A preliminary work on blue carbon stock mapping in mangrove habitat using satellite-based approach

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Abstract. Mangrove habitat is among blue carbon components that offer a strong base for mitigation strategies in coastal ecosystems. It provides numerous significant economic and ecological services such as being capable of serving as a long-term carbon sink via sequestering carbon from the atmosphere by photosynthesis as well as carbon burial within the sediment. Therefore, it is essential to comprehend the distribution of carbon dioxide stored in mangrove habitat in spatiotemporal bases. This article seeks to map mangrove blue carbon stock in coastal water of Penang, Malaysia using a moderate spatial resolution of passive remote sensing data. In this study, an established allometric equation for tree and root was implemented on Landsat ETM for mangrove area to estimate below-ground carbon and above-ground carbon stocks by measuring biomass using Diameter at Breast Height (DBH) parameter. Afterwards, the biomass of every single stand was multiply by 0.464 gC to obtain the contents of carbon. DBH-radiance relationship models were generated using polynomial regression equation and employed to predict the entire above-ground and below-ground biomass of mangrove in the study area by plotting DBH value against radiance value. For accuracy, acceptable $R^2$ Adjusted values of 0.415, 0.438, 0.593 and $p = $ values of 0.0503, 0.0440, and 0.0154 were obtained for blue, green and red bands, respectively. The study revealed the capabilities of satellite-based approach in estimating mangrove blue carbon stock, whose conservation and storage are paramount as outlined in the 2030 agenda of the United Nations Sustainable Development Goals.

1. Introduction

Mangrove habitat is among the coastal blue carbon component that provides economically and ecologically significant ecosystem services, including carbon and nutrient sequestration [1, 2]. The ecosystem sequesters large quantity of carbon dioxide (CO$_2$) [3], derived from the earth atmosphere and act as natural sinks through accumulating carbon in sediments [2, 4, 5]. The quantity of carbon sequestered in blue carbon habitats is generally larger than the majority of terrestrial forests, regardless of having a global coverage. [6, 7]. The success of carbon sequestration in this habitat is because of the high primary productivity and efficiency in carbon storage and nutrients in soils [7, 8]. Mangrove area is effectual in trapping and accumulating sediments related to sea level [5, 7, 9, 10]. Therefore, comprehending the blue carbon stock in mangrove habitat is substantial in a spatial context, not only for reducing the concentrated CO$_2$ in the atmosphere, but also for sustainable coastal health. This is in line with the Sustainable Development Goals (SDG) 14 and 13 of the United Nations.
Currently, blue carbon components including seagrass and mangrove areas are facing a critical loss due to inappropriate land use management [11] that needs effective action from the coastal authorities such as coastal managers, governments and other stakeholders. The advancements in aquaculture, agriculture, industry, settlements, and tourism along the coastal environments are the main triggers [12, 13]. It is stated that 20% of mangroves have been lost since 1980 and 2000 - 2005, where about 118 km$^2$ of mangrove forests were deforested annually. Hence, all the unprotected mangroves may perhaps be lost in the next coming century [14, 15]. In Malaysia, mangrove forest covers 641,886 ha out of which about 106,544 ha of land are located in Peninsula Malaysia. This habitat offers enormous ecosystem services [16], although they are suffering a continuing deterioration that needs immediate action [17]. However, no official report or scientific document shows the carbon content of this ecosystem at large areal coverage. Most studies used only field-based approach in this country that limits the ability to estimate the potential carbon contents in mangrove ecosystem, due to constraining of time, manpower, cost and expertise. Therefore, estimating Above-ground Carbon (AGC) and Below-Ground Carbon (BGC) of mangrove carbon stocks are essential to obtain the preliminary amount of blue carbon stock, except soil carbon contents. This study contributes to climate change mitigation, coastal management, and natural resources conservation.

Significant information on mangrove carbon stocks at large area can be only obtained through remote sensing technology. The recent advancement in satellite technology allows data to be attained with higher resolution (RS), spectral sensitivity, radiometric precision, and temporal frequency. It is evidence that remote sensing approach have been utilized to estimate and map blue carbon stocks. For an instance, Hashim, Yahya [18] and Wicaksono, Danae [19] estimated and mapped blue carbon stocks using satellite-based approach and field data. Hence, the study complimented other research on blue carbon stocks estimation on mangrove habitat. Therefore, this study aimed to quantify AGC and BGC stocks of mangrove habitat in Penang state of Peninsula Malaysia. Landsat ETM was chosen due its large areal coverage and the ability for constant monitoring of carbon sequestration in this state.

2. Study Location
The study was conducted in Penang state, located on the north-west coast of the Peninsula Malaysia. (Figure 1). It bordered by the state of Kedah to the north and east, Perak state by the south and in the western part is straits of Malacca as well as Sumatra in Indonesia. The sample sites was Pulau Gazumbo, located along (5˚21’N, 100˚19’E), it is an island close to the bridge of Penang which links between the mainland, of Peninsula Malaysia. The island is claimed as a manmade.

![Figure 1. Study area](image-url)
3. Methods Materials

In this study, two sets of data (primary and secondary) were integrated to answer the objective of the study, consist of Landsat ETM with 30 m resolution and field samples were utilized to map mangrove AGC and BGC contents SF. During the field measurement of mangrove, tree Diameter at Breast Height (DBH) was measured using tape and the coordinate of each sampling point was taken, as well as photographs (as can be seen in Figure 2). The tree and root biomass method were employed to measure mangrove Above-Ground Biomass (AGB) and Below-Ground Biomass (BGB). A non-destructive allometric equation for mangrove biomass developed by Komiyama et al. (2005) was adopted because the equation was developed for mangrove location in the tropical region. In the equation, wood density is kg/m3 which is inclusive all mangrove species, to accommodate the stretches pattern of mangrove in the study area. The AGB and BGB were converted to carbon contents, using conversion factor of 0.464gC per 1 g, as adopted by Wicaksono, Danoedoro [20].

\[ W_{agb} = 0.247 \rho (D^2)^{1.23} \]  \hspace{1cm} (1)

where: \( W_{agb} \) stands for the above-ground biomass kg; \( \rho \) represents the species wood density; and diameter at breast height is representing as \( D \).

The following formula was used to compute the biomass of the root:

\[ W_R = 0.199 \rho^{0.899} (D^2)^{2.22} \]  \hspace{1cm} (2)

Figure 2. Diameter at breast height measurement of a Mangrove species in Gazumbo Island, Penang Malaysia

3.1. Processing of Satellite Data

The two major steps (Figure 3 shows), comprising of four stages of data processing involved in the study: (a) pre-processing of data includes atmospheric correction, geometric correction, radiometric calibration on satellite image; (b) quantifying and mapping of the mangrove AGC and BGC stock in the study area. The flowchart in Figure 3 illustrated all these stages of data processing with. Data processing operations were conducted using remote sensing software ENVI 5.0 version and ArcMap version 10.2. Hence, all the process mentioned above is not detailed explain in this paper.
Figure 3. Flowchart of the study methodology

3.1.1. Pre-Processing of Satellite Data. The stages of data pre-processing comprise: (a) geometric correction; (b) removal of sun glint; (c) satellite digital number (DN) conversion to radiance; as well as (d) atmospheric correction. Image subset was performed to extract the area of interest. To conduct the procedure of image processing only the areas of water and mangrove cover were extracted to simplify further analysis. Method of image masking was applied, to mask out some part of the land, shadow and cloud areas, before carrying on to the next levels of the pre-processing. In the masking procedure, band4 near infrared with (0.76–0.89 μm) was selected because it offers a good description of land and water [17].

4. Results and Discussions

Eight species of mangrove were estimated (see Table 1). These species include Avicennia amarina, Rhizophor amuncronata, Rhizophor amuncronata, Rhizophor aapiculate, Rhizophora aapiculate, Rhizophor astylosa, Rhizophor amuncronata and Rhizophor astylosa. Subsequent, mangrove AGC and BGC contain were derived using a conversion factor to multiply the biomass of every single stand by 0.464 gC. Lastly, AGC and BGC value for each mangrove stand were added up to get sample carbon stock which was later adopted as dependent variable within regression analysis, as seen below.

The above table explained the results of the allometric equation and generated radiance from blue, green and red bands that were used to map the AGC and BGC of mangrove forest in Penang state of Peninsula Malaysia.

4.1 Total Mangrove carbon estimation

DBH-radiance relationship models were generated using polynomial regression equation and employed to predict the entire AGB and BGB of mangrove in the study area by plotting DBH value against radiance value as can be seen in Figure 4 and equations 1, 2 and 3 below. An acceptable results R² Adjusted values of 0.415, 0.438, 0.593 and p = values of 0.0503, 0.0440, and 0.0154 were obtained.
for blue, green and red bands, respectively. Subsequently, the mangrove carbon stock map was derived.

\[
\begin{align*}
DBH-B &= -0.3186(B1)^2 + 46.192(B1) - 1658.2 \quad (3) \\
DBH-G &= -0.1774(B2)^2 + 20.698(B2) - 588.72 \quad (4) \\
DBH-R &= -0.1462(B3)^2 + 11.198(B3) - 199.71 \quad (5)
\end{align*}
\]

where DBH is the dependant variable and an acronym stands for diameter at breast height, DBH-B stands for DBH of blue band radiance. DBH-G stands for DBH of green band radiance, and DBH-R stands for DBH of red band radiance. B1, B2 and B3 are the independent variables.

### Table 1. Mangrove Species, DBH value and the generated radiance value of blue, green red bands

| S/No | Species               | Local name | DBH (cm) | B        | G        | R        |
|------|-----------------------|------------|----------|----------|----------|----------|
| 1    | *Avicennia marina*    | Api-api    | 7.5      | 67.00156 | 52.712597| 31.677349| 0.73     |
| 2    | *Rhizophora mucronata*| Bakaukurap | 5.1      | 67.7803  | 51.913776| 31.677349| 0.94     |
| 3    | *Rhizophora mucronata*| Bakaukurap | 9.4      | 68.55904 | 54.310234| 32.92065 | 0.94     |
| 4    | *Rhizophora apiculata*| Bangkita   | 12.3     | 74.78896 | 59.901962| 39.13715 | 0.88     |
| 5    | *Rhizophora apiculata*| Bangkita   | 16.2     | 74.78896 | 59.901962| 39.13715 | 0.94     |
| 6    | *Rhizophora stylosa*  | BakauPutih | 15.9     | 70.11652 | 55.109055| 36.650547| 0.94     |
| 7    | *Rhizophora mucronata*| Bakaukurap | 12.5     | 68.55904 | 53.511414| 32.92065 | 0.94     |
| 8    | *Rhizophora stylosa*  | BakauPutih | 8.1      | 67.00156 | 51.11496 | 30.434048| 0.94     |

**Total** 0.906

![Figure 4](image-url)

**Figure 4.** DBH-Radiance relationship for predicting radiance values of below-ground and above-ground biomass content of (A) Blue, (B) Green and (C) Red bands
In this study, the radiance was multiplied by 0.464 to obtain the carbon content (as seen in Figure 5) and the total carbon content in the study area is 584.6 tC ha⁻¹ of the AGC and BGC of mangrove habitat. The result indicated that there is a high percentage of mangrove carbon content in the western part then the other parts of the state. This is mainly due to variation in geographic location, as the western part of the state bordered straits of Malacca as well as Sumatra in Indonesia. These areas have highly diverse mangrove forests, with high conservation values.

Figure 5. Map showing the number of sequestered CO2 in mangrove calculated from multi-temporal Landsat ETM+

5. Conclusions
The outcome of this study pointed out that Landsat ETM imagery offers spatially explicit mangrove AGC and BGC stock mapping of Penang state in Peninsula Malaysia. Some acceptable $R^2$ Adjusted values of 0.415, 0.438, 0.593 and $p$-values of 0.0503, 0.0440, and 0.0154 from DBH-radiance relationship models was derived, which shows a significant accuracy of the prediction result. Multi-temporal RS approach to estimate carbon stock rate demonstrated a promising result because the mapping method could be employed for C sequestration mapping in all over Malaysian blue carbon ecosystems where mangrove is occurring. The result will be beneficial to coastal managers, academics and scientists involved with implementing projects on mapping and developing predictive models on mangrove habitat carbon stock. Lastly, the map obtained from satellite data may enhance the availability of information on spatio-temporal mangrove carbon stock distribution. Future work should be able to involve the sediment, seagrass and salt marshes carbon stock, in order to obtain total blue carbon stock in the study area.

Acknowledgement
The authors enormously acknowledge the Dr. Syarifudin Misbari for the assistance. Facilities of research utilized from Universiti Teknologi Malaysia also are acknowledged.

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