUE, and GREEN) or other combinations, such as (RED, GREEN, and NIR) as described in previous studies [29, 30] and implemented in the work of Hai-Hoa [27, 28]. Additionally, visual interpretation involved observing the presence or absence of mangrove forests, which was adopted in this study as outlined by Asrat [31].

Mangrove classification: In Tien Yen, field data were collected from three different coastal land-use/cover types, including Mangrove covers with closed and open canopies, and Non-mangrove forests consisting of abandoned aquaculture ponds, bare and wetlands, mudflats, and water bodies. The Combined Mangrove Recognition Index (CMRI) was selected to map and estimate the mangrove covers in the area. This index is a combination of the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI), which is used to explore the spectral differences between mangrove covers and non-mangrove classes.

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

Vegetation indices	Equations	References
NDVI	(NIR- RED)/(NIR+RED)	[32, 33]
NDWI	(GREEN–NIR)/(GREEN+NIR)	[34, 35]
CMRI	NDVI–NDWI	[36, 37]

Where: *NIR is Near Infrared Band (Band 4); RED is RED Band (Band 3); GREEN is GREEN Band (Band 2).*

Accuracy assessments: This study aims to evaluate the accuracy of classified images using mangrove forest cover. To achieve this goal, the study constructed a thematic map of mangrove forest cover based on PlanetScope images and the CMRI index. Then, high-resolution satellite images of Google Earth in 2020 and 2021 with randomly generated GPS points, including 100 points for mangrove forests, 60 points for non-mangrove forests, and 40 points for water bodies, were used to assess the accuracy of classified mangrove covers. In the year of 2022 and 2023, the study conducted the field survey to select randomly GPS points. The accuracy of the mangrove forest cover was evaluated for each year using intuitive and statistical interpretation methods. As a result, the study assessed the accuracies of mangrove forest covers in all selected years, which have met the expectations in terms of high reliability. To ensure accurate statistics, the study used independent test samples to create a computational matrix and used the Kappa coefficient to measure consistency between observed and reference data. A Kappa coefficient value of 0-0.4 indicates inconsistency; 0.41-0.6 indicates moderate consistency; 0.61-0.8 indicates remarkable homogeneity and 0.81-1.0 indicates almost perfect homogeneity [1, 38]. To guarantee data accuracy, a minimum interpretation accuracy of 85% was set, consistent with previous studies on coastal land covers and mangrove cover maps by Foody [39].

Estimation of AGB and AGC of mangrove forests based on PlanetScope:

Mangrove structure investigation:

The study established 14 standard circular plots in various locations, with a radius of 7 m (for pure forests) and 14 m (for mixed forests) and areas of 153.9 m^2 and 615 m^2. Methods by Kauffman and Donato [43] and Castillo [19] were adopted in our study.

AGB estimation-based NDVI: To estimate AGB in mangrove forests, we employed the NDVI thresholds to differentiate among land covers through using the Raster Calculator Tool in the ArcGIS 10.4.1. The NDVI values ranged from -0.1 to 1.0 and classified into different classes [40]. Based on the differentiation of land covers through the NDVI values, we adopted a model developed by Hoa and Hien [10] in Tien Yen district, Quang Ninh province, which offered a high correlation coefficient (R^2 = 0.98), p-value < 0.0001, and RMSE = 224.7

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

Above-ground carbon stock (AGC): AGC can be calculated based on AGB using conversion factors that involves the amount of carbon to the amount of biomass [41].

$$AGC = AGB * 0.475$$

Accumulation of CO_2 sequestration (ACS): To estimate the CO_2 absorption capacity of mangrove forests absorbed by the formula [42]:

$$ACS = AGC * 3.67$$

AGB and AGC estimation-based field data:

Under each standard plot survey data, AGB and AGC of mangrove forests were estimated. In particular, the AGB of each species was computed at each plot using the formula shown in Table 3. The AGB was calculated separately for each species and the average for each plot value was taken.

Table 3. Above-ground biomass estimation formula for mangrove species

No	Species	Formula of Biomass (kg)	Mangrove structures used	Sources
1	*Bruguiera gymnorrhiza*	$0.1681*\rho*DBH^{2.31}$ ($R^2=0.99$) ρ= 0.801	DBH, H	[44]
2	*Kandelia obovata*	$2.5904*CD^2*H$ ($R^2=0.84$) $0.251*\rho*DBH^{2.46}$ ($R^2=0.98$) ρ= 0.0776	Canopy diameter, H (DBH <5 cm) DBH, H (DBH > 5 cm)	[45, 46]
3	*Avicennia marina*	$1.8247*CD^2*H$ ($R^2=0.97$)	Canopy diamter, H	[46]
4	*Aegicera corniculatum*	$3.1253*CD^2*H$ (R^2=0.99)	Canopy diamter, H	[46]
5	*Rhizophora* stylosa	$0.168*D^{2.42}$ + $Biomass_{stilt}$ (kg) = $0.0209*D^{2.55}$ ($R^2=0.99$)	D_{30}, H	[44]

Where: AGB is the total aboveground biomass of mangrove individual (kg), CD represents canopy diameter (m), and H, DBH is tree height (m). ρ *is the density of the tree [47].*

3. RESULTS AND DISCUSSION

3.1. Multi-temporal extent of mangrove forests

Accuracy assessments of mangrove cover mapping:

CMRI is a highly suitable index for separating between mangrove cover and non-mangrove cover in this study. As a result, mangrove covers were classified from PlanetScope data with a high accuracy and Kappa coefficient greater than 0.9. In particular, the accuracies of mangrove cover mapping are greater than 99.0%, while non-mangrove cover are assessed at 85.0%, 86.7%, 81.7%, and 90.0% in 2020, 2021, 2022, and 2023, respectively. The overall accuracy of land cover mapping are recorded at more than 93.6% with a Kappa coefficient of 0.92, 0.9, 0.9, and 0.94 in 2020, 2021, 2022, and 2023, respectively.

Table 4. Summary of accuracy assessments of land cover/mangroves

	2020	2021	2022	2023
UA (%) for Man	99.0	99.0	100	99.0
UA (%) for Non-	85.0	86.7	81.70	90.0
OA (%)	95.0	94.0	93.50	96.0
KC	0.92	0.90	0.90	0.94

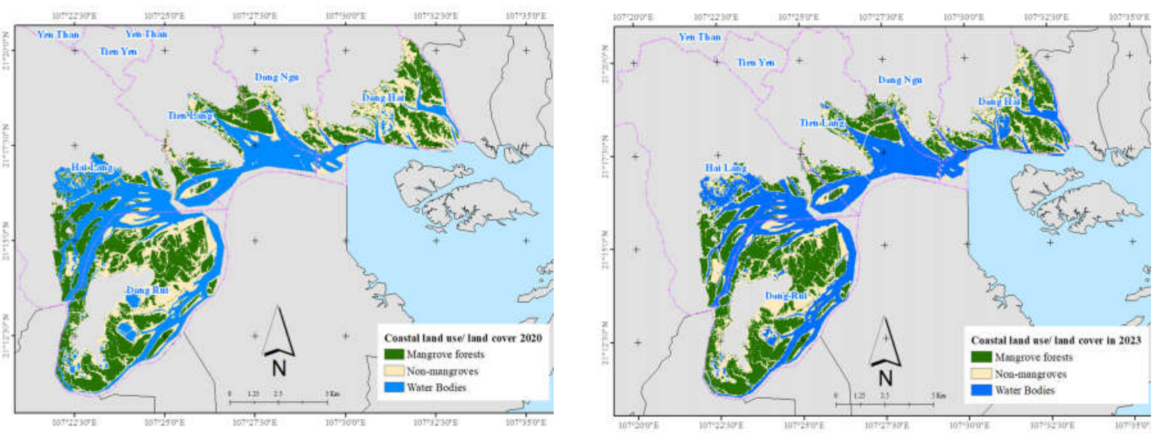
Where: Man (mangrove forests); Non- (Non-Mangrove forests); UA (User's accuracy), PA (Producer's accuracy), OA (Overall accuracy), KC (Kappa coefficient).

Coastal mangrove and non-mangrove covers mapping:

As indicated in Table 5, the areas of mangrove forest and non-mangrove covers have changed over the past four years, from 2020 to 2023. Specifically, the area of mangrove forest has increased from 3,487.4 ha in 2020 to 3,625.1 ha in 2023, while the area of non-mangrove cover has decreased from 3,230.2 ha to 2,932.5 ha during the same period. Meanwhile, there has been no significant change in the area of water bodies in the region during this time.

Table 5. Coastal land covers along the coast of Tien Yen during selected years (ha)

Land covers	2020	2021	2022	2023
Mangrove	3487.4	3535.0	3558.2	3625.1
Non-mangrove	3230.2	2812.2	3674.2	2932.5
Water	3249.3	3619.6	2734.3	3409.2
Total	*9,966.82*	*9,966.82*	*9,966.82*	*9,966.82*



(a) (b)

Fig. 2. Land cover and mangrove cover along the coast of Tien Yen: (a) 2020 and (b) 2023

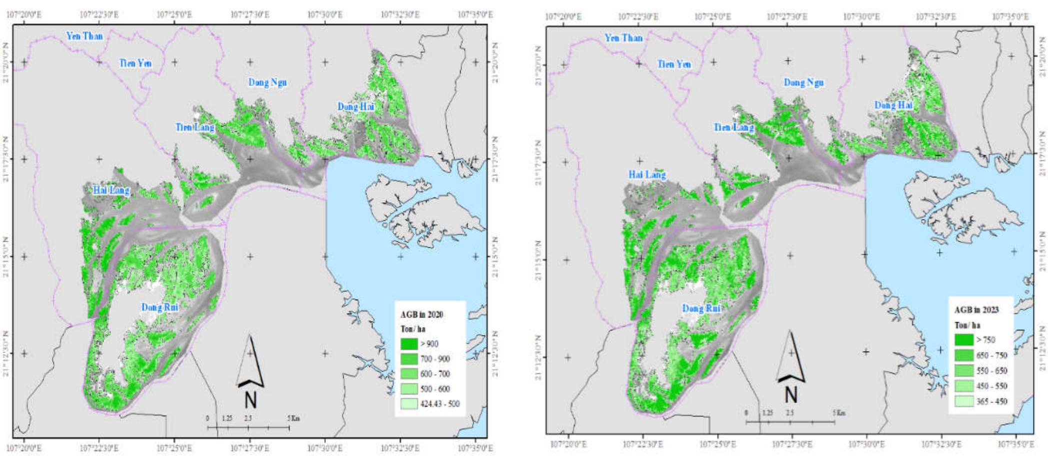
The findings indicate that the local people are aware of the importance of conserving mangrove forests and the coastal ecosystem. The local community, as well as the mangrove forest management agencies Tien Yen district are strongly committed to protecting and managing mangroves. They have well-acknowledge the critical role mangroves in terms of providing important natural resources, like shrimps, crabs, and fish, and improving the local likelihoods. In this areas, to enhance the resilience and biodiversity of mangrove forests, multiple reforestation projects have been implemented at the different scales. Organizations, including the KVT project (Netherlands), ACTMANG (Japan), and the Vietnamese Academy of Forest Science (Vietnam), have continuously offered the support of mangrove plantation and restoration. Their collaborations with the local people also strengthens the capacity and resilience of mangroves and positively impacts the socio-economic values.

3.2. Estimation and mapping of AGB and AGC sequestration of mangrove forests

AGB and AGC estimation-based PlanetScope data:

Based on the calculation formula by Hai-Hoa and Hien [10], PlanetScope data was used with different NDVI thresholds for each year, the AGB was then estimated during the period from 2020 to 2023 in Tien Yen district as shown in Fig. 3 and Table 6.

The results indicate that the AGB values vary among different years. The minimum and maximum of AGB values range from 364.8 tons ha^{-1} to 424.4 tons ha^{-1} and 1,000.1 tons ha^{-1} to 1,126.5 tons ha^{-1}, respectively. Similarly, the mean AGB values range from 629.5 to 682.1. The standard deviation values vary from 134.1 tons to 176.8 tons, suggesting a higher variation in AGB estimates in among selected years. The total estimated AGB also varies across the years, with the highest value is recorded at 284,598,404.4 tons in 2021 and the lowest value is estimated at 241,730,970.6 tons in 2023.



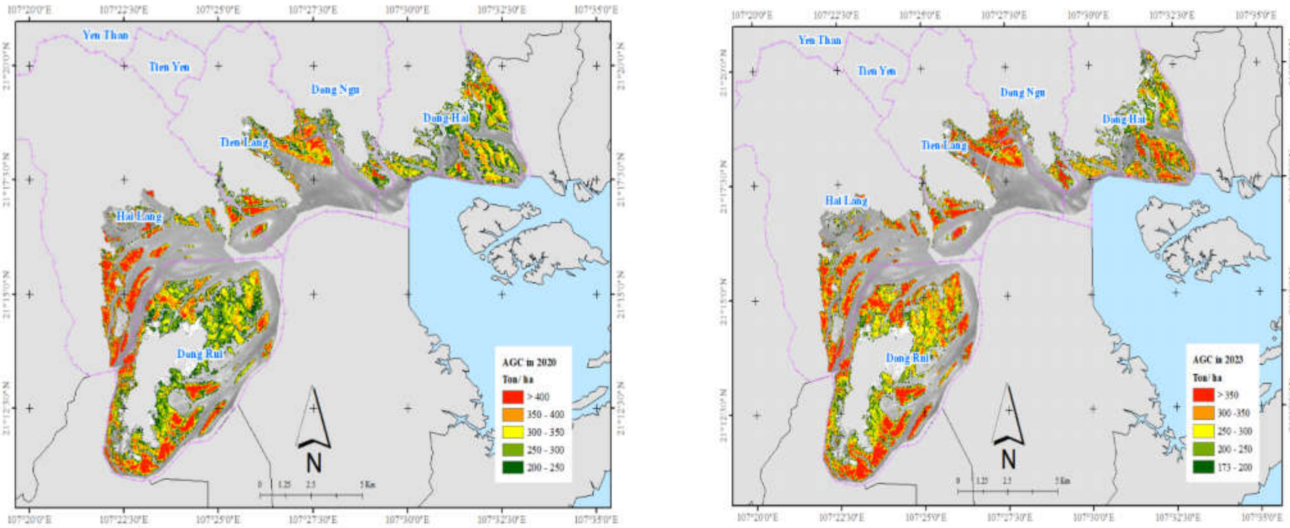
(a) **(b)**

Fig. 3. Estimated AGB of mangrove forests using PlanetScope data: (a) 2020 and (b) 2023

Table 6. Estimation of AGB from PlanetScope data in selected each years

AGB *(Ton ha^{-1})*	2020	2021	2022	2023
Min	424.4	366.2	413.8	364.8
Max	1,126.5	1,099.2	1,004.8	1,000.1
Mean	682.1	682.1	659.9	629.5
SD	156.8	176.8	134.1	150.5
Total	**259,544,842.7**	**284,598,404.4**	**262,339,023.5**	**241,730,970.6**

Based upon the formula of Howard [41], this study estimated AGC using PlanetScope data from 2020 to 2023 (Fig. 4, Table 7).



(a) (b)

Fig. 4. Results estimated AGC of mangrove forests using PlanetScope data: (a) 2020 and (b) 2023

As can be seen Table 8, it shows the variations in the minimum, maximum, mean value, standard deviation, and total value of AGC stocks. The mean AGC stocks of 2020 and 2021 are almost the same, with 324.00 tons and 324.01 tons, respectively. The year 2022 shows a decrease in the mean by 313.4 tons, and a sharper decrease in 2023 data, with a mean value of 299.0 tons. The decrease in mean AGC stocks in 2023 is due to various factors, including environmental changes, deforestation, and climate-affecting carbon accumulation. Since PlanetScope data has medium resolution and is affected by weather, tides, and clouds, it is important to carefully evaluate and take note of these factors to ensure the quality of the data collected.

Table 7. Estimation of AGC from PlanetScope data each selected year

AGC *(Ton ha^{-1})*	2020	2021	2022	2023
Min	201.60	173.93	196.57	173.29
Max	535.08	522.12	477.27	475.05
Mean	324.00	324.01	313.43	299.00
SD	74.46	83.96	63.70	71.50
Total	123,283,798.10	135,184,238.90	124,611,034.10	114,822,211.04
ACS	452,451,539.03	496,126,156.76	457,322,495.15	421,397,514.50

AGB and AGC estimation-basedd field investigation

Mangrove forests in Tien Yen district is a natural forest with many mangrove species, such as *Bruguiera gymnorrhiza*, *Rhizophora stylosa*, *Aegiceras corniculatum*, *Kandelia candel* and *Avicennia marina*. Their biomass are highly dependent on mangrove density, species composition and growth and is determined by the total aboveground biomass of forest trees. Based on Table 8, it can be seen that the average value of AGB is 733.99 tons ha^{-1}. In addition, the maximum and minimum values are 904.15 tons ha^{-1} in Plot 7 and 565.07 tons ha^{-1} in plot 5, respectively.

Table 8. Measuring carbon storage of mangrove forests in 14 plots

Plots	Species	Longitude	Latitude	Density (tree ha^{-1})	DBH (cm)	H (cm)	AGB (ton ha^{-1})	AGC (ton ha^{-1})
1	BG, RS, AC, AM	107.40676	21.24150	4732	5.23	1.83	720.36	338.57
2	BG, RS, AC, KC	107.40651	21.24014	3670	5.75	1.90	666.66	313.33
3	BG, RS, AC, KC	107.40604	21.24262	3670	5.55	1.92	605.33	284.51
4	BG, RS, AM	107.40140	21.24164	3638	6.01	2.08	806.41	379.01
5	AC, RS, BG, AM, KC	107.40422	21.24176	2810	4.58	1.83	565.07	265.58
6	BG, RS, KC, AC	107.38812	21.24463	3559	4.51	1.73	605.58	284.62
7	BG, RS	107.39080	21.24910	8969	5.15	2.49	904.15	424.95
8	BG, RS, AC, KC	107.39152	21.24810	2584	5.72	2.48	800.92	376.43
9	BG, RS	107.38829	21.24612	10529	5.42	2.35	628.88	295.57
10	AC, BG, AM	107.37800	21.22073	2876	5.70	1.84	679.96	319.58
11	BG, RS	107.39588	21.24630	12804	4.58	2.13	818.39	384.64
12	BG, RS	107.39933	21.24728	14234	4.73	2.26	891.63	419.07
13	BG, RS	107.40469	21.24422	12024	4.39	2.14	737.33	346.55
14	BG, RS	107.37463	21.18790	14494	4.05	2.11	845.18	397.23
			Mean	7185	5.10	2.08	1.56	733.99
			Max	14494	6.01	2.49	2.02	904.15
			Min	2584	4.05	1.73	1.30	565.07

Where: BG is Bruguiera gymnorrhiza (Vẹt Dù); RS is Rhizophora stylosa (Đước Vòi); AC is Aegiceras corniculatum (Sú); KC is Kandelia candel (Trang); AM is Avicennia marina (Mắm Biển).

According to the study of Clough [44], forest biomass also depends on climate, forest structure, and sediment as well as nutrition condition, salinity of seawater and temperature of the plantation area. The average of AGC was 344.97 tons ha^{-1} for 14 plots and the maximum and minimum values are 424.95 tons ha^{-1} and 265.58 ton ha^{-1}, respectively. The greater the AGB of mangrove forests is, the larger the AGC of mangrove forests is.

Difference of AGB and AGC estimation-based field and PlanetScope data:

We used PlanetSCope data-based AGB and AGC estimation to compare with the estimation of AGB and AGC-based field data from 14 standard circular plots (Table 9). As a result in Table 9, there were variations of AGB and AGC of mangrove forests among field measurements and PlanetScope data-based estimation in 2023. More specifically, variations between field and PlanetScope data ranged from 1% to 37% (from 2.02 tons ha^{-1} to 98.84 ton ha^{-1}), respectively.

Table 9. Field- and Sentinel-based estimation of AGB and AGC in 2023

Plots	GPS		Field (tons/ha)		PlanetScope (tons/ha)		Variations between field and Sentinel estimation	
	X	Y	Biossmass	C stocks	Biomass	C stocks	C Stock	%
1	107.4068	21.2415	720.36	342.17	731.06	347.26	5.08	1
2	107.4065	21.24015	666.66	316.66	680.01	323.00	6.34	2
3	107.406	21.24262	605.33	287.53	601.09	285.52	2.02	1
4	107.4014	21.24164	806.41	383.04	837.84	397.97	14.93	4
5	107.4042	21.24177	565.07	268.41	773.16	367.25	98.84	37
6	107.3881	21.24463	605.58	287.65	576.39	273.79	13.86	5
7	107.3909	21.24911	904.15	429.47	839.61	398.81	30.65	7
8	107.3915	21.24811	800.92	380.44	849.94	403.72	23.29	6
9	107.3883	21.24612	628.88	298.72	751.91	357.16	58.44	20
10	107.378	21.22073	679.96	322.98	574.02	272.66	50.32	16
11	107.3959	21.24631	818.39	388.74	702.75	333.81	54.93	14
12	107.3993	21.24729	891.63	423.52	836.04	397.12	26.41	6
13	107.4047	21.24423	737.33	350.23	838.49	398.28	48.05	14
14	107.3746	21.18791	845.18	401.46	834.63	396.45	5.01	1

Blue carbon approach-based mangrove management:

Mangrove forests that are rich in carbon have experienced deforestation and degradation as a result of land use and land cover changes, as well as various drivers, such as the cutting of trees for fuel, charcoal, and timber [48-51]. The effects of mangrove deforestation and degradation on carbon emissions have been reported at different scales, including regional, national, and global. While natural disturbances can have mixed impacts on carbon stocks held by mangrove forests, sea-level rise are more likely to drown these forests and result in the loss of carbon stocks, but also offers opportunities for new carbon sequestration [52]. To enhance carbon stocks and reduce greenhouse gas emissions caused by land use and land cover changes, mangrove rehabilitation practices have been implemented [52]. Recently, international conservation policy has paid special attention to blue carbon in mangroves, as it has been proven beneficial for carbon sequestration and greenhouse gas reduction. A better understanding of the relationship between carbon stocks and fluxes in response to both human and biophysical disturbances can provide better incentives to help conserve and manage mangroves sustainably [52].

In Vietnam, the main drivers of mangrove deforestation and degradation are aquaculture development, agricultural land use, and infrastructure development [27, 49]. In spite of significant investments, most mangrove projects have chosen to focus on low-diversity planting and have had mixed success, accordingly [53]. Many efforts have come to nothing as a consequence of planting inappropriate species in environmentally unsuitable settings [54].

Blue carbon is a natural solution which refers to the organic carbon that is stored and sequestered by oceans and coastal ecosystems, including mangrove forests [55]. Blue carbon may be used as a tool to incentivize individuals and organizations to conserve and restore mangroves through payments for ecosystem services (PES). PES can provide a financial incentive for reducing the anthropogenic drivers of mangrove loss by using financial mechanisms such as mandatory carbon credit schemes or voluntary carbon credit markets [22]. Substantial up-scaling and investments in PES can significantly reduce greenhouse gas emissions and improve local livelihoods. Although mangrove forests can be influenced by significant external factors like upstream catchments and tropical storms, mangrove PES projects can still be implemented by using frames against the levels of risk that can affect carbon gains, with management actions, for example, credit buffers and large-scale threat assessment [22, 56]. A better understanding of mangrove blue carbon and its dynamics under anthropogenic pressures is needed to conserve and manage this ecosystem as well as reduce its impact on climate change. Mangrove blue carbon can be achieved through the carbon stock of community-managed mangroves, which can provide a sustainable income source for local communities while improving carbon stocks [56]. However, to establish effective community-based mangrove PFES in Vietnam challenges such as unclear tenure rights, poor ecological consideration in reforestation, and poor coastal management planning need to be addressed [55]. Private-sector initiatives should also be encouraged to protect and restore mangrove forests, and develop suitable local livelihoods.

4. CONCLUSION

This study investigated the structure and extent of mangrove forests in Tien Yen district, Quang Ninh province by using PlanetScope data and the field surveys. The study revealed that the mangrove forests comprise a mixed natural forest of five tree species with varying densities, heights, and diameters. Furthermore, it is found the coastal mangrove forests in Tien Yen increased in extent by 137.7 ha in 2023 (3625.1 ha) compared to 2020 (3487.4 ha). The study also estimated the total AGB and AGC of mangrove forests in Tien Yen, which was 241,730,970 tons and 114,822,211 tons in 2023, respectively. Moreover, mangrove forests sequestered 421,397,514 tons of CO_2 in 2023 compared to 452,451,539 tons of CO_2 in 2020. Additionally, the findings indicate that mangrove forests have significant ecological and climate benefits. Therefore, the study suggests the adoption of mangrove blue carbon approach for sustainable mangrove management in Tien Yen district. It is also suggested that Payment for Ecosystem Services (PES) and Reducing Emissions from Deforestation and Forest Degradation (REDD+) schemes should be taken into consideration to promote mangrove forest conservation along with supporting local livelihoods. Such interventions would incentivize mangrove forest management by protecting these valuable ecosystems and mitigating climate change.

REFERENCES

[1]. Dat P.T. & Yoshino K. (2016). Impacts of mangrove management systems on mangrove changes in the Northern Coast of Vietnam. Tropics. 24:141-151. https://doi.org/10.3759/tropics.24.141

[2]. Sulochanan B., Ratheesh L., Veena S., Padua S., Prema D., Rohit P., Kaladharan P. & Kripa V. (2022). Water and sediment quality parameters of the restored mangrove ecosystem of Gurupura River and natural mangrove ecosystem of Shambhavi River in Dakshina Kannada, India. Marine Pollution Bulletin. 176:113450.

[3]. Nagelkerken I., Blaber S., Bouillon S., Green P., Haywood M., Kirton L., Meynecke J.-O., Pawlik J., Penrose H. & Sasekumar A. (2008). The habitat function of mangroves for terrestrial and marine fauna: A review. Aquatic Botany. 89(2):155-185.

[4]. Sathirathai S. & Barbier E. B. (2001). Valuing mangrove conservation in southern Thailand. Contemporary Economic Policy. 19(2):109–122.

[5]. Othman M. A. (1994). Value of mangroves in coastal protection. Hydrobiologia, 285:277-282.

[6]. Tri N.H., Adger W.N. & Kelly P. (1998). Natural resource management in mitigating climate impacts: The example of mangrove restoration in Vietnam. Global Environmental Change. 8(1):49–61.

[7]. Alongi D.M. (2014). Carbon cycling and storage in mangrove forests. Annual Review of Marine Science. 6:195–219.

[8]. Leal M. & Spalding M. D. (2022). The State of the World's Mangroves 2022 (p. 49). Global Mangrove Alliance. https://www.mangrovealliance.org/resources/the-state-of-the-worlds-mangroves-2022.

[9]. Veettil B.K., Ward R.D., Quang N.X., Trang N.T.T. & Giang T.H. (2019). Mangroves of Vietnam: Historical development, current state of research and future threats. Estuarine, Coastal and Shelf Science. 218:212–236.

[10]. Hai-Hoa N. & Hien N.T.T. (2021). Above-ground biomass estimation models of mangrove forest based-on remote sensing and field-surveyed data: Implication for C-PFES implementation in Quang Ninh province, Vietnam. Regional Studies in Marine Science. 48:101985. http://dx.doi.org/10.1016/j.rsma.2021.101985

[11]. Fourqurean J.W., Duarte C.M., Kennedy H., Marbà N., Holmer M. Mateo, M.A. & Serrano O. (2012). Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience. 5(7), 505–509. doi:10.1038/ngeo1477.

[12]. Lasco R.D. (2004). The clean development mechanism and LULUCF projects in the Philippines. International Symposium/Workshop on the Kyoto Mechanism and the Conservation of Tropical Forest Ecosystems, Waseda University. 53-57.

[13]. Yee M.S. (2010). Project "REDD and BLUE Carbon: Carbon Payments for Mangrove Conservation". Center for Marine Biodiversity and Conservation.

[14]. Albert J., Warren-Rhodes K., Schwarz A. & Duke N. (2012). Mangrove ecosystem services and payments for blue carbon in Solomon Islands.

[15]. Vo Q.T., Künze, C., Vo Q.M., Moder F. & Oppelt N. (2012). Review of valuation methods for mangrove ecosystem services. Ecological Indicators. 23:431-446.

[16]. Fletcher, R., Dressler, W., Büscher, B. & Anderson, Z. R. (2016). Questioning REDD+ and the future of market-based conservation. Conservation Biology. 30(3):673-675.

[17]. Kovacs J.M., Santiago F.F., Bastien J. Lafrance P. (2010). An Assessment of Mangroves in Guinea, West Africa, using a Field and Remote Sensing Based Approach. Wetlands. 30:773-782. https://doi.org/10.1007/s13157-010-0065-3

[18]. Giri C. (2016). Observation and monitoring of mangrove forests using remote sensing: Opportunities and challenges. Remote Sensing. 8(9):783. https://doi.org/10.3390/rs8090783

[19]. Castillo J.A.A., Apan A.A., Maraseni T.N. & Salmo S.G. (2017). Estimation and mapping of above-ground biomass of mangrove forests and their replacement land uses in the Philippines using sentinel imagery. ISPRS J. Photogramm. Remote Sens. 134:70-85. http://dx.doi.org/10.1016/j.isprsjprs.2017.10.016

[20]. Hai-Hoa N., Lan T.T.N., An L.T., Nghia N.H., Linh D.V.K., Thu N.H.T., Bohm S. & Premnath C.F.S. (2020). Monitoring changes in coastal mangrove extents using multi-temporal satellite data in selected communes, Hai Phong city, Vietnam. Forest and Society. 4 256–720.

[21]. Huang H. & Roy D.P. (2021). Characterization of Planetscope-0 Planetscope-1 surface reflectance and normalized difference vegetation index continuity. Science of Remote Sensing. 3.

[22]. Yan C., Anton V., Francesco F., Michele M., Michael M. & Stella G. (2020). Phenology of short vegetation cycles in a Kenyan rangeland from PlanetScope and Sentinel-2. Remote Sensing of Environment 248.

[23]. Planet Developers. (2023). PlanetScope Data API Documentation. Retrieved from https://developers.planet.com/docs/data/planetscope/

[24]. Saad S.N.M., Wan Mohd Jaafar W.S., Omar H., Abdul Maulud K.N., Muhmad Kamarulzaman A.M.,

Adrah E., Mohd Ghazali N. & Mohan M. (2023). Modeling Carbon Emissions of Post-Selective Logging in the Production Forests of Ulu Jelai, Pahang, Malaysia. Remote Sens. 15:1016. https://doi.org/ 10.3390/rs15041016

[25]. Son H.T., Quang P.D., Hai-Hoa N. & Truong V.V. (2022). Using Sentinel-2 data for above-ground mangrove biomass and carbon stocks mapping over 7 years (2016-2022) in Tien Yen, Quang Ninh province. Journal of Forestry Science and Technology 14:153-165. https://doi.org/10.55250/jo.vnuf.2022.14.153-165.

[26]. Hai-Hoa N., Nghia N.H., Hien N.T.T., An L.T., Lan T.T., Linh D., Simone B. & Michael F. (2020). Classification Methods for Mapping Mangrove Extents and Drivers of Change in Thanh Hoa Province, Vietnam during 2005-2018. Forest and Society. 4:225.

[27]. Hai-Hoa N., Quang P.D., Truong V.V. & Tuan L.P. (2022). Mapping mangrove cover change using PlanetScope data (2017-2022) in Quang Yen town, Quang Ninh province toward sustainable mangrove management. Journal of Forestry Science and Technology. 13: 071-80.

[28]. Hai-Hoa N., Cuong T.N. & Nguyen D.V. (2022). Spatial-temporal dynamics of mangrove extent in Quang Ninh Province over 33 years (1987-2020): Implications toward mangrove management in Vietnam. Regional Studies in Marine Science. 52:102212. https://doi.org/10.1016/j.rsma.2022.102212

[29]. Pavlovic V.I., Sharma R. & Huang T.S. (1997). Visual interpretation of hand gestures for humancomputer interaction: a review. IEEE Transactions on Pattern Analysis and Machine Intelligence. 19(7):677-695. https://doi:10.1109/34.598226

[30]. Ye N., Morgenroth J., Xu C. & Chen N. (2021). Indigenous forest classification in New Zealand – A comparison of classifiers and sensors. International Journal of Applied Earth Observation and Geoinformation. 102:102395. https://doi:10.1016/j.jag.2021.102395

[31] Asrat Z., Taddese H., Orka H., Gobakken T., Burud I. & Næsset E. (2018). Estimation of Forest Area and Canopy Cover Based on Visual Interpretation of Satellite Images in Ethiopia. Land, 7(3):92. http://doi:10.3390/land7030092

[32]. Rouse J.W., Hass R.H., Schell J.A., Deering D.W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. 3rd ERTS Symposium, NASA SP351, Washington DC, 10-14 December 1973, 309-317.

[33]. Thu P.M. & Populus J. (2007). Status and changes of mangrove forest in Mekong Delta: Case study in Tra Vinh, Vietnam. Estuarine, Coastal and Shelf Science. 71(1-2):98-109. https://doi.org/10.1016/j.ecss.2006.08.007

[34]. Du Y., Zhang Y., Ling F., Wang Q., Li W. & Li X. (2016). Water Bodies' Mapping from Sentinel-2 Imagery with Modified Normalized Difference Water Index at 10-m Spatial Resolution Produced by Sharpening the SWIR Band. Remote Sensing. 8(4): 354. http://doi:10.3390/rs8040354

[35]. Kaplan G. & Avdan U. (2017). Object-based water body extraction model using Sentinel-2 satellite imagery. European Journal of Remote Sensing. 50(1):137-143.

[36]. Gupta K., Mukhopadhyay A., Giri S., Chanda A., Datta Majumdar S., Samanta S. & Hazra S. (2018). An Index for discrimination of mangroves from non-mangroves using LANDSAT 8 OLI imagery. MethodsX. doi:10.1016/j.mex.2018.09.011.

[37]. Jamaluddin I., Thaipisutikul T., Chen Y.N., Chuang C.H. & Hu C.L. (2021). MDPrePost-Net: A Spatial-Spectral-Temporal Fully Convolutional Network for Mapping of Mangrove Degradation Affected by Hurricane Irma 2017 Using Sentinel-2 Data. Remote Sens. 13:5042. https://doi.org/10.3390/rs13245042

[38]. Conchedda G., Durieux L. & Mayaux P. (2008). An object-based method for mapping and change analysis in mangrove ecosystems. ISPRS Journal of Photogrammetry and Remote Sensing. 63:578-589. https://doi.org/10.1016/j.isprsjprs.2008.04.002

[39]. Foody G.M. (2002). Status of land cover classification accuracy assessment. Remote Sensing of Environment. 80:185-201. https://doi.org/10.1016/S0034-4257(01)00295-4

[40]. Sha H., Tang L., Hupy J.P., Wang Y. & Shao G. (2020). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. Journal of Forestry Research. doi:10.1007/s11676-020-01155-1

[41]. Howard J., Hoyt S., Isensee K., Telszewski M. & Pidgeon E. (eds.) (2014). Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and sea-grasses. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA.

[42]. Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. (2006). IPCC Guidelines for National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[43]. Kauffman J.B. & Donato D.C. (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.

[44]. Clough B.F. & Scott K. (1989) Allometric relationships for estimating above-ground biomass in six mangrove species. For. Ecol. Manag. 27:117–127.

[45]. Komiyama A., Poungparn S. & Kato S. (2005) Common allometric equations for estimating the tree weight of mangroves. J. Trop. Ecol. 21:471-477.

[46]. Fu W. & Wu Y. (2011) Estimation of aboveground biomass of di_erent mangrove trees based on canopy diameter and tree height. Procedia Environ. Sci. 10:2189–2194.

[47]. Simpson W.T. (1996). Method to estimate dry-kiln schedules and species groupings: Tropical and temperate hardwoods. RPL-RP-548. USDA Forest Service, Forest Products Laboratory, Madison, USA.

[48]. Hai-Hoa N., McAlpine C., Pullar, D., Johansen

K. & Duke N.C. (2013). The relationship of spatial–temporal changes in fringe mangrove extent and adjacent land-use: Case study of Kien Giang coast, Vietnam. Ocean and Coastal Management. 76:12–32. http://dx.doi.org/10.1016/j.ocecoaman.2013.01.003

[49]. Hai-Hoa N. (2014). The relation of coastal mangrove changes and adjacent land-use: A review in Southeast Asia and Kien Giang, Vietnam. Ocean and Coastal Management. 90:1-10. https://doi.org/10.1016/j.ocecoaman.2013.12.016

[50]. Adenan R. (2018). Restoration of mangrove co-management to sequester coastal blue carbon. Advances in Social Sciences Research Journal. 5(3):27-40. https://doi.org/10.14738/assrj.53.4134

[51]. Sasmito S.D., Basyuni M., Kridalaksana A., Saragi-Sasmito M.F., Lovelock C.E. & Murdiyarso D. (2023). Challenges and opportunities for achieving Sustainable Development Goals through restoration of Indonesia's mangroves. Nature Ecology & Evolution. 7:62-70.

[52]. Friess D.A., Krauss K.W., Taillardat P., Adame M.F., Yando E.S., Cameron C., Sasmito S.D. & Sillanpaa, M. (2020). Mangrove blue carbon in the face of deforestation, climate change and restoration. Annual Plant Reviews. 3:427-456. https://doi.org/10.1002/9781119312994.apr0752

[53]. Primavera J.H. & Esteban J.M. (2008). A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. Wetlands Ecology and Management. 16: 345–358. https://doi.org/10.1007/s11273-008-9101-y

[54]. Bayraktarov E., Saunders M.I., Abdullah S. Mills M., Beher J., Possingham H.P., Mumby P.J. & Lovelock C.E. (2016). The cost and feasibility of marine coastal restoration. Ecological Applications. 26: 1055–1074. https://doi.org/10.1890/15-1077

[55]. Macreadie P.I., Anton A. & Raven J.A. (2019). The future of Blue Carbon science. Nat Commun 10, 3998. https://doi.org/10.1038/s41467-019-11693-w

[56]. Friess D.A., Phelps J., Garmendia E. & Gómez-Baggethun E. (2015). Payments for ecosystem services (PES) in the face of external biophysical stressors. Global Environmental Change. 30:31-42. https://doi.org/10.1016/j.gloenvcha.2014.10.013

SỬ DỤNG DỮ LIỆU ẢNH PLANETSCOPE ĐỂ ƯỚC TÍNH TRỮ LƯỢNG CÁC-BON RỪNG NGẬP MẶN TẠI HUYỆN TIÊN YÊN, TỈNH QUẢNG NINH

Nguyễn Hải Hoà, Hà Trí Sơn[1], Nghiêm Thị Linh[1],
Daniel Ojeda de Vicent[2], Nguyễn Ngọc Linh[1]
[1]Trường Đại học Lâm nghiệp
[2]Trường Đại học Eberswalde vì sự Phát triển bền vững (HNEE), Đức

TÓM TẮT

Rừng ngập mặn được tìm thấy dọc theo các bờ biển nhiệt đới và cận nhiệt đới. Chúng có chức năng quan trọng trong việc ngăn chặn xói mòn ven bờ, giảm thiểu tác động của sóng và bảo vệ các môi trường sống ven bờ. Nghiên cứu này sử dụng rừng ngập mặn PlanetScope và chỉ số CMRI. Chỉ số này phù hợp để phát hiện phủ kín rừng ngập mặn dọc bờ ven biển huyện Tiên Yên với độ chính xác tổng thể lên đến 93,0% và hệ số Kappa lớn hơn 0,90 trong suốt các năm được chọn. Tổng diện tích rừng ngập mặn ven biển huyện Tiên Yên, tỉnh Quảng Ninh đã tăng thêm 137,8 ha vào năm 2023 so với năm 2020. Hơn nữa, tổng AGB và AGC của rừng ngập mặn được ước tính lần lượt đạt khoảng 241.730.970 tấn và 114.822.211 tấn vào năm 2023. Tổng khối lượng phản ứng hấp thụ CO_2 được ước tính đạt 421.397.514 tấn năm 2023, giảm 17.813.872,1 tấn so với năm 2020. Nghiên cứu đề xuất triển khai việc giải pháp blue carbon rừng ngập mặn để đạt được mục tiêu quản lý rừng ngập mặn bền vững tại huyện Tiên Yên, bao gồm chương trình chi trả dịch vụ sinh thái (PES) cho các khu rừng ngập mặn. Tuy nhiên, để đảm bảo sự thành công của giải pháp blue carbon cho rừng ngập mặn tại huyện Tiên Yên, một số vấn đề liên quan, bao gồm tăng cường nhận thức về giá trị của hệ sinh thái rừng ngập mặn, khuyến khích sự tham gia của cộng đồng địa phương và rà soát bổ sung các chính sách liên quan đến chi trả dịch vụ môi trường.

Từ khoá: các-bon trên mặt đất (AGC, Above-ground Carbon), chỉ số CMRI (Combined Mangrove Recognition Index), chỉ số NDVI (Normalized Difference Vegetation Index), PlanetScope, sinh khối trên mặt đất (AGB, Above-ground Biomass), Tien Yen.

Received : 24/3/2023
Revised : 26/4/2023
Accepted : 11/5/2023