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Vegetation characteristic and carbon stock variation of mangrove forests in Sambas Regency, West Kalimantan province, Indonesia

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Abstract

Mangrove area is a transitional area with abundant natural resources, providing environmental services for coastal communities in regulating water systems, preventing seawater intrusion, as well as providing oxygen and carbon stock (C-stock). Comprehensive data of mangrove forests in Sambas Regency, West Kalimantan province is very limited. This study aims to monitor the condition of mangrove forests and estimate their potential carbon stocks in Sambas Regency. There are six dominant mangrove species in Sambas Regency, namely *Avicennia alba*, *A. marina*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *Lumnitzera littorea*, and *Rhizophora apiculata*. Vegetation density varies from sparse to dense, ranging from 800–4700 trees per ha with a canopy cover of 55.00–86.63 %. The range of mangrove species diameter values is from 4.39 ±0.69 – 27.45 ±21.14 cm. Potential C-stock ranged from 7.17 ±0.32 – 546.67 ±70.83 Mg C·ha^{-1} with an average of 130.62 ±166.34 Mg C·ha^{-1}. The highest potential of mangrove C-stock was found at the Sebubus location. Mangrove vegetation in this study has a high potential of carbon stock, the potential value close to Kubu Raya Regency, West Kalimantan province, and higher than several mangrove ecosystems in Indonesia. In general, the condition of mangrove vegetation in this area is still good and has great potential for carbon stock. However, protection and sustainable use are needed in conserving the mangrove ecosystem in this area.

Key words: canopy cover, mangrove density, mangrove ecosystems, structure and composition.

Introduction

Mangrove forest is a unique ecosystem as a constituent of coastal ecosystems in tropical and subtropical regions (Giri et al. 2010), and has the ability to adapt to high salinity and tidal conditions of seawater (Kandasamy and Bingham 2001). The role of mangrove ecosystems is important in coastal areas, roots that stick to the ground as a support for plant defense can function as fish habitat. In addition, due to its physical characteristics, mangroves are able to act as a barrier to seawater intrusion, prevent coastal erosion and abrasion, breaking waves, and protect the mainland from sea storms if the mangrove conditions are still well maintained (Saifullah 1985).

Indonesia is an archipelagic country with the second-longest coastline in the world, located in the tropics area, and has a high potential for mangrove forests. According to data from the IMEF (2021), the area of mangroves in Indonesia reaches 3.12 million ha, with 92 % of them in good condition (dense canopy). Furthermore, data on the area of mangroves in West Kalimantan province is estimated at 161,967 ha or the eighth widest of 34 provinces in Indonesia.

Coastal ecosystems consisting of mangrove forests, tidal salt marshes, and seagrass have a high potential for the carbon stored in living biomass (above and below ground), non-living biomass and soil, known as blue carbon (Howard et al. 2014). According to Murdiyarso et al. (2015) and Donato et al. (2011), mangrove forests can store 3–5 times higher carbon than lowland tropical forests. Based on the estimation of Alongi et al. (2015), mangrove and seagrass areas in Indonesia have carbon potential as much as 3.4 Pg or contribute about 17 % of the total blue carbon potential in the world.

The coastal area of West Kalimantan province according to the Zoning Plan for Coastal Areas and Small Islands of 2014–2034 (West Kalimantan Provincial Regulation Number 7 of 2014) consists of two regions, namely the northern coastal area (Pontianak Regency, Bengkayang Regency, Singkawang City, and Sambas Regency) and southern coastal areas (Kubu Raya Regency, North Kayong Regency, and Ketapang Regency). Carbon stock estimation in West Kalimantan has been widely carried out in Kubu Raya Regency, but not with 6 other regencies, including Sambas Regency. This study aims to estimate the potential of carbon stocks in the northern coastal area of West Kalimantan province, especially Sambas Regency, based on several characteristics of the mangrove vegetation found. The results of this study are expected to be authentic information regarding the characteristics and potential of mangrove vegetation carbon stocks in Sambas Regency.

Material and Methods

Study area

The study area was determined by detecting the presence of mangroves using Landsat 8 satellite imagery (data acquisition in January 2019 – September 2021 to minimize cloud cover), with a false-colour RGB (NIR-SWIR-Red) band composite. Areas that appear red-brown in coastal areas are detected as mangrove areas (Fig. 1). Surveys and research data collection was carried out from September to October 2021. A total of 4 out of 6 districts on the coast of Sambas Regency were selected as study areas, with a total of 10 observation plots (Selakau District: 1 plot, Pemangkat District: 1 plot, Jawai District: 2 plots, and Paloh District: 6 plots).

Analysis of the structure and composition of mangrove forests was carried out by making an observation plot of 10×10 m^2 perpendicular to the coastline representing the stratification of mangrove forests based on guidelines from the IIS (2020). Measurements in each plot were carried out on each trees with stem diameter (DBH) 4 cm, species identification was carried out based on the reference of Rusila Noor et al. (2012) and Giesen et al. (2006). The density and basal area of mangrove vegetation were calculated in each research plot and then

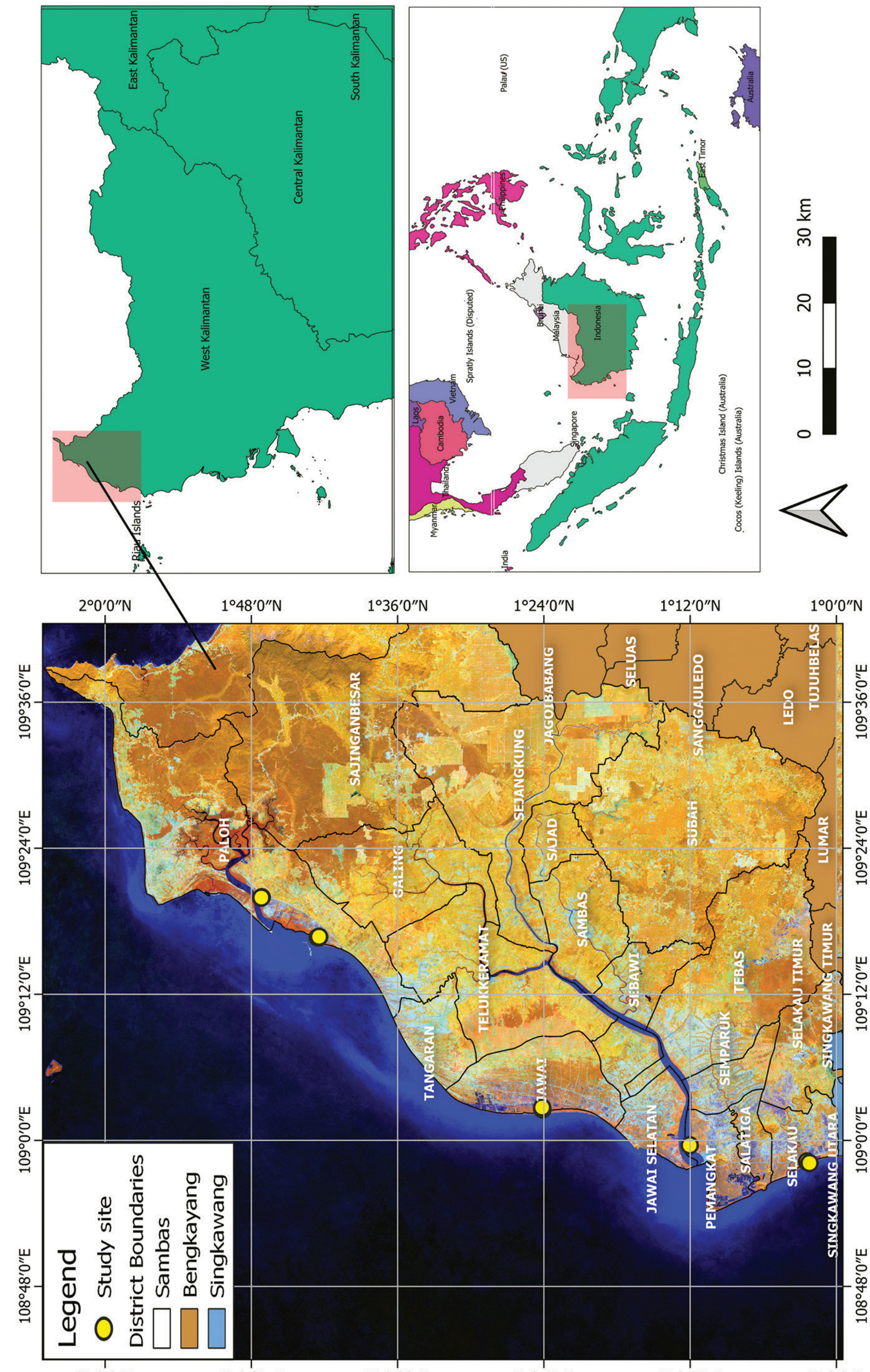
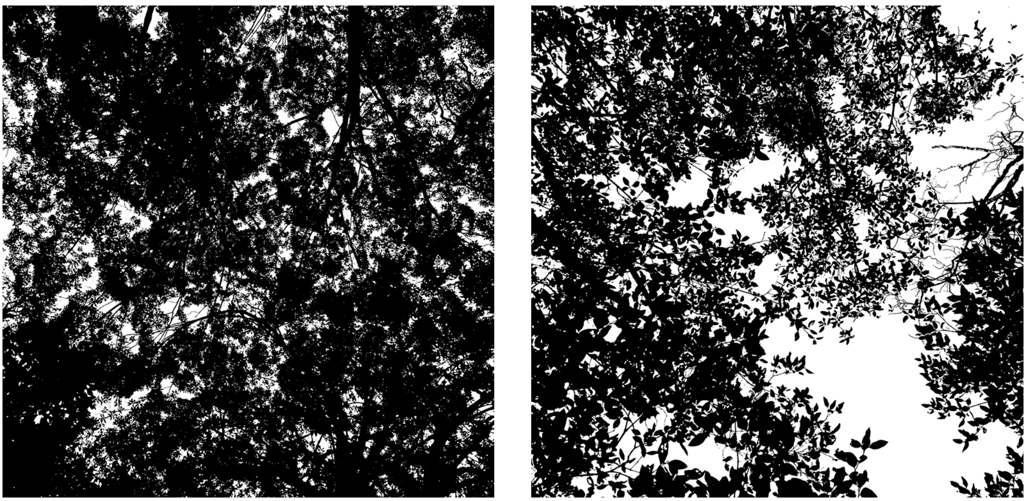


Fig. 1. Map of study area showing mangrove vegetation distribution (Landsat 8 RGB NIR-SWIR-Red Band Combination).

converted per reference unit. Vegetation canopy density (Fig. 2) was measured using the hemispherical photography method based on the IIS (2020) reference. The photograph was taken vertically to the canopy, four times in each plot, consisting of one picture in the center of each side of the 5×5 m^2 sub-plot. The hemispherical photo was analyzed by ImageJ software to measure the dark pixel (as a canopy) and white pixel (as the sky).

Biomass and C-stock estimates were carried out in each vertical stratification of mangrove forests, consisting of estimates of above-ground biomass (AGB) and carbon stocks (AGC), belowground vegetation biomass (BGB) and carbon stocks (BGC). The estimation of biomass and carbon stocks was carried out by non-destructive methods using observation plots and based on available species-specific allometric or common allometric formulations (Table 1). The estimation of belowground biomass and C-stock is carried out using AGB:BGB ratio approach in mangrove forests (Kauffman and Donato 2012).



a b

Fig. 2. Hemispherical photography method for measuring canopy cover: a – Dense canopy cover (≥ 75 %), b – Medium canopy cover (50–75 %).

Table 1. Allometric equations to determine biomass and C-stock in this study.

No	Species	Allometric	ρ, g·cm^3	Sources
1	*Avicennia alba* Blume	$AGB = 0.251 \cdot \rho \cdot D^{2.46}$ $BGB = 0.199 \cdot \rho^{0.899} \cdot D^{2.22}$	0.506	Komiyama et al. (2005)
2	*Bruguiera cylindrica* (L.) Blume		0.749	Komiyama et al. (2005)
3	*B. gymnorrhiza* (L.) Lam.		0.699	Komiyama et al. (2005)
4	*Lumnitzera littorea* (Jack) Voigt		0.670	Komiyama et al. (2005) and Zanne et al. (2009)
5	*Rhizophora apiculata* Blume		0.770	Komiyama et al. (2005)

No	Species	Allometric	ρ, g·cm3	Sources
6	*Avicennia marina* (Forssk.) Vierh.	AGB = $0.1848 \cdot D^{2.3524}$ BGB = $0.1682 \cdot D^{1.7939}$	-	Dharmawan and Siregar (2008)
		Other allometrics		
1	Dead tree – Decay status 1	B = 0.975·AGB		Kauffman and Donato (2012)
2	Dead tree – Decay status 2	B = 0.8·AGB		Kauffman and Donato (2012)
3	Aboveground C-stock	C-stock = 0.47·AGB		Kauffman and Donato (2012)
4	Belowground vegetation C-stock	C-stock = 0.39·AGB		Kauffman and Donato (2012)

Note: ρ is wood density, *D* is diameter at breast height, *B* is biomass.

Results and Discussion

Structure and composition of mangrove forest

Field data collection from the observation plots was carried out to describe the structure and composition of mangrove forests in Sambas Regency. Based on observations, it was found that there were 6 dominant mangrove species in Sambas Regency, namely *Avicennia alba, A. marina, Bruguiera cylindrica, B. gymnorrhiza, Lumnitzera littorea*, and *Rhizophora apiculata*. Tree density about 800–4700 individuals per ha, vegetation height about 3–18 m, and canopy density about 55–86.63 %. The number of natural tillers of each type of mangrove is quite varied in the observation plot, there are several locations with the potential for a large number of mangrove tillers, such as in the locations of Malek, Sebubus and Sarang Burung Usrat Village. The availability of sufficient natural seedlings is one of the important factors in maintaining the sustainability and regeneration of mangrove vegetation in the future.

The range of mangrove species diameter values in the observation plot is about 4.39 ±0.69 – 27.45 ±21.14 cm, where the Selakau location has the smallest average individual diameter and the Sebubus location has the largest average individual diameter (Table 2). The range of diameter values found at the location is smaller than that of mangrove forest vegetation in Kubu Raya Regency (CFCRRD-FORDA and CIFOR 2011) and Mempawah Regency (Rafdinal et al. 2019), West Kalimantan province, with individual mangrove diameters found to reach more than 55 cm and 80 cm. However, from the value of individual density per ha, mangrove vegetation in Sambas Regency was found to be higher than the report from Rafdinal et al. (2019) in Mempawah Regency. The large diameter of mangrove tree can describe in general the age of mangrove vegetation at the site, in addition to the suitability of ecological factors that support the life of the mangrove vegetation. Sebubus location has a fairly high range of individual mangrove diameter values, this is presumably because this location is not directly facing the sea, so the received wave intensity is minimal compared to several other locations in Sambas Regency.

Table 2. Structure and composition of mangrove forest in Sambas Regency.

Location (District, Village)	Code	Description	Major species	*N* (DBH ≥4 cm)	DBH Average ±SD, cm	Total seedling
Selakau	Sel1	Tree density 1500 ha^{-1}, Canopy density 55 %, Vegetation height about 3–4 m	*Avicennia marina*	15	4.83 ±0.72	32
Pemangkat	Pem1	Tree density 800 ha^{-1}, Canopy density 58 %, Vegetation height about 5–8 m	*Avicennia marina*	8	15.00 ±3.66	8
Paloh, Malek	Mal1	Tree density 1700 ha^{-1}, Canopy density 81.91 %, Vegetation height about 3–4 m	*Avicennia marina*	7	11.92 ±2.66	0
			Bruguiera gymnorrhiza	10	7.58 ±3.49	125
Paloh, Malek	Mal2	Tree density 4700 ha^{-1}, Canopy density 76.89 %, Vegetation height about 3–4 m	*Avicennia marina*	30	7.08 ±2.80	45
			Bruguiera gymnorrhiza	17	6.15 ±3.14	8
Paloh, Malek	Mal3	Tree density 3400 ha^{-1}, Canopy density 71.04 %, Vegetation height about 5–6 m	*Avicennia marina*	12	7.30 ±3.82	4
			Bruguiera gymnorrhiza	22	4.39 ±0.69	529
Paloh, Sebubus	Seb1	Tree density 2200 ha^{-1}, Canopy density 86.63 %, Vegetation height about 8–13 m	*Rhizophora apiculata*	22	12.55 ±4.82	9
Paloh, Sebubus	Seb2	Tree density 2400 ha^{-1}, Canopy density 81.70 %, Vegetation height about 8–13 m	*Rhizophora apiculata*	16	7.15 ±2.96	4
			Bruguiera cylindrica	8	19.51 ±13.09	3
Paloh, Sebubus	Seb3	Tree density 2000 ha^{-1}, Canopy density 83.98 %, Vegetation height about 12–18 m	*Avicennia marina*	4	26.75 ±6.87	0
			Bruguiera cylindrica	11	12.91 ±8.13	133
			Lumnitzera littorea	5	27.45 ±21.14	47
Jawai, Sarang Burung Usrat	USR1	Tree density 1700 ha^{-1}, Canopy density 72.36 %, Vegetation height about 4–6 m	*Avicennia alba*	17	9.46 ±3.85	65
			Rhizophora apiculata	0	0	6
Jawai, Sarang Burung Usrat	USR2	Tree density 1900 ha^{-1}, Canopy density 81.92 %, Vegetation height about 8–12 m	*Avicennia alba*	19	10.60 ±4.68	25
			Rhizophora apiculata	0	0	4

Carbon stock

Total C-stock estimation of mangrove vegetation using non-destructive methods in Sambas Regency is about 7.17 ±0.32 – 546.67 ±70.83 Mg C·ha^{-1} with an average of 130.62 ±166.34 Mg C·ha^{-1} (Table 3). The highest C-stock value from all locations was found at Sebubus village, Paloh District (546.67 ±70.83 Mg C·ha^{-1}), while the lowest was found at Selakau site, Selakau District (7.17 ±0.32 Mg C·ha^{-1}). The highest value of biomass and C-stock at the Sebubus location was due to the composition of a high average tree diameter (12.91 ±8.13 – 27.45 ±21.14 cm) and a fairly high tree density (2000 trees ha^{-1}) compared to several other observation locations.

Table 3. Total vegetation C-stock of mangrove forest in Sambas Regency.

Location code	*N* (DBH≥4 cm)	Aboveground vegetation C-stock, Mg C·ha^{-1}	Belowground vegetation C-stock, Mg C·ha^{-1}	Total vegetation C-stock, Mg C·ha^{-1}
Sel1	15	5.48 ±0.28	1.69 ±0.078	7.17 ±0.32
Pem1	8	43.91 ±5.82	7.01 ±0.90	50.92 ±6.32
Mal1	17	38.32 ±3.63	10.40 ±1.18	48.72 ±3.12
Mal2	47	49.23 ±2.59	14.42 ±0.98	63.66 ±2.08
Mal3	34	23.09 ±2.30	6.67 ±0.43	29.76 ±1.71
Seb1	22	127.08 ±11.81	44.26 ±4.46	171.33 ±9.53
Seb2	24	209.38 ±46.19	63.71 ±15.32	273.10 ±34.56
Seb3	20	437.37 ±94.32	109.30 ±29.07	546.67 ±70.83
USR1	17	32.50 ±3.26	12.68 ±1.46	45.17 ±2.64
USR2	19	50.80 ±6.79	18.93 ±2.69	69.73 ±5.32
Average	22.3	101.72 ±132.43	28.91 ±34.22	130.62 ±166.34

The potential for vegetation carbon stocks in Sambas Regency is greater than some mangrove forest locations, such as study from Harishma et al. (2020) in mangrove ecosystems of Kerala, India (AGB and BGB; 35.14 and 23.42 Mg C·ha^{-1}), study from Savari et al. (2020) in Gowatr mangrove forest, Gulf of Oman (AGB and BGB; 28.51 and 66.69 Mg C·ha^{-1}), and study from Wanthongchai and Pongruktham (2019) in mangroves of the Lower Andaman Coast, Thailand (AGB and BGB; 2.25 and 1.5 Mg C·ha^{-1}). The potential C-stock in Sambas Regency was close to the value of the largest mangrove forest in West Kalimantan, namely in Kubu Raya Regency (AGB and BGB; 134.8 and 14.3 Mg C·ha^{-1}) (Murdiyarso et al. 2015) (Fig. 3). The amount of vegetation carbon stock value is influenced by the structure and composition of mangrove vegetation in each location, especially the density and average diameter of individual mangrove trunks found.

Mangrove forests in Sambas Regency have great carbon potential and can support climate change mitigation efforts. Based on the contribution of carbon stocks of each species, the three species with the highest contribution were *Bruguiera cylindrica* with a value of 35.86 Mg C·ha^{-1}, *Lumnitzera littorea* with a value of 33.28 Mg C·ha^{-1} and *Avicennia marina* with a value of 23.40 Mg C·ha^{-1}. These three species have the highest contribution to carbon stocks because they have a high density (*Avicennia marina* are quite dominant) and have a high average tree

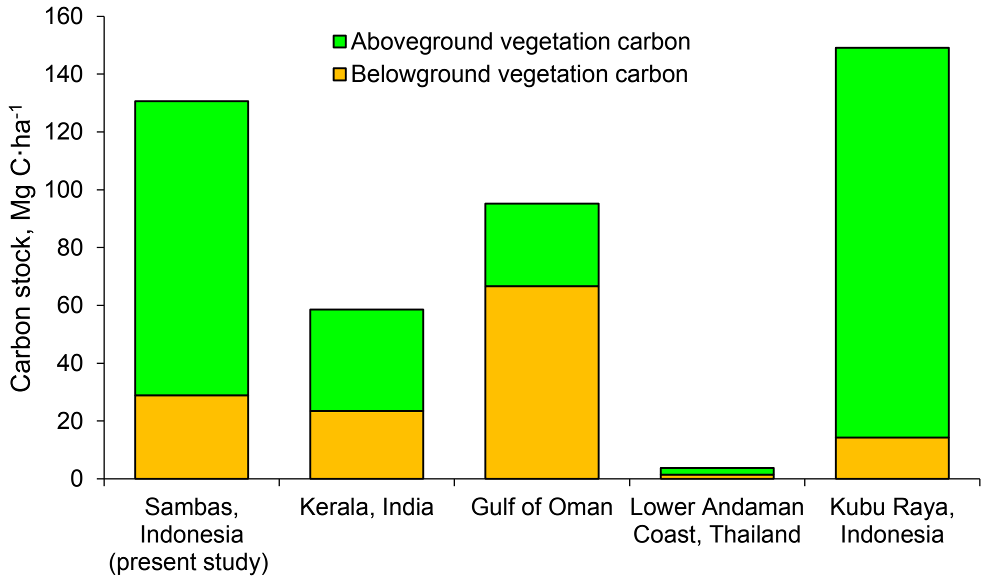


Fig. 3. Comparation of several mangrove forest carbon stock.

diameter (*Bruguiera cylindrica* and *Lumnitzera littorea*). According to Komiyama et al. (2005), tree density and tree diameter affect the carbon potential value of a species in a mangrove forest ecosystem. Based on the structure and composition, also potential carbon stock, Sambas Regency has a high potential for mangrove forests compared to several mangrove forests in Indonesia and other countries. Conservation efforts from both the community and the local government are needed to maintain the potential of existing mangrove forests and sustainable use for the preservation of mangrove forests in the Sambas Regency.

Conclusions

An assesment of mangrove vegetation in Sambas Regency in this study found six dominant mangrove species, namely *Avicennia alba, A. marina, Bruguiera cylindrica, B. gymnorrhiza, Lumnitzera littorea* and *Rhizophora apiculata*. Vegetation density varies from sparse to dense, ranging from 800–4700 trees·ha^{-1} with a canopy cover of 55.00–86.63 %. The range of mangrove species diameter values ranged from 4.39 ±0.69 – 27.45 ±21.14 cm. Potential vegetation C-stock is about 7.17 ±0.32 – 546.67 ±70.83 Mg C·ha^{-1} with an average of 130.62 ±166.34 Mg C·ha^{-1}, the highest potential was found at the Sebubus Village.

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