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ESTIMATION OF CARBON STORAGE POTENTIAL IN THE MANGROVE FOREST REHABILITATION AREA IN SEBELE VILLAGE, RIAU ISLANDS

Estimasi Potensi Simpanan Karbon Pada Kawasan Rehabilitasi Hutan Mangrove Desa Sebele, Kepulauan Riau

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ABSTRACT

Global warming is a phenomenon of increasing the average temperature of the earth's surface. Carbon can be stored in various forms in ecosystems, one of which is the concept of blue carbon. This research aims to analyze the condition of the mangrove ecosystem and the potential for carbon storage in the mangrove forest rehabilitation area in Sebele Village, Karimun Regency, Riau Islands. This research was conducted from October 2024 to July 2025 in the mangrove forest rehabilitation area of Sebele Village, Riau Islands Province. The method used in this research is the survey method. Standing biomass data was obtained using allometric equations. The research results show that the level of tree density in the mangrove forest rehabilitation area of Sebele Village is in the Sparse category. At the tree level, it is dominated by the *Xylocarpus granatum* species, while at the sapling level it is dominated by the *Rhizophora mucronata* species. The highest carbon storage value is found in the *Avicennia marina* species with a carbon storage value of 14.44 tons/ha. And the potential carbon storage from the calculation results obtained a carbon storage value of 61.43 tons/ha. The carbon storage value is directly proportional to the standing biomass. The greater the standing biomass, the greater the carbon stored.

Key words: Global Warming, Blue Carbon, Allometric, Biomass

ABSTRAK

Pemanasan global adalah fenomena peningkatan suhu rata-rata permukaan bumi. Karbon dapat disimpan dalam berbagai bentuk pada ekosistem, salah satunya dengan konsep *blue carbon*. Riset ini bertujuan untuk menganalisis kondisi ekosistem mangrove dan potensi simpanan karbon pada kawasan rehabilitasi hutan mangrove di Desa Sebele, Kabupaten Karimun, Kepulauan Riau. Riset ini dilaksanakan pada bulan Oktober 2024 hingga juli 2025 di kawasan rehabilitasi hutan mangrove Desa Sebele, Provinsi Kepulauan Riau. Metode yang digunakan pada riset ini adalah metode survey. Data biomassa tegakan didapatkan dengan menggunakan persamaan allometrik. Hasil riset menunjukkan tingkat kerapatan pohon di kawasan rehabilitasi hutan mangrove Desa Sebele pada kategori Jarang. Pada tingkat pohon, didominasi oleh spesies *Xylocarpus granatum,* sedangkan pada tingkat pancang didominasi oleh spesies *Rhizophora mucronata*. Nilai simpanan karbon tertinggi terdapat pada spesies *Avicennia marina* dengan nilai simpanan karbon sebesar 14,44 ton/ha. Serta potensi simpanan karbon dari hasil perhitungan didapatkan nilai simpanan karbon sebesar 61,43 ton/ha. Nilai simpanan karbon berbanding lurus dengan biomassa tegakan. Semakin besar biomassa tegakan maka karbon yang tersimpan akan semakin besar.

Kata Kunci: Pemanasan Global, Karbon Biru, Allometrik, Biomassa

INTRODUCTION

Global warming is a serious challenge facing the world today. It is caused by greenhouse gases, such as carbon dioxide (CO2) emissions from the combustion of fossil fuels and deforestation. Global warming can impact our lives, including climate change and sea level rise (Fitria & Dwiyanto 2021). Sea level rise can lead to natural disasters such as erosion, flooding, and wetland shifts, as well as changes in water quality (Asadi *et al.,* 2019; Fitria & Dwiyanto 2021).

One way to significantly reduce the concentration of carbon dioxide in the atmosphere is through photosynthesis by plants. This storage process in plants spans periods ranging from years to centuries (Sarwono 2016). Carbon can be stored in various forms within ecosystems, one of which is the concept of blue carbon. Three main ecosystems play a role in storing carbon, both in biomass and in sediments: seagrass meadows, brackish swamps, and mangroves, found in coastal areas (Azzahra *et al.,* 2020).

Mangroves are coastal ecosystems that play a vital role in the environment and human life. They serve three primary functions: physical, biological, and economic. Furthermore, mangroves play a crucial role in mitigating the impacts of global warming by absorbing atmospheric carbon for photosynthesis and storing it in biomass and sediment (Ati *et al.,* 2014). Mangrove forests have the capacity to store more than three times the average carbon per hectare stored by terrestrial tropical forests (Donato *et al.,* 2012). Optimally, mangroves can absorb up to 77.9% of carbon. The carbon absorbed by mangroves is stored in biomass, specifically in stems, leaves, and sediment (Darusman 2006; Bismark et al., 2008; Bachmid et al., 2018). Mangrove ecosystems are coastal areas rich in biological and non-biological resources. However, they are vulnerable to environmental change. High population growth rates and increased coastal development for various purposes put ecological pressure on coastal habitats, particularly mangrove ecosystems. Increasing ecological pressures will cause damage to mangrove forests, both directly (through logging and conversion of land into fishponds) and indirectly (including through pollution or waste from port construction activities) (Alimuna et al., 2009). This can threaten the existence of mangrove ecosystems and their capacity to store carbon.

As an archipelagic country, according to the Geospatial Information Agency (BIG), in 2017, the area of mangrove forests in Indonesia reached 3.36 million hectares (Rahadian et al., 2019). Indonesia's mangrove forests are the largest in Asia (Karimah 2017). One area with a fairly extensive mangrove forest is Sebele Village, Belat District, Riau Islands Province. Sebele Village has an area of 2,700 ha, with 200 ha of mangrove forest. This study was conducted with the aim of analyzing the condition of the mangrove ecosystem and the potential reserves in the mangrove forest rehabilitation area in Sebele Village, Karimun Regency, Riau Islands.

RESEARCH METHODS

Time and Location of Research

This research was conducted from October 2024 to July 2025. The research location was in the mangrove forest in Sebele Village, Belat District, Karimun Regency, Riau Islands Province. A map of the research location can be seen in Figure 1.

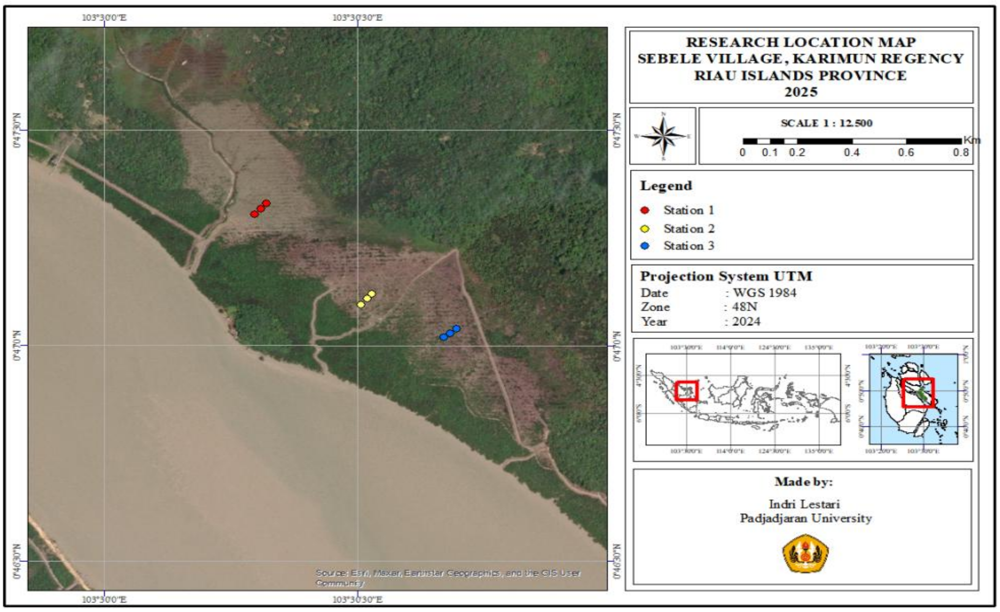

Figure 1. Research Location Map

Tools and materials

The tools used in this study included a GPS (Global Positioning System), a roll meter, transects, a phi-band, and ArcGIS software. The materials used in this study were ropes to create the transects.

Work procedures

Determining Sampling Locations

The location of observation and data collection was carried out in the mangrove forest area in Sebele Village, which was used in this study as a rehabilitation area. Mangrove vegetation data collection was carried out using Transect Line Plots. The observation station consisted of three different stations. Each station consisted of three plots starting from the sea towards the land. The observation plot measured 10 x 10 m for tree-level inventory, and within the plot, a subplot measuring 5 x 5 m was created for sapling-level inventory (Jamili et al., 2009; Analuddin et al., 2015; Ibrahim *et al.,* 2021). Tree diameter was measured by measuring the Diameter at Breast Height (DBH), which is the diameter at breast height or approximately 1.3 m from the ground surface (Peñaranda *et al.,* 2019). Identification of mangrove species was carried out based on the morphological characteristics of roots, leaves, fruits, and flowers using the book "Guide to the Introduction to Mangroves in Indonesia" (Noor *et al.,* 2006).

Data analysis

Specific Density (K)

The density value describes the level of mangrove abundance at the research location. The calculation of the species density value uses the following equation (Fachrul 2007):

$$\mathrm{K\ (ind/ha)} = \frac{\text{Number of individuals of a species}}{\text{Sample plot area}}$$

Relative Density (KR)

Relative density is the result of comparing the density of a species with the density of all species at the research location. The calculation of relative density values uses the following equation (Fachrul, 2007):

$$\text{KR}\ (\%) = \frac{\text{Density of a type}}{\text{Density of all types}}\ \text{x}\ 100\%$$

Type Frequency (F)

Frequency is a value used as a parameter to indicate the distribution or spread of a species within an ecosystem. The calculation of species frequency values uses the following equation (Fachrul, 2007):

$$\text{Frequency (F)} = \frac{\text{Number of plots found of a type}}{\text{Total number of sample plots}}$$

Relative Frequency (FR)

Relative frequency is the result of comparing the frequency of a species with the frequency of all species at the research location. The calculation of the relative frequency value uses the following equation (Fachrul, 2007):

$$\text{FR}\ (\%) = \frac{\text{Frequency of a type}}{\text{Total frequency of all types}}\ \text{x}\ 100\%$$

Dominance (D)

Dominance indicates a major species that influences a community by means of the number of a species and its size. The calculation of dominance values uses the equation (Fachrul, 2007):

$$\text{Basal area}\ (\text{m}^2) = \frac{\pi \text{D}^2}{4}$$

$$\text{D}\ (\text{m}^2/\text{ha}) = \frac{\text{Basal area of a type}}{\text{Sample plot area}}$$

Information :
π : 3,14
D : Stem diameter (m)

Relative Dominance (DR)

Relative dominance is the result of comparing the dominance of a species with the dominance of all species at the research location. The calculation of the relative dominance value uses the equation (Fachrul 2007):

$$\text{DR}\ (\%) = \frac{\text{Dominance of an area}}{\text{Total dominance of all species}}\ \text{x}\ 100\%$$

Importance Value Index (IVI)

IVI shows whether the presence of a type of mangrove has an influence or not in a community or ecosystem (Seran 2019). The calculation of the INP value uses the equation (Fachrul 2007):

$$IVI\ (\%) = KR + DR + FR\ (tree)$$
$$IVI\ (\%) = KR + FR\ (Stake)$$

Biomass

Biomass calculations to determine biomass in mangrove stems used allometric equations with mangrove stem diameter (DBH) data. Data processing was performed on all sapling and tree stands included in the transect. The allometric equations can be seen in Table 1.

Table 1. Allometric equations above ground

Types of Mangrove	Allometric Equations	Research Sources
Avicennia alba	$B= 0.079211 \times D^{2.470895}$	Tue *et al.*, 2014; Suryono *et al.* 2018
Avicennia marina	$B= 0.1848 \times D^{2.3524}$	Dharmawan dan Siregar 2008
*Ceriops tagal**	$B= 0.251 \times p \times D^{2.46}$	Sapriyadi 2003
Rhizophora mucronata	$B= 0.1466 \times D^{2.3136}$	Dharmawan 2010; Rifandi 2020
Xylocarpus granatum	$B= 0.1832 \times D^{2.21}$	Tarlan 2008; Suryono *et al.*, 2018

Description: B = Biomass (kg); D (DBH) = Tree diameter at breast height or 1.3 m (cm); p = Plant specific gravity (gr/cm^2) *0.746 g/cm^2

Carbon Storage

Aboveground carbon storage can be assumed to consist of 47% of mangrove biomass (National Standardization Agency 2019). Carbon storage at each station is calculated using the following formula:

$$C_b = B \times \%C\ organic$$
$$C_b = B \times 0{,}47$$

Information:
Cb : Carbon content of biomass (kg)
B : Total biomass/organic matter (kg)
%C organik : The percentage of carbon content is 0,47

After calculating carbon storage in kilograms, it is necessary to convert carbon storage into tons/ha (Indonesian National Standard 2019), as follows:

$$Carbon\ storage\ (ton/ha) = \frac{C_b}{1000} \times \frac{1000}{plot\ area\ (m^2)}$$

RESULTS

Mangrove Vegetation Structure

Mangrove stand structure was analyzed based on field data collected from the three research stations. The species found included Rhizophora mucronata, Avicennia alba, Avicennia marina, Ceriops tagal, and Xylocarpus granatum. Mangrove tree-level density at station 1 was 433 trees/ha, station 2 367 trees/ha, and station 3 366 trees/ha. The tree density at the research site ranged from 367 to 433 trees/ha, making it categorized as sparse (KLH 2004). The highest INP at the tree level was found in the X.granatum species, ranging from 219 to 300%. The mangrove vegetation structure at the tree level at the research site can be seen in Table 2.

Table 2. Tree level importance value index

Station	Type	K	KR (%)	F	FR (%)	D	DR (%)	INP (%)
1	*X. granatum*	366	85	1	75	0,41	70	230
	A. alba	67	15	0,33	25	0,17	30	70
	Amount	**433**	**100**	**1,33**	**100**	**0,58**	**100**	**300**
2	*X. granatum*	367	100	1	100	0,43	100	300
	Amount	**367**	**100**	**1**	**100**	**0,43**	**100**	**300**
3	*X. granatum*	333	91	1	75	0,41	53	219
	A. marina	33	9	0,33	25	0,38	47	81
	Amount	**366**	**100**	**1,33**	**100**	**0,79**	**100**	**300**

The mangrove density at the sapling level at station 1 was 4,400 ind/ha, at station 2 5,600 ind/ha, and at station 3 1,334 ind/ha. The highest IVI at the sapling level was found in the R. mucronata species, ranging from 131-141%. The mangrove vegetation structure at the sapling level in this study can be seen in Table 3.

Table 3. Stake level importance value index

Station	Type	K	KR (%)	F	FR (%)	INP (%)
1	*R. mucronata*	4.000	91	1	50	141
	X. granatum	267	6	0,67	33	39
	A. alba	133	3	0,33	17	20
	Amount	**4400**	**100**	**2,00**	**100**	**200**
2	*R. mucronata*	4533	81	1	50	131
	C. tagal	1067	19	1	50	69
	Amount	**5600**	**100**	**2,00**	**100**	**200**
3	*A. marina*	400	30	0,33	20	50
	A. alba	267	20	0,67	40	60
	C. tagal	667	50	0,67	40	90
	Amount	**1334**	**100**	**2,00**	**100**	**200**

Carbon Storage

Mangrove biomass at this research location ranged from 674.51-727.60 kg/m², with carbon storage ranging from 317.01-341.98 kg/m² which is equivalent to 15.04-20.67 tons/ha. The total carbon storage in this study was 61.44 tons/ha. Karyati et al., (2021) stated that mangrove carbon storage in Bangka Belitung Regency, Bangka Belitung Islands had a total carbon of 389.75 tons/ha. Sahari et al., (2024) stated that carbon storage on Tok Haji Island was 145.8 ± 12.6 tons C/ha, Semut Island was 96.78 ± 12.2 tons C/ha, and Busung Island was 105.3 ± 13.3 tons C/ha. Kusumaningtyas et al. (2019) reported that carbon storage in Berau was 130.1 ± 32.1 Mg C/ha, Kongsi Island was 74.3 ± 20.2 Mg C/ha, and Segara Anakan Lagoon was 15.8 ± 8.6 Mg C/ha in the eastern part and 10.3 ± 3.0 Mg C/ha in the central part of the lagoon.

Table 4. Estimation of carbon storage potential in mangroves

Station	Type	Biomass (Kg/m²)	Carbon Storage (Kg/m²)	Carbon Storage (ton/ha)
1	*X. granatum*	574,29	269,91	10,38
	A. alba	85,06	39,98	4,66
	R. mucronata	36,71	17,25	2,30
	Total	**696,06**	**327,14**	**17,33**
2	*X. granatum*	579,24	272,24	9,07
	R. mucronata	43,15	20,28	2,70
	C. tagal	52,12	24,49	3,27
	Total	**674,51**	**317,01**	**15,04**
3	*X. granatum*	535,61	251,74	8,39
	A. marina	125,64	59,06	14,44
	A. alba	13,92	6,54	1,31
	C. tagal	52,43	24,64	4,93
	Total	**727,60**	**341,98**	**29,67**

DISCUSSION

Mangrove Vegetation Structure

The mangrove species found at the three stations consisted of Rhizophora mucronata, Avicennia alba, Avicennia marina, Ceriops tagal, and Xylocarpus granatum. The density value describes a species with a high density value having a large adaptation pattern by calculating the number of individuals of each species with the area of the plot used (Fachrul 2007). The INP indicates whether the presence of a mangrove species has an influence or not in a community or ecosystem (Seran 2019). The INP in this study was dominated by the Xylocarpus granatum species at the tree level and the Rhizophora mucronata species at the sapling level. This indicates that the X. granatum species has a higher adaptation level compared to other species at the study site. Therefore, the mangrove species X. granatum has the potential to increase its sustainability rate over time. Meanwhile, the high INP in the R. mucronata species is due to the high relative density and relative frequency values. The high density value is caused by the results of rehabilitation at the mangrove site carried out starting from propagules. With mangrove growth currently reaching sapling stage, this indicates that the R. mucronata species can survive in the mangrove environment in Sebele Village. In other words, the environmental conditions of the mangrove forest in Sebele Village are very suitable for the growth of the R. mucronata species. The R. mucronata species is widely used for rehabilitation because its fruit is readily available, it is easy to sow, and it can grow in areas with high or low tidal inundation (Aini et al., 2016).

Carbon Storage

The biomass value is influenced by the diameter of the stand itself, where the larger the diameter of the stand, the greater the biomass value will also be (Mandari et al., 2016). There is a high correlation between tree biomass and its height and diameter, especially with the diameter of the tree. Tree stands will produce biomass and carbon storage values in significant amounts as they grow because photosynthesis absorbs CO2 from the atmosphere to produce biomass, which is then distributed throughout the leaves, branches, stems, and roots to increase the diameter and height of the tree (Adinugroho 2001; Mandari et al., 2016). In this study, the highest carbon storage was found at station 3, while the lowest was at station 2. This is because the tree stands found at station 3 had a larger diameter, while at station 2 the diameter of the tree stands found had a smaller diameter.

The results of this study are significantly lower than those obtained by Karyati et al. (2021). This is because the mangrove density found in the Bangka Belitung Islands is higher, ranging from 1,000 to 1,500 trees/ha. This study, however, found a density of 366 to 433 trees/ha. Mangrove density can reflect the number of mangrove stands in an area (Ibrahim et al., 2021). Similar to the location in this study, the Belitung region is generally close to seawater, so mangroves are not unfamiliar to the community. However, the difference is that the mangrove stands in Belitung Regency are already categorized as mature and constitute primary forest with very low levels of anthropogenic intervention. Meanwhile, the mangroves in Sebele Village are currently rehabilitated as a restoration of degraded areas, so the age of the stands is relatively still at the sapling stage. This is supported by research conducted by Kusumaningtyas et al., (2019), from the results of the study, it was found that the carbon stock value was higher in the mangrove areas of Kongsi and Berau Islands with natural or undisturbed conditions, compared to the mangrove areas in Segara Anakan Lagoon which had experienced degradation.

CONCLUSION

The mangroves in Sebele Village, Riau Islands, consist of five mangrove species: Rhizophora mucronata, Avicennia alba, Avicennia marina, Ceriops tagal, and Xylocarpus granatum. The mangrove density at the tree level is sparse, at 366-466 trees/ha. At the tree level, Xylocarpus granatum dominates with an IVI of 219-300%. At the sapling level, Rhizophora mucronata dominates with an IVI of 131-141%. The highest carbon storage value is found in Avicennia marina, with a carbon storage value of 14.44 tons/ha. The total carbon storage potential calculated is 61.43 tons/ha. The carbon storage value is directly proportional to the standing biomass. The greater the standing biomass, the greater the carbon storage.

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