Spatial pattern of carbon mangrove stock based on habitat characteristics in Bali Province

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Abstract. Although climate change mitigation regarding mangrove forest management has been given significant international attention during the past decade, there are no sufficiently reliable data to quantify the availability of carbon stock in mangrove forests. The mangrove forest in the Bali Province is divided into three habitat types, namely an open bay located in the West Bali National Park, a semi-closed bay located in Tahura Ngurah Rai and a small island in the protected forest of Nusa Lembongan. The objective of this study is to analyse the relationship between carbon stock characteristics of mangrove forests with the different types and morphologies of mangrove forest habitats. Biomass calculations were carried out by using the allometric formula. However, the similar allometric equations produced varying accuracies at different locations. Results revealed that the mangrove forest carbon stock for the semi-closed bay habitat has the highest estimation value of 51.35 tons/ha and a positive relationship pattern of 60 %. On the contrary, the lowest carbon stock value is the open bay beach with a value 26.28 tons/ha and positive relationship pattern of 48 %. This study reveals that each type of mangrove forest habitat has its own living ecosystem characteristics that affect the carbon stock value.

Keywords: Mangrove forest, habitat, carbon estimates

1. Introduction

Forests play an important role in the carbon cycle and carbon emissions reduction strategies. Research has shown that mangrove forests are one of the richest sources of carbon in the tropics containing approximately 1,023 Mg carbon per ha [1]. The largest mangrove forest area in Southeast Asia is located primarily in Indonesia. It comprises, 3,790,468.08 ha, which is 22 % of the mangrove worldwide [2]. The highest diversity of mangrove forest species in Southeast Asia is almost 75 % of the world’s mangrove species. Furthermore, 45 of the 70 true mangrove species are found in Indonesia [3]. Large areas of mangrove land throughout the world has been degraded and deforested. This is especially the case in Asia, where mangrove areas have declined by 30–50 % in the last 50 years [1]. Mangrove forest degradation and deforestation have an impact on carbon absorption in mangrove forests [4, 5].

Climate change is a global phenomenon caused by human activities that involve the use of fossil fuel energy as well as land and forest conversion activities [6]. Forest management to store carbon and climate change mitigation have received significant attention internationally during the past decade [7]. The Reduction of Emissions from Deforestation and Forest Degradation (REDD+) has been proposed

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as a mechanism to provide financial incentives for developing countries to reduce emissions from forest loss by promoting forest conservation, sustainable forest management and enhancement of forest carbon stocks. The REDD+ program has further proposed key technical challenges to estimate carbon emissions at regional and national levels [8]. However, the REDD+ program has experienced difficulties as a result of the lack of reliable data to assist policymakers to quantify how much carbon is present in the forests of Africa, Southeast Asia and Latin America [1, 4]. The calculation of forest carbon stock estimation data is essential in order to establish an accurate and accountable National Reference Emission Level [9, 10].

2. Methodology

The study was conducted in the Bali Province, an area whose landscape is varied and rather complex, ranging from mountains to small islands. The total area of the Bali Province is 5,636.66 km² [11] and the length of its coast is 529 km. Coastal areas are transitional areas between terrestrial and marine ecosystems that are affected by changes in land and sea [12]. Ecologically mangrove forests are defined as a collection of trees and shrubs that grow in intertidal regions of tropical and sub-tropical beaches, where river water mixes with sea water [13]. The study was conducted in three locations with different habitat morphologies: an open bay in West Bali National Park, a semi-closed bay at Taman Hutan Raya Ngurah Rai, and a small island in Hutan Lindung Nusa Lembongan (figure 1).

Biological natural resources conservation is the management of biological natural resources that are wisely utilized so as to ensure continuity of its stocks while maintaining and enhancing the quality of its diversity and value [14]. Activities in the conservation area that are prohibited include making changes to its territorial integrity such as reducing, and eliminating the function of the area, and adding types of plants and animals that are not indigenous. An assumption was made that conservation area selected for this study consisted of mangroves that were naturally grown and developed.

Figure 1. Map of research area: A. Open bay; B. Semi-closed bay; C. Small island.
The management and monitoring of mangrove forests in biomass measurements require a comprehensive, spatial-based study. One of the problems of remote sensing applications is the incompleteness of information and the complexity of the natural resource ecosystem that has to be measured [15]. The biomass estimation and carbon content of a mangrove forest area is often conducted by utilizing a vegetation transformation index, where the value obtained is a combination of several channels in the image so as to highlight the appearance of vegetation [5].

The remote sensing base mapping method evolved and was judged as an effective method in comparison to the terrestrial mapping method [16]. Vegetation index transformation produces a map of the canopy density and is employed as the basis for creating a field sampling map. The application of stratified sampling methods in carbon stock estimates by remote sensing data is recommended increasing output accuracy and cost effectiveness [17, 18]. Each class of mangrove canopy density in each habitat type has and importance value index (IVI) that is employed to obtain the dominant mangrove species occupying the habitat. The objective of the study is to analyse the relationship between carbon stock characteristics of mangrove forests with the different types and morphologies of mangrove forest habitats. Each type of mangrove was calculated by using allometric and field measurements to obtain the biomass value of the vegetation. The biomass value that was calculated in this study was the above-ground biomass (AGB). It includes stems, stumps, branches, leaves, and fruits [18]. Mangrove biomass calculation using the remote sensing method not only is based on spectral value but also considers the characteristics and conditions of the area. The integration of the analysis through remote sensing data was expected to produce a different perspective to understand the complexity of the mangrove forest area.

3. Results and discussion
The physical concept involved in remote sensing is that the objects on earth have a spectral reflection that characterizes the incoming energy source, thus allowing the study of remote sensing of vegetation [5]. Mangrove forests have unique spectral colors compared with other vegetation. Spectral composition 432 (Near-Infrared Red Green) has an advantage compared to the spectral composition of 321 (Red Green Blue) as it maximizes the difference between mangrove vegetation and other terrestrial vegetation. The infrared wavelength is close to the wavelength range (0.760–0.890 µm), which is sensitive to leaf structure and water content in vegetation. Mangrove vegetation has a thicker leaf structure compared to other land vegetation. The infrared reflection of mangrove vegetation is higher and has less transmission while absorbed by the soil. This result in a darker red color in comparison to the brighter red forest land vegetation. The difference between the composite images of true color (321) and false color (432) is depicted in figure 2.

The results from the vegetation index classification using the soil adjusted vegetation index (SAVI) revealed a different distribution pattern of mangrove forest density across the three habitat types (figure 3). The habitat of mangrove forests is affected by the coastal typology that is formed by the ongoing physical processes in the ocean and on land. Furthermore, this is depending on the genetic processes and their constituent material [19-21]. Mangrove rarely grows on rocky beaches and coral reefs, but its growth is more substantial and denser on sandy and muddy substrates [22]. The open bay is dominated by a sandy substrate, which has medium and moderate density grades and spreads evenly in coastal areas. The mangrove forest density class in the mangrove forest habitat of the semi-closed bay dominated by the mud substrate and has the largest percentage of dense growth, that is evenly distributed throughout the mangrove forest area, thus indicating the area is particularly suitable for mangrove. In the small islands, the mangrove forest habitats that are associated with corals are moderately dense. From the figure it is shown that the inner area of the island has a denser mangrove canopy.

Mangrove is one of the most important types of vegetation found in wetland ecosystems. It grows on the banks of rivers, estuaries, and coastlines. Furthermore, it is able to adapt to various conditions of inundation and water salinity [23]. Mangroves can grow in muddy, sandy, or coral tidal areas. Each type
of mangrove adapts specifically to its environmental conditions. This result in distinct composition and zone differences as a process of adaptation and succession, which is the result of reactions from ecosystem conditions. The different conditions also have an impact on the zone and ecosystems living in the region because each ecosystem comprises various organisms and species that interact with each other.

From an ecological perspective, species with a high significance value index have higher adaptability and greater dominance. Suitable environmental conditions play a critical role in the selection of the survival of species. The *Rhizophora apiculata*, *Rhizophora stylosa*, and *Bruguiera gymnorrhiza* are examples of species that can be found in every mangrove forest in the Bali Province. These three species are known to have a higher tolerance to various conditions of the mangrove forest ecosystem. In table 1, an IVI table is illustrating the comparison of dominant species found in each mangrove forest habitat.

A comparison of IVI mangrove values in three mangrove forest habitats reveals that mangrove forest habitat types may indicate the discovery of a particular species. The open bay habitat of mangrove forest is dominated by *Rhizophora apiculata* and *Sonneratia alba*, and the semi-closed mangrove forest habitat dominated by *Rhizophora spp*. The small island mangrove habitat is dominated by *Rhizophora apiculata* and *Lumnitzera racemosa*. Types of *Lumnitzera racemosa* are commonly found in small mangrove forest habitats on small islands and sometimes in open bay habitats, as they favor dry climatic conditions. They tend to favor sandy or muddy solids that are hardly encountered in semi-closed bay habitats, which are often inundated muddy-soil conditions.

![Figure 2](image1.png)

**Figure 2.** Mangrove forest in the SPOT 6 image of West Bali National Park: (a) True color image, and (b) False color image.

![Figure 3](image2.png)

**Figure 3.** Distribution of mangrove canopy density: (a) Open bay, (b) Semi-closed bay, and (c) Small island.
The extent of mangrove forest area is not always linked to high carbon content (table 2). There are some cases such as larger habitats that contain lower carbon content. This may be caused by fewer mangrove trees and more saplings and seedlings. Smaller habitat areas contain a greater carbon content potential because more individual trees are possible rather than saplings or seedlings. The results of the normality data test by using one-way analysis ANOVA indicated normally distributed data with data variance assumed normal/homogenic. Based on the results of the test, it can be concluded that there is no significant relationship between the type of beach and carbon value. Therefore, every mangrove forest habitat has an average impact on the carbon content and its increase is almost equal.

The relationship between carbon values in the three habitats in each density class can also be explained by the correlation coefficient. The size of the changes in the variable carbon content affects the density level of the mangrove forest canopy. Mangrove forest habitat types in open bays and semi-closed bays have a positive relationship with their carbon values. However, in the mangrove forest

### Table 1. Comparison of Importance Value Index (IVI) of Mangrove forest habitat.

| Habitat         | Species          | Importance Value Index |
|-----------------|------------------|------------------------|
|                 | Tree             | Sapling    | Seedling  |
| Open bay        | Rhizophora apiculate | 114.23   | 0.00      | 50.00     |
|                 | Rhizophora stylosa | 16.67     | 0.00      | 0.00      |
|                 | Sonneratia alba  | 51.77      | 0.00      | 0.00      |
|                 | Ceriops tagal    | 19.11      | 0.00      | 0.00      |
|                 | Avicennia marina | 23.23      | 0.00      | 0.00      |
|                 | Bruguiera gymnorrhiza | 0.00    | 25.00     | 0.00      |
|                 | Lumnitzera racemosa | 0.00   | 25.00     | 0.00      |
| Semi-closed bay | Rhizophora apiculate | 10.50     | 48.02     | 16.67     |
|                 | Rhizophora mucronata | 69.10    | 74.17     | 0.00      |
|                 | Rhizophora stylosa | 25.00      | 16.67     | 0.00      |
|                 | Sonneratia alba  | 25.00      | 0.00      | 0.00      |
|                 | Sonneratia caseolaris | 14.50    | 0.00      | 0.00      |
|                 | Bruguiera gymnorrhiza | 30.90   | 26.39     | 0.00      |
|                 | Aegiceras Coriculatum | 0.00   | 34.76     | 0.00      |
| Small island    | Rhizophora apiculate | 122.14    | 86.67     | 0.00      |
|                 | Rhizophora stylosa | 13.58      | 26.67     | 0.00      |
|                 | Rhizophora mucronata | 0.00      | 26.67     | 0.00      |
|                 | Bruguiera gymnorrhiza | 44.28   | 40.00     | 0.00      |
|                 | Lumnitzera racemosa | 60.00     | 40.00     | 0.00      |

### Table 2. Carbon stock of Mangrove forest (ton/ha).

| Canopy density | Semi-closed bay | Open bay | Small island |
|----------------|-----------------|---------|--------------|
| Very rare      | -               | 4.33    | 4.02         |
| Rare           | 21.86           | 20.30   | 30.98        |
| Moderate       | 30.88           | 31.31   | 42.54        |
| Dense          | 59.16           | 35.95   | 55.57        |
| Very dense     | 144.87          | 39.49   | -            |
| Total area     | 256.77          | 131.38  | 133.11       |
The value of the determinant coefficient ($R^2$) often defined as the ability of the independent variable (in this case, the carbon stock) in explaining the dependent variable (in this case, the types of the habitat). The habitat of mangrove forest in the semi-closed bay has the highest determinant coefficient (0.60) compared with the other two types of mangrove forest habitats. The value of this determination coefficient for the open bay was 0.48 and the small island was 0.22. The small island mangrove habitat has the lowest response to its carbon value, this reveals that the canopy density class condition in this habitat type is less able to reveal the amount of carbon stock. The difference in conditions can be affected by the stable zonation formed, the low inter-species competition, and the dominance of the canopy density class. Furthermore, this may be due to the age of the ecosystem in the mangrove forest habitat on the small island in comparison to the other mangrove forest habitats. Each type of mangrove forest habitat has its own ecosystem characteristics that reside in its territory and affect the value of carbon stock.

4. Conclusion
The calculation of mangrove forest carbon stock in the mangrove forest habitats of a semi-closed bay (Taman Hutan Raya Ngurah Rai) indicates the highest estimate of carbon stock of 256.77 ton/ha compared with the carbon content in the mangrove forest habitat in the open bay (West Bali National Park; 131.38 ton/ha) and small island habitat (Hutan Lindung Nusa Lembongan; 133.11 ton/ha). Each type of mangrove forest habitat has its own characteristic ecosystems that exist in its territory and affect its carbon value. The carbon pattern in the mangrove forest habitats of the semi-closed bay, the open bay and small islands have a positive relationship of 60 %, 48 % and 22 %, respectively. In essence, this study revealed that similar mangrove canopy density classes if located in different types of mangrove habitats will produce different values of carbon stocks.

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