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Research Article

Biomass, Carbon Stock and Oxygen Produced by Mangrove Vegetation in Tropical Forest in Central Kalimantan, Indonesia

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Abstract

Background and Objective: The mangrove conversion in Indonesia is running massively, although its ecological function in climate change mitigation cannot be replaced by physical buildings made by humans. This study was aim at analyzing the composition of species, biomass, carbon stock and oxygen produced by mangrove vegetation. **Materials and Methods:** The study site was in mangrove forest at Kubu village, West Kotawaringin district, Central Kalimantan province, Indonesia. Estimation of biomass, carbon stock and oxygen produced by mangrove were calculated using combination of destructive and non-destructive methods. **Results:** The results show that the number of mangrove species found as many as 13 species, from 7 families and mostly included in the major mangrove species group. The species that dominating at all growth phases is *Rhizophora stylosa*, indicated by its highest importance value index (IVI). The total potential of biomass, carbon stock and oxygen produced are 97.12, 45.65 t ha⁻¹ and 121.88 O₂ t ha⁻¹, respectively. The most dominant type of vegetation is *Rhizophora stylosa* in the growth phase of trees, saplings and seedlings. **Conclusion:** The authors call for mangrove forest conservation activities in order to increase the potential of biomass storage, carbon stocks and oxygen production.

Key words: Biomass, carbon, oxygen, *Rhizophora stylosa*, mangrove

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The mangrove forest ecosystem in Indonesia is currently facing the threat of conversion into ponds, hotels, tourism and human settlements¹. This pressure occurs because the community prohibited from utilising forest for non-forest-related purposes². As a result, people choose the coastal zone, where the mangrove ecosystem is placed, for daily economic activities, because occupying the area will lead to lower legal consequences. Mangrove ecosystems have long been a source of livelihood for local people who live below the poverty line³. Thus, mangrove conversion not only threatens the survival of coastal ecosystems but also suppresses the livelihoods of local communities⁴.

On the other hand, various studies have shown the importance of mangrove forests as habitat for fish, shrimp, crabs, wood energy producer⁵, as well as to protect those who live around the coast from the dangers of Tsunami and tidal waves⁶. The Indonesian government has spent much money to build physical buildings in order to prevent coastal abrasion, protect the coast from waves and seawater intrusion. Even mangrove ecosystems can cover all environmental services that are provided by those physical buildings.

People assume mangrove vegetation species and their ability to support coastal ecosystem life are indifferent. This fact causes the parties to view mangrove forests as something homogeneous. In fact, the ability of mangrove vegetation to store biomass and carbon and its ability to produce oxygen varies. Oxygen is essential in improving the quality of living things around the coast⁷. Furthermore, the ecological function of mangroves in mitigating climate change cannot be replaced by physical buildings made by humans. Before these reasons, this study aim to analyze the composition of mangrove species along with biomass and carbon stock and their ability to produce oxygen.

MATERIALS AND METHODS

Study area: Research site is mangrove forest located in Kubu Village, Kumai District, Kotawaringin Barat Regency, Central Kalimantan Province. The data were collected for 3 months, from June to August 2018. The research area is lowland with altitudes of 1-5 m from sea level. Its climatic conditions categorized into Type A according to Schmidt and Ferguson with dry season from June to September and the highest rainy season in December. The maximum air temperature ranges between 30.7-32.6°C and the minimum air temperature⁸ around 22.7-23.5°C.

Research procedures: Data collection is distinguished based on the vegetation growth phase, namely trees, saplings and seedlings. The tree is vegetation with a trunk diameter of ≥ 10 cm, when saplings with a diameter of < 10 cm and a height of > 1.5 m and seedlings with height < 1.5 m⁹. The sample plot was a combination of lines and checkered lines. The number of the lane was 2, with the length and width of each was 400 and 10 m, respectively and distance between the two lanes was 150 m. Observation plots are set in each lane with a size of 10×10 m for tree phase, 5×5 m for sapling phase and 2×2 m for seedling phase. Vegetation data collected include vegetation species, diameter, total height and number of individuals.

Data analysis

Analysis of vegetation: The parameters of mangrove composition species calculated included: Number of species, individual density and important value index (IVI) at each growth phase. The IVI for tree growth phase was the sum of relative density, relative frequency and relative dominance^{10,11}, whereas IVI for sapling and seedling phases was the sum of relative density and relative frequency.

Biomass stock: Above and below-ground biomass stock for tree and sapling phases were calculated using allometric equations for each mangrove species found with the diameter and wood density as independent variables. Allometric equations is a formula widely used by scientists to estimate biomass and calculate biomass carbon stored in certain species of tree or forest area¹². Types of allometric equations for estimating above and below-ground biomass deposits as in Table 1 and 2.

This biomass estimation equation was also used by Kauffman²³ while calculated mangrove biomass for tree and sapling phases.

The amount of above and below ground biomass for seedlings was analyzed using destructive methods²⁴. In the destructive method, the seedling vegetation in the 2×2 m sample plot is removed. The seedlings are then separated into stems, leaves, roots and each is weighed to obtain its wet weight (BB_{total}). A total of 100-300 g of stems, leaves and roots were taken for sub-samples ($BB_{sub\ sample}$) and was dried in an oven at 80°C for 48 h and weighed to obtain its dry weight ($BK_{sub\ sample}$). Seedling biomass is the ratio of the dry weight of sub-sample $BK_{sub\ sample}$ to the $BB_{sub\ sample}$ multiplied by BB_{total} . The total stored biomass of mangrove vegetation is the sum of biomass in the growth phase of trees, saplings and seedlings.

Table 1: Allometric equations used to estimate aboveground biomass stock at tree and sapling growth phases

Mangrove species	Allometric equations	References	Wood specific gravity (ρ) ITTO ¹⁹ (g cm ⁻³)
<i>Rhizophora stylosa</i>	$W = 0.251 \times \rho \times D^{2.46}$	Komiyama <i>et al.</i> ¹³	0.913
<i>Rhizophora mucronata</i>	$W = 0.1466 \times D^{2.3136}$	Dharmawan ¹⁴	-
<i>Avicennia marina</i>	$W = 0.2905 \times D^{2.2598}$	Dharmawan and Siregar ¹⁵	-
<i>Xylocarpus granatum</i>	$W = 0.0823 \times D^{2.59}$	Clough and Scott ¹⁶	-
<i>Xylocarpus moluccensis</i>	$W = 0.1823 \times D^{2.21}$	Tarlan ¹⁷	-
<i>Bruguiera cylindrical</i>	$W = 0.251 \times \rho \times D^{2.46}$	Komiyama <i>et al.</i> ¹³	0.763
<i>Sonneratia alba</i>	$W = 0.1848 \times \rho \times D^{2.3524}$	Dharmawan and Siregar ¹⁵	0.647
<i>Lumnitzera littorea</i>	$W = 0.251 \times \rho \times D^{2.46}$	Komiyama <i>et al.</i> ¹³	0.737
<i>Bruguiera parviflora</i>	$W = 0.168 \times D^{2.42}$	Clough and Scott ¹⁶	-
<i>Bruguiera gymnorrhiza</i>	$W = 0.0754 \times \rho \times D^{2.505}$	Kauffman and Donato ¹⁸	0.730
<i>Sonneratia spp.</i>	$W = 0.1848 \times \rho \times D^{2.3524}$	Dharmawan and Siregar ¹⁵	0.340
<i>Cerbera manghas</i>	$W = 0.251 \times \rho \times D^{2.46}$	Komiyama <i>et al.</i> ¹³	0.380
<i>Hibiscus tilliaceus</i>	$W = 0.251 \times \rho \times D^{2.46}$	Komiyama <i>et al.</i> ¹³	0.550

W: Aboveground biomass (kg tree⁻¹), D: Tree diameter at 1.3 m above ground level or 20 cm above root support and buttresses (cm)

Table 2: Allometric equations used to estimate belowground biomass stock at tree and sapling growth phases

Mangrove Species	Allometric equations	References	Wood specific gravity (ρ) ITTO ¹⁹ (g cm ⁻³)
<i>Rhizophora stylosa</i>	$WR = 0.261D^{1.86}$	Comley and McGuinness ²⁰	-
<i>Rhizophora mucronata</i>	$WR = 0.00974(D^2H)^{1.05}$ $H = D/(0.02D+0.678)$	Tamai <i>et al.</i> ²¹	-
<i>Avicennia marina</i>	$WR = 1.28D^{1.17}$	Comley and McGuinness ²⁰	-
<i>Xylocarpus granatum</i>	$WR = 0.145D^{2.25}$	Poungparn <i>et al.</i> ²²	-
<i>Xylocarpus moluccensis</i>	$WR = 0.199\rho^{0.899}D^{2.22}$	Poungparn <i>et al.</i> ¹³	0.571
<i>Bruguiera cylindrical</i>	$WR = 0.0188(D^2H)^{0.909}$ $H = D/(0.025D+0.583)$	Tamai <i>et al.</i> ²¹	-
<i>Sonneratia alba</i>	$WR = 0.199\rho^{0.899}D^{2.22}$	Poungparn <i>et al.</i> ¹³	0.647
<i>Lumnitzera littorea</i>	$WR = 0.199\rho^{0.899}D^{2.22}$	Poungparn <i>et al.</i> ¹³	0.737
<i>Bruguiera parviflora</i>	$WR = 0.0188(D^2H)^{0.909}$ $H = D/(0.025D+0.583)$	Tamai <i>et al.</i> ²¹	-
<i>Bruguiera gymnorrhiza</i>	$WR = 0.0188(D^2H)^{0.909}$ $H = D/(0.025D+0.583)$	Tamai <i>et al.</i> ²¹	-
<i>Sonneratia spp.</i>	$WR = 0.199\rho^{0.899}D^{2.22}$	Poungparn <i>et al.</i> ¹³	0.340
<i>Cerbera manghas</i>	$WR = 0.199\rho^{0.899}D^{2.22}$	Poungparn <i>et al.</i> ¹³	0.380
<i>Hibiscus tilliaceus</i>	$WR = 0.199\rho^{0.899}D^{2.22}$	Poungparn <i>et al.</i> ¹³	0.550

WR: Belowground biomass (kg tree⁻¹), D: Tress diameter at 1.3 m aboveground level or 20 cm above root support and buttresses (cm)

Carbon stock: Carbon stored in each mangrove species is estimated using the formula taken from Badan Standar Nasional Indonesia or Indonesian National Standardization Agency²⁵, namely:

$$C_T = W_T \times 0.47$$

Where:

C_T = Total vegetation carbon stock (t ha⁻¹ C)

W_T = Total vegetation biomass (t ha⁻¹)

0.47 = Organic-C fraction

Oxygen production: The amount of oxygen produced by mangrove vegetation is the result of multiplication between the amount of carbon stored with the weight ratio of oxygen atoms with carbon²⁶, which is formulated as follows:

$$O_2 = C_T \times 2.67$$

Where:

O_2 = Oxygen produced by vegetation (O₂ t ha⁻¹)

C_T = Total vegetation carbon stock (t ha⁻¹ C)

2.67 = Ratio of atomic weights of O₂ to C (32/12)

RESULTS

Species composition: There are 13 species of mangroves found at the study site. They originate from 7 families, namely Rhizophoraceae (5 species), Meliaceae (2 species), Sonneratiaceae (2 species), Avicenniaceae (1 species), Combretaceae (1 species), Apocynaceae (1 species) and Malvaceae (1 species). It is widely known that, floristically, mangrove vegetation can be classified into 3 groups, namely major mangrove, minor mangrove and association mangrove. Table 3 presents mangrove species found at the study site based on its floristic classification.

Table 3: Classification of mangrove vegetation types found at research locations

Vegetation species	Family	Mangrove type classification		
		Major Mangrove	Minor Mangrove	Association Mangrove
<i>Rhizophora stylosa</i>	Rhizophoraceae	✓		
<i>Rhizophora mucronata</i>	Rhizophoraceae	✓		
<i>Avicennia marina</i>	Avicenniaceae	✓		
<i>Xylocarpus granatum</i>	Meliaceae		✓	
<i>Xylocarpus moluccensis</i>	Meliaceae		✓	
<i>Bruguiera cylindrical</i>	Rhizophoraceae	✓		
<i>Bruguiera gymnorhiza</i>	Rhizophoraceae	✓		
<i>Bruguiera parviflora</i>	Rhizophoraceae	✓		
<i>Lumnitzera littorea</i>	Combretaceae	✓		
<i>Sonneratia alba</i>	Sonneratiaceae	✓		
<i>Sonneratia caseolaris</i>	Sonneratiaceae	✓		
<i>Cerbera manghas</i>	Apocynaceae			✓
<i>Hibiscus tilliaceus</i>	Malvaceae			✓
Total		9	2	2

Table 4: Mangrove vegetation density in the growth phase of tree, sapling and seedling

Growth phases	Individual density (N ha ⁻¹)	Percentage
Tree	264	4.73
Sapling	1125	20.17
Seedling	4188	75.10
Total	5577	100.00

Table 5: Importance value index (IVI) of five most dominant mangrove species in growth phase of tree, sapling and seedling

Growth phases	Rank	Vegetation species	IVI (%)
Tree	1	<i>Rhizophora stylosa</i>	60.32
	2	<i>Xylocarpus granatum</i>	42.49
	3	<i>Avicennia marina</i>	39.47
	4	<i>Xylocarpus moluccensis</i>	29.04
	5	<i>Sonneratia alba</i>	27.59
Sapling	1	<i>Rhizophora stylosa</i>	40.41
	2	<i>Avicennia marina</i>	26.26
	3	<i>Xylocarpus granatum</i>	24.69
	4	<i>Xylocarpus moluccensis</i>	17.05
	5	<i>Bruguiera parviflora</i>	16.61
Seedling	1	<i>Rhizophora stylosa</i>	70.44
	2	<i>Avicennia marina</i>	40.95
	3	<i>Sonneratia alba</i>	36.48
	4	<i>Lumnitzera littorea</i>	19.93
	5	<i>Xylocarpus moluccensis</i>	10.58

Table 3 shows that there are 9 major mangrove species, 2 minor mangroves and 2 association mangroves. Mangrove vegetation density based on the growth phase ranges from 264-4188 N ha⁻¹ with a total density of 5577 N ha⁻¹. The seedling growth phase has the highest density (75.10%) compared to saplings (20.17%) and trees (4.73%). Mangrove vegetation density based on the growth phase is shown in Table 4.

The mangrove species dominating in all growth phase is *Rhizophora stylosa*, which is indicated by its highest importance value index (IVI). The Importance value index is one of the parameters used in determining species

Table 6: Biomass stock above and belowground at tree and sapling growth phases

Vegetation species	Biomass stock in the growth phase					
	Tree (t ha ⁻¹)			Sapling (t ha ⁻¹)		
	AGB	BGB	Total	AGB	BGB	Total
<i>Avicennia marina</i>	7.57	1.32	8.89	1.86	1.27	3.13
<i>Bruguiera cylindrical</i>	6.05	1.23	7.28	0.45	0.08	0.54
<i>Bruguiera gymnorhiza</i>	0.72	0.45	1.17	0.27	0.16	0.43
<i>Bruguiera parviflora</i>	3.25	0.83	4.08	1.25	0.30	1.55
<i>Cerbera manghas</i>	0.91	0.40	1.31	0.11	0.06	0.17
<i>Hibiscus tilliaceus</i>	1.47	0.61	2.08	0.40	0.22	0.62
<i>Lumnitzera littorea</i>	3.89	1.55	5.44	0.91	0.47	1.38
<i>Rhizophora mucronata</i>	0.36	0.22	0.58	0.05	0.02	0.07
<i>Rhizophora stylosa</i>	11.27	2.50	13.77	4.85	1.73	6.58
<i>Sonneratia alba</i>	5.73	4.09	9.82	0.57	0.50	1.07
<i>Sonneratia caseolaris</i>	1.50	1.16	2.66	1.32	0.17	1.48
<i>Xylocarpus granatum</i>	9.24	5.49	14.73	1.41	1.29	2.71
<i>Xylocarpus moluccensis</i>	2.70	1.83	4.53	0.58	0.39	0.97
Total	54.66	21.68	76.34	14.03	6.67	20.70

AGB: Aboveground biomass, BGB: Belowground biomass

Table 7: Biomass stock above and belowground at seedling growth phase

Growth phase	Biomass (t ha ⁻¹)		
	AGB	BGB	Total
Seedling	0.06	0.02	0.08

dominance in a forest association. The IVI data of 5 most dominant mangrove species according to their growth phase are served in Table 5.

Biomass stock: Biomass stock (above and below ground) in the growth phase of trees, saplings and seedlings are 76.34, 20.70 and 0.08 t ha⁻¹, respectively, so that the total biomass storage of mangrove vegetation is 97.12 t ha⁻¹. Data on above and belowground vegetation biomass storage at the tree, sapling and seedling growth stages is shown in Table 6 and 7.

Table 8: Carbon storage and oxygen produced by mangrove vegetation in tree and sapling growth stages

Vegetation species	Carbon storage (t ha ⁻¹ C) in the growth phase		Oxygen Produced (t ha ⁻¹ O ₂) in the growth phase	
	Tree	Sapling	Tree	Sapling
<i>Avicennia marina</i>	4.18	1.47	11.16	3.92
<i>Bruguiera cylindrical</i>	3.42	0.25	9.13	0.67
<i>Bruguiera gymnorrhiza</i>	0.55	0.20	1.47	0.53
<i>Bruguiera parviflora</i>	1.92	0.73	5.13	1.95
<i>Cerbera manghas</i>	0.61	0.08	1.63	0.21
<i>Hibiscus tilliaceus</i>	0.98	0.29	2.62	0.77
<i>Lumnitzera littorea</i>	2.56	0.65	6.84	1.74
<i>Rhizophora mucronata</i>	0.27	0.04	0.72	0.11
<i>Rhizophora stylosa</i>	6.47	3.09	17.27	8.25
<i>Sonneratia alba</i>	4.62	0.50	12.34	1.34
<i>Sonneratia caseolaris</i>	1.25	0.70	3.34	1.87
<i>Xylocarpus granatum</i>	6.92	1.27	18.48	3.39
<i>Xylocarpus moluccensis</i>	2.13	0.46	5.69	1.23
Total	35.88	9.73	95.80	25.98

Table 9: Carbon storage and oxygen produced by mangrove in the seedling growth phase

Growth phase	Carbon storage (t ha ⁻¹ C)	Oxygen production (t ha ⁻¹ O ₂)
Seedling	0.04	0.10

Based on its growth phase, mangrove in tree growth phases have the highest biomass stock (78.60%) compared to those in saplings (21.31%) and seedlings (0.09%) forms.

Carbon storage and oxygen production: The amount of carbon stored in mangrove vegetation at tree is 35.88 and sapling phase is 9.73 total of which is 45.65 ton ha⁻¹ C and the amount of oxygen produced at the same phases is about 121.88 t ha⁻¹ O₂. Complete data on carbon stock in and oxygen produced by each mangrove species is shown in Table 8 and 9.

Table 8 shows that accumulative carbon stored by *Rhizophora stylosa* in both tree and sapling forms is the highest one (9.56 t ha⁻¹ C), compared to those stored by other species in the same growth phases. *Rhizophora stylosa* also has the highest ability to produce oxygen (25.52 t ha⁻¹ O₂). Meanwhile, *Rhizophora mucronata* has the lowest ability in storing carbon (0.31 t ha⁻¹ C) and producing oxygen (0.83 t ha⁻¹ O₂).

DISCUSSION

The number of mangrove types found in research area are smaller compared to the number of mangrove vegetation types in Indonesia. Kusmana²⁷ states that the composition of mangrove vegetation types in Indonesia includes 47 species of trees, 5 species of shrub, nine species of herbaceous plants and grasses and 2 types of parasitic plants. Noor *et al.*

(cited in Pramudji)²⁸ shows that Indonesia's forests are home for about 202 mangrove species, consisting of 89 species of trees (wooden vegetation), 5 types of palm, 19 types of climbers, 44 types of Tracheophyta, 44 types of epiphytes and 1 type of fern.

Major mangrove species are the most often observed species compared to minor mangrove and associated species (Table 2). This condition is related to the ability of mangrove groups that quickly adapt to their habitats so that they can form a pure stand community. Tomlinson²⁹ suggests that the characteristics of major mangrove species are: (a) Not found in terrestrial/terrestrial communities, (b) Has a major role in the structure of mangrove vegetation communities and is able to form pure stands, (c) Able to adapt to their habitat by the formation of special morphology and (d) Able to grow at low to high salinity levels. While minor mangrove species and mangrove associations generally grow in seashore area that tend toward the mainland and do not form pure stands.

Analysis of mangrove vegetation density shows that the status of the condition of mangrove forests in study site categorized as "good" criteria. These criteria refer to the standard mangrove damage criteria³⁰, where the criteria for "good mangrove forests" have a stand density >1500 N ha⁻¹ and tree-covered area are larger than 70% of total land. This condition is also strengthened by the high vegetation density of the seedling growth phase and the phenomenon of decreasing the number of vegetation densities during the sapling and tree growth phases. The phenomenon of decreasing the amount of vegetation density forms an inverted "J" curve, which means that the rate of regeneration of the seedling growth phase in the mangrove forest can guarantee the survival of the stands in the future³¹.

Rhizophora stylosa is the most dominant type among other types in the seedling, sapling and tree growth phase. The dominance of a species in a vegetation community shows that it has a better level of adaptation to its habitat³². *Rhizophora stylosa* is a type of major mangrove group that has a major role and tends to form mangrove communities and can form pure stands and can grow at low to high salinity levels. Also, the species can utilize nutrients or minerals, sunlight energy and water well in its growth process, has a competitive nature and tends to have a good ability to adapt to environmental factors^{33,34}. *Rhizophora stylosa* has a broad range of environmental coverage compared to other species so that it can dominate the existence of other species found at the study site. Odum³⁵ stated that the dominance of a type of vegetation can be interpreted to have a broader range of environmental ranges and have an impact on the broad range of tolerance of environmental factors to cause wider distribution of vegetation.

The potential for biomass storage of mangrove vegetation is higher than mangrove forest vegetation in canopy cover in Sebatuana Village, Sambas Regency, West Kalimantan³⁶, at 62.08 t ha⁻¹. However, it is lower when compared to the potential storage of Perancak mangrove vegetation in Bali's Jembrana Regency³⁷, which is 312,653 t ha⁻¹. According to Donato *et al.*³⁸, in Southeast Asia, good mangrove ecosystems have biomass potential ranging from 250-275 t ha⁻¹ and the lowest <7.9 t ha⁻¹.

The average diameter of the trunk influences the number of biomass potential in the tree growth phase. The average trunk diameter of the tree is 18.77 cm, higher than the average diameter of the sapling phase of 5.31 cm. Stem diameter and height, soil fertility, vegetation density and wood density can affect the potential value of biomass storage in mangrove ecosystems³⁹. Seedling growth phase has the lowest biomass storage potential because generally, the seedling growth is still in the form of hypocotyl derived from fruit so that the amount of biomass produced is still limited⁴⁰.

The amount of carbon stored in mangrove vegetation is influenced by the value of biomass stored in vegetation. The higher the value of vegetation biomass, the carbon stored will be even higher. The potential carbon stock of mangrove vegetation results of this study (45.65 t ha⁻¹ C) tends to be lower compared to the carbon stored in mangrove forest stands in the estuary of Gembong Bekasi Regency⁴¹ at 55.35 t ha⁻¹ C. Primary mangrove forest ecosystems in Indonesia have carbon deposits ranging from 41.80-393.62 t ha⁻¹ C with an average of 188.30 t ha⁻¹ and in secondary mangrove forests around 37.03-142.90 t ha⁻¹ with an average⁴² of 94.07 t ha⁻¹, while the potential carbon storage of mangrove forests for Kalimantan

bioregion averages 162 t ha⁻¹ C in primary mangrove forests and 116 t C ha⁻¹ in secondary mangrove forests⁴³.

Forest vegetation acts as oxygen producer through the process of photosynthesis. The results of this study indicate that oxygen (O₂) produced by mangrove at tree growth phases (95.80 t ha⁻¹ O₂) is higher than the of O₂ produced by the tree stands in urban forests of Palangka Raya City⁴⁴, that is 49.84 t ha⁻¹ O₂. In term of the growth phase, it is known that tree vegetation contributes the most in producing oxygen compared to the sapling and seedling phases, which is caused by the higher ability of trees to absorb CO₂ compared to saplings and seedlings. If the absorption of CO₂ during photosynthesis exceeds the amount of CO₂ released in the respiration process throughout the year, the tree will store carbon higher so that the amount of oxygen produced will be higher. Julius and Nagel⁴⁵ states that the more vegetation and forest area, the amount of CO₂ absorbed by the leaf surface for photosynthesis will increase so that the amount of O₂ produced will be higher. Supriatna⁴⁶ stated that tropical forests are capable of producing much oxygen (600,000 t ha⁻¹/year O₂) compared to lush agricultural areas (20,000-40,000 t ha⁻¹/year O₂).

This study only calculates the potential for biomass stock and vegetation carbon at tree, sapling and seedling growth phases, whereas biomass and carbon stored in understorey vegetation, litter, deadwood and soil have not been studied. Therefore, it is necessary to calculate the biomass and carbon in understorey vegetation, litter, deadwood and soil to obtain more accurate data about carbon stored in mangrove forest.

CONCLUSION

The number of mangrove vegetation types that are found is relatively small and most are included in the group of major mangrove types. The rate of regeneration of mangrove vegetation for future survival is categorized "quite good" because the density of vegetation is dominated by seedling growth phase. The most dominant type of vegetation is *Rhizophora stylosa* in the growth phase of trees, saplings and seedlings. It is necessary to conduct mangrove forest conservation in order to increase the potential of biomass storage, carbon stocks and oxygen production.

SIGNIFICANCE STATEMENT

This study discovered that the mangrove vegetation has the potential to store biomass, to absorb carbon and to produce oxygen that can be beneficial for human and coastal life. This study will help the researchers to uncover the critical areas of oxygen production from the coastal zone that many researchers were very limited to cover.

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