

ANALYSIS OF THE ABILITY OF MANGROVE SEQUESTRATION AND CARBON STOCK IN PEJARAKAN VILLAGE, BULELENG REGENCY, BALI

ANALISIS KEMAMPUAN SEKUESTRASI DAN PENYIMPANAN KARBON HUTAN MANGROVE DI DESA PEJARAKAN, KABUPATEN BULELENG, BALI

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ABSTRACT

Mangroves have a major role as carbon absorption and stock. However, this potential cannot be maximized, due to the high level of mangrove damage. The research question is the extent of the ability of mangroves to absorb carbon dioxide (CO₂) and store it in the form of biomass. The purpose of this study was to determine the absorption ability and carbon stock of various types of mangrove. The research location was chosen in Pejarakan village, Buleleng Regency, Bali Province, Indonesia as a case study. The method used is non-destructive to obtain diameter data at the height of mangrove trees, by collecting garbage and sediment samples manually on the floor of mangrove forests and to motivate the Government and local communities to restore mangrove forests. The results showed that the high density types of *Sonneratia alba* turned out to have the ability to absorb and store carbon, compared to other mangrove species. The results showed that *S. alba* is estimated to have the ability to absorb 57.60 tons of CO₂ ha⁻¹ which is equivalent to 15.71 tons C ha⁻¹. While the lowest value is the *Osbornia octodonta* with the lowest density value. *S. alba*'s ability to store carbon is 5.56 tons of CO₂ ha⁻¹ or equivalent to 1.52 tons C ha⁻¹. The conclusion is that *S. alba* has the highest ability to absorb and store carbon.

Keywords: carbon, mangrove forest, *Sonneratia alba*

ABSTRAK

Mangrove memiliki peran besar sebagai penyerap dan stok karbon. Namun, potensi ini tidak dapat dimaksimalkan, karena tingginya tingkat kerusakan mangrove. Pertanyaan penelitian adalah sejauh mana kemampuan mangrove untuk menyerap karbon dioksida (CO₂) dan menyimpannya dalam bentuk biomassa. Tujuan dari penelitian ini adalah untuk mengetahui kemampuan penyerapan dan stok karbon dari berbagai jenis mangrove. Lokasi penelitian dipilih di desa Pejarakan, Kabupaten Buleleng, Provinsi Bali, Indonesia sebagai studi kasus. Metode yang digunakan adalah non-destruktif untuk mendapatkan data diameter pada ketinggian pohon mangrove, dengan mengumpulkan sampel sampah dan sedimen secara manual di lantai hutan mangrove dan untuk memotivasi Pemerintah dan masyarakat setempat untuk memulihkan hutan mangrove. Hasil penelitian menunjukkan bahwa jenis *Sonneratia alba* dengan kepadatan tinggi ternyata memiliki kemampuan untuk menyerap dan menyimpan karbon, dibandingkan dengan spesies mangrove lainnya. Hasil penelitian menunjukkan bahwa *S. alba* diperkirakan memiliki kemampuan menyerap 57,60 ton CO₂ ha⁻¹ yang setara dengan 15,71 ton C ha⁻¹; sedangkan nilai terendah ditemukan pada jenis *Osbornia octodonta* dengan nilai kerapatan terendah. Kemampuan *S. alba* untuk menyimpan karbon adalah 5,56 ton CO₂ ha⁻¹ atau setara dengan 1,52 ton C ha⁻¹. Kesimpulannya adalah bahwa *S. alba* memiliki kemampuan tertinggi untuk menyerap dan menyimpan karbon.

Kata kunci: hutan mangrove, karbon, *Sonneratia alba*

I. INTRODUCTION

Climate change is currently the most global and crucial issue and a trending topic discussed in various national and international meeting. Increasing temperature of the earth caused by the greenhouse gas effect is caused by gas emission such as carbon dioxide (CO₂) (Ministry of Environment, 2011). Coastal wetlands (especially mangroves, tidal swamps, and seagrass) is important protection because of its capacity to absorb and store carbon (C) (Xiong *et al.*, 2018). However, Nehren and Wicaksono (2018) reported that there is no correlation between (a) soil TOC and distance from shoreline, (b) total ecosystem carbon stock and distance from shoreline, (c) total C of living biomass and distance from shoreline, and (d) soil TOC and living biomass. Possible reasons for the lack of correlation between soil TOC and distance from shoreline could be due to the inhomogeneous underlying basement rocks and sediments, as well as varying soil depths and development stages. Donato *et al.* (2011) in Kusumaningtyas *et al.* (2018) showed that mangrove ecosystems are also one of the richest ecosystems that absorb and store carbon in 65 tropical regions. Mangroves absorb and store large amounts of organic carbon in sediments and biomass of plants, trees and leaves which makes them an important natural 67 carbon sink (Twilley *et al.*, 1992; Bouillon *et al.*, 2008). On a local scale, they depend notably on tree species, sediment salinity, nutrient availability, and, thus, on the forest's position in the tidal zone. Therefore, preservation in mangrove forests is the most important including the efforts to restore coastal ecosystems (Rudianto, 2017). Reservation can occur due to environmental factors such as: (1) climate (rainfall and temperature) and landform; (2) soils, determined by anoxic or oxic conditions, pH (acidity), and mineralogical composition (minerals belonging to the clay group and iron and aluminum oxyhydroxides); (3) the

type of organic matter and its degree of preservation; and (4) communities of micro-organisms that can affect the biopolymers and their alteration rates (Lehmann and Kleber, 2015). The ability of mangroves to absorb carbon is shown by Waskitho *et al.* (2018) which states that the prediction of carbon reserves in the mangrove forest in the Sigogor Mountain Nature Reserve area is 426.05 tons and this mangrove forest can absorb carbon dioxide of 1,601.93 tons. The mangrove vegetation in the area has a considerable carbon dioxide uptake of 1,601.93 tons. Waskito's research shows that mangrove forests do have the ability to absorb carbon. Mangrove forest damage also occurs intensively and results in a decrease in the absorption capacity of mangrove forests. The destruction of mangrove forests is indicated by the results of a study by Sulistyawati *et al.* (2006) which stated that during the 1994-2001 period, landscape level carbon stocks in the Papadayan Mountain region had decreased from 2,772,575 mg to 1,944,151 mg (30% reduction) due to conversion 2,702 ha of forest area into agricultural land.

The results of the experts research show that government policies for the management of mangrove forest areas are very weak. The Government of Indonesia is committed to reducing CO₂ emissions 26% by 2020, through tropical rainforest and mangrove forests in Indonesia. In fact Indonesia is ranked 22nd in terms of climate policy management (CCPI, 2017). Besides being a greenhouse gas contributor, Indonesia is also affected by global warming, sea level rise, acidification of sea water, extreme rainfall, the occurrence of floods in the dry season as examples of the impact of climate change due to warming global (Manuri *et al.*, 2011).

The coastal village of Pejarakan, Gerogak District, Buleleng Regency in Bali. In Bali has a mangrove ecosystem with high species diversity of mangrove. It was found that there were 13 mangroves with good

mangrove conditions in Pejarakan village (Ginantra *et al.*, 2018). This high density of mangrove could assist potentially to contribute the carbon sequestration and stock in Indonesia. The purpose of this study is to determine the ability of carbon sequestration and stock from various types of mangrove and to encourage the government and local people to restoring mangrove forests.

II. METHODS

2.1. Time and Place of Research

This study was carried out in the period of March-April 2018 at the Pejarakan Village, Gerokgak District, Buleleng Regency, Bali. Analysis of carbon storage and absorption was carried out at the Central Laboratory of Biological Sciences of

Brawijaya University and the Integrated Freshwater Fisheries Management Unit located at the Sumber Pasir village, Malang district.

To measure carbon sequestration and stock, this is done using a measurement station. This measurement station is divided into four stations which represent the use of mangrove forest in Pejarakan Village (Figure 1). Station 1 was located in the tourist area of mangrove; Station 2 was located in the management forest location located in the port area from the entrance to the West Bali National Park area; Station 3 was located in the location of mangrove forests in a conservation area known as the Nature Conservation Forum; and Station 4 was located in the location of mangrove forests in areas adjacent to farm activity.

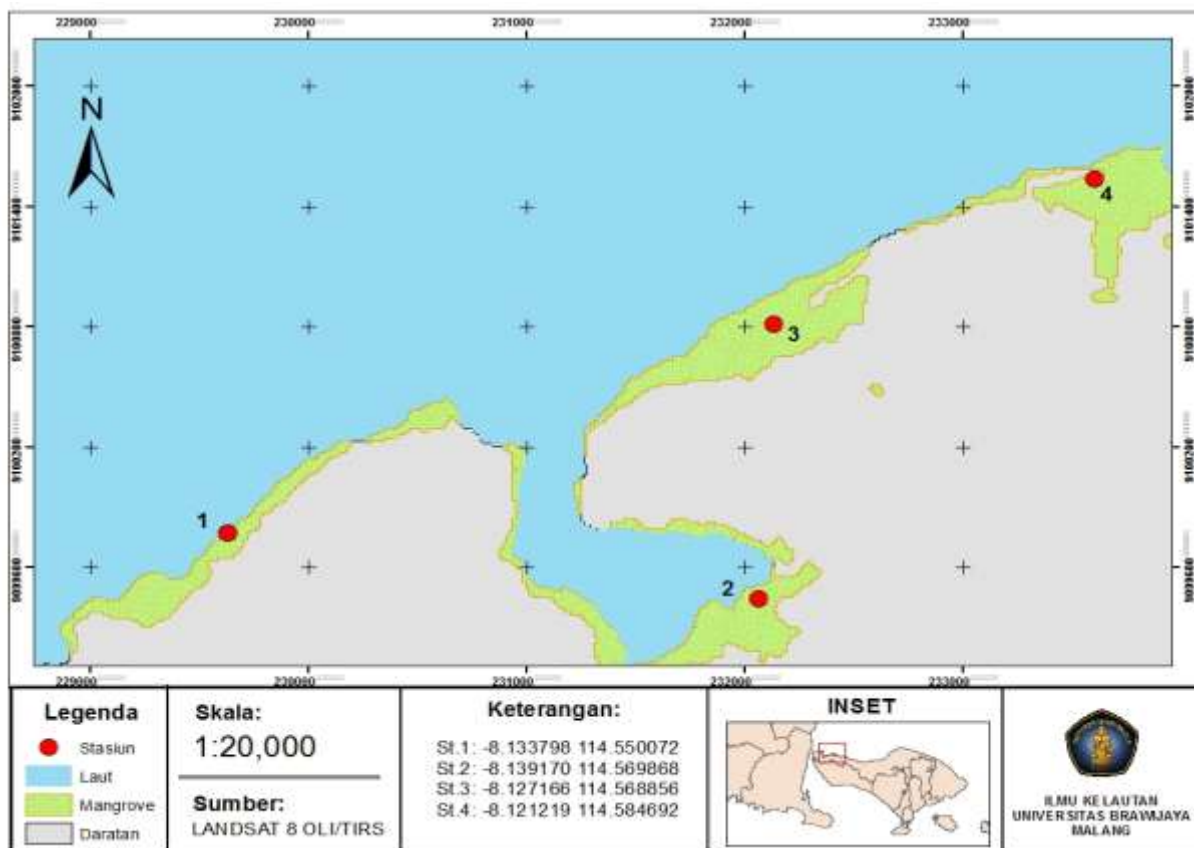


Figure 1. Site of the research (data collection) and sampling in Pejarakan village, Buleleng Regency in Bali Island.

2.2. Material and Data Collection

The method used for data sampling was purposive random sampling, based on specific objectives and considerations of the high distribution of mangrove species variations. Each station was deployed three 10 x 10 m square plots for measuring the tree class DBH (Diameter at Breast Height ≥ 20 cm), and each plot is divided into two 5 x 5 m plots, for belta/sapling class (DBH $\geq 2 - < 10$ cm), and 2 x 2m for seedling class (DBH < 2 cm).

2.2.1. Live Mangrove Surface Data Collection

In calculating carbon biomass, it used a non-destructive method. This method is not detrimental to target plants, because it is only limited to measuring the height or diameter of trees, which will later be extrapolated using allometric equations to obtain biomass values (Sutaryo, 2009).

2.2.2. Litter Sampling

Litter data collection is carried out by collecting litter directly on sub-plots of 2m x 2 m. Litter is in the form of avalanches of fresh leaves, twigs, and parts of fruit / flowers that are located on the forest floor or lower layers. Then the litter sample is weighed. After that the litter is taken as much as 300 g to be weighed as the weight of the sample. Furthermore, the sample was dried using an oven with a temperature range of 70-85 °C to reach a consistent weight. After drying, weigh the litter dry weight and analyze the organic carbon content.

2.2.3. Sediment Sampling

Mangrove sediments was sampled by inserting vertically a paralon pipe (PVC) with a diameter of 2 in to a depth of 30 cm depth. Sampling was carried out at five points on each plot, then composite sediment samples were mixed according to depth at intervals of 10 cm.

2.3. Laboratory Analysis

2.3.1. Litter Laboratory Analysis

Analysis of laboratory tests is carried out after the litter is dried at a temperature of 70- 85 °C for approximately 48 hours or until the dry weight reaches a constant. After that litter is calculated using the formula:

$$Bop = BKc / BBc \times BBt \dots\dots\dots (1)$$

Where:

Bop = Biomass organ parts (grams),
 BBc = sample wet weight (gram), BKc = constant dry weight example (gram), BBt = Total wet weight (gram / m²).

For litter carbon calculation from organic material contained in litter, it can be seen using the following formula:

$$Csr = Bo \times \% C \text{ organically} \dots\dots\dots (2)$$

Where:

Csr = organic matter content in litter (gram),
 Bo = total biomass or organic dry weight (gram), % C organic = presentation value of carbon content of 0.47.

2.3.2. Laboratory Analysis for Sediments

Laboratory analysis for sediments was carried out as follows: sediment samples that had been taken from the study area were then weighed wet weight and dried in an oven at 60 °C for 2 x 24 hours. This is dried so that the sediment sample is completely dry. After drying, the sediment sample is weighed and recorded the dry weight. After that the sediment density was analyzed by the density of specific sediments (bulk density) including the carbon content of the sediment samples. To analyze organic carbon, a loss in ignition (LOI) method is used. The steps of LOI analysis refer to Howard *et al.* (2014), as follows: that sediment samples placed on aluminum plates were previously weighed in cups. After that the sediment sample is placed in a cup at 60 °C for 48 hours. After drying the sample is smoothed with mortal and pestle until it

becomes homogeneous, then wrapped in plastic samples. The dry and fine samples are then taken and placed on top of the whip container as (W1). The sample was put into the oven furnace and burned at 450 °C for 4 hours so that the carbon in the precipitate burned completely, then weighed again as (W2).

2.4. Data Analysis

2.4.1. Condition of Mangrove

The condition of mangrove vegetation were measured by diameter data at breast height in mangrove stands, such as density, frequency and dominance values using mangrove surveys and mapping according to the National Standardization Agency (2011). Table 1 is indicated the condition of mangrove.

2.4.2. Carbon Sequestration and Stock

Calculation of carbon biomass in mangrove vegetation using a non-destructive method can be calculated with below allometric equations.

Table 1. Mangrove density.

Types	St I		St II		St III		St IV	
	D (ind/ha)	RD (%)	D (ind/ha)	RD (%)	D (ind/ha)	RD (%)	D (ind/ha)	RD (%)
<i>R. stylosa</i>	200	25	-	-	67	9	-	-
<i>O. octodonta</i>	133	17	-	-	-	-	-	-
<i>S. alba</i>	333	42	33	17	433	57	133	17
<i>C. tagal</i>	33	4	67	33	67	9	-	-
<i>A. marina</i>	100	13	100	50	-	-	-	-
<i>R. apiculata</i>	-	-	-	-	200	26	633	83
TOTAL	800	100	200	100	767	100	767	100

Remarks: D (Density); RD (Relative Density)

Table 2. Allometric equations for various of mangroves.

No	Species	Allometric Equations (DBH)
1.	<i>Avicennia marina</i>	0.308 x DBH ^{2.11}
2.	<i>Rhizophora mucronata</i>	0.1466 x DBH ^{2.3136}
3.	<i>Sonneratia alba</i>	0.251 x 0.6443 x DBH ^{2.46}
4.	<i>Rhizophora apiculata</i>	0.235 x DBH ^{2.42}

After obtaining the value of biomass stand, the estimated carbon stored can used the formula from the National Standardization Agency (2011), regarding to the measurement and calculation of carbon stocks (SNI 7724: ICS 65,020), as follows:

$$CS = SB \times \% C \text{ organik (0.4)} \dots\dots\dots (3)$$

Where:

CS : Carbon Stock, SB : Standing Biomass (Kg) ((Biomass = total dry weight or total biomass of organic matter).

Furthermore, the carbon dioxide uptake by the upper surface stand used the formula used by Heriyanto and Subiandono (2012), as follows:

$$CO_2: \frac{Mr CO_2}{Ar C} \times CS \dots\dots\dots (4)$$

Where:

Mr CO₂ : Relative molecular mass of CO₂ compounds (44), Ar C : Relative atomic mass (12), CS : Carbon Stock.

No	Species	Allometric Equations (DBH)
5.	<i>Rhizophora stylosa</i>	0.251 x 0.9400 x DBH ^{2.46}
6.	<i>Ceriops tagal</i>	0.251 x 0.8859 x DBH ^{2.46}
7.	<i>Osbornia octodonta</i>	0.251 x 0.9475 x DBH ^{2.46}

Source: (Komiya, 2008) and (Dharmawan, 2010).

2.4.3. Analysis of Litter Biomass

Specifically for calculating carbon biomass from litter samples collected from a 2 x 2 m subplot from the samling site was dried in an oven at 70 - 85 °C for approximately 48 hours or until constant dry weight, then it was calculated using the following formula:

$$Bop = \frac{BKc}{BBc} \times BB \dots\dots\dots (5)$$

Where:

Bop = Biomass of organ parts (gram), BBc = Sample wet Weight (gram), BKc = Constant dry weight sample (gram), BBt = Total wet weight (gram/m²).

For calculation of carbon litter from organic matter contained in litter, it used the following formula:

$$Csr = Bo \times \% C \text{ organic} (0,47) \dots\dots\dots (6)$$

Where:

Csr = Organic matter Content in Litter (gram); Bo = Total biomass or organic dry weight (gram).

2.4.4. Analysis of Sediment Carbon Stock

Sediment samples collected from the field were then analyzed to determine the organic carbon content using the Loss On Ignition (LOI) method (Howard *et al.*, 2014) sediment sample was placed in a crucible and heated with a temperature of 60 °C for 48 hours to remove the water content. Then, the sample was put into an oven furnace and burned at 450 °C for 4 hours so that the organic carbon in the sediment was completely burned. Furthermore, carbon content of bulk density in the sediment was calculated by using the formula, as follows:

$$BD = \frac{Dry\ Weight}{Sample\ Volume} \dots\dots\dots (7)$$

Where:

BD = Bulk density (g/cm³), Dry Weight = Sample Taken (g), Sample Volume = specific depth sample wet weight (cm³).

Then, it is calculated the percentage of organic carbon using the formula, as follows:

$$\% LOI = \frac{(W1-W2)}{W1} 100 \dots\dots\dots (8)$$

Where:

W1 = The Weight of the sample before the open furnace (g), W2 = The Weight of the sample after the open furnace (g).

During the combustion process in the furnace, organic material is burned into carbon. Therefore carbon calculation requires correction using the LOI percentage formula and the percentage of organic C, as follows:

$$\% C = 0,415 \times \% LOI + 2,89 \dots\dots\dots (9)$$

Furthermore, sediment carbon was calculated with the following formula:

$$Ct = Kd \times \rho \times \% C \text{ Organic} \dots\dots\dots (10)$$

Where:

Ct = Sediment Carbon Content (g/cm³), Kd = Depth of Sample Sediment (cm), ρ = Bulk density (g/cm³), % C Organic = value of carbon presentation (laboratory results).

2.4.5. Calculation Carbon Stocks

Manuri *et al.* (2011) stated that there are three main categories of carbon sources

that are important to calculate, namely stand biomass, dead or necromassic organic matter, and soil. For the benefit of mangrove forest management activities, the calculation of total carbon savings was done by summing up carbon sources using the formula, as follows:

$$Ct = (Cbs + Cn + Cs) \dots\dots\dots (11)$$

Where:

C t: C total, Cbs: C biomass stand, Cn: C nekromass, Cs : C soil.

III. RESULTS AND DISCUSSION

3.1. The Status of Mangrove Forest in Field Study

Based on the findings in the study area that found 6 (six) types of mangrove, namely: *R. stylosa*, *R. apiculata*, *O. octodonta*, *S. alba*, *C. tagal*, and *A. marina*. The growth of 6 (six) types of mangroves has the same type of mangrove growth. One of the habitats that supports the growth of the six types of mangroves is the type of muddy substrate which is very suitable for the stands of the six types of mangroves. Ecologically, mangrove forest is one of the core of coastal ecosystem that have a very important role in protecting the mainland. Beside, mangrove forest also provide three other ecological functions, namely as wildlife habitat, aquatic nurseries, and to maintain the water quality in clean condition, because the anaerobic mangrove sediments can trap heavy metals and pesticides without harm to the trees.

Table 3. Density of mangrove vegetation.

Types Density	St I		St II		St III		St IV	
	F(ind ha ⁻¹)	FR (%)	F (ind ha ⁻¹)	FR (%)	F (ind ha ⁻¹)	FR (%)	F (ind ha ⁻¹)	FR (%)
<i>R. stylosa</i>	200	25	-	-	67	9	-	-
<i>O. octodonta</i>	133	17	-	-	-	-	-	-
<i>S. alba</i>	333	42	33	17	433	57	133	17
<i>C. tagal</i>	33	4	67	33	67	9	-	-
<i>A. marina</i>	100	13	100	50	-	-	-	-

Related to the density of mangroves, it was informed that based on data analysis in the study area that each station had a density that was not much different, except at station II. In the port area it has a very low density compared to other stations. Station II has the lowest density with a value of 200 ind/ha, this is related to the condition of the mangrove which is diminishing due to the eviction by the establishment of buildings to support the activities of the harbor port to West Bali National Park. In addition, the area is also often traversed by crossing vessels which cause frequent waves. This causes mangroves both seedling classes and belta difficult to grow. For stations with the highest acquisition by station I, with the number 800 ind/ha, followed by stations II and III, each of which has a density of 767 ind/ha.

Mangrove frequency is an opportunity for finding a species in the area of observation and distribution of a type of mangrove. The frequency value is obtained from processing data on the number of plots found in certain types of mangrove data attachments, by calculating the total number of plots of a type divided by the number of plots that exist. Table 4 shows the mangrove frequency data.

The results of the calculation of the frequency of types and relative frequencies of tree-class mangrove species can be seen in Table 3 below. From the table the four existing stations are only types of *S. alba* found in all stations with a total value of 160% relative frequency, followed by type *C. tagal* with frequency values relative 67%.

Types Density	St I		St II		St III		St IV	
	F(ind ha ⁻¹)	FR (%)	F (ind ha ⁻¹)	FR (%)	F (ind ha ⁻¹)	FR (%)	F (ind ha ⁻¹)	FR (%)
<i>R. apiculata</i>	-	-	-	-	200	26	633	83
TOTAL	800	100	200	100	767	100	767	100

Remarks: F (Frequency); FR (Frequency Relative).

Table 4. Mangrove frequency.

Types	St I		St II		St III		St IV	
	F	FR (%)	F	FR (%)	F	FR (%)	F	FR (%)
<i>R. stylosa</i>	1.0	30	-	-	0.3	17	-	-
<i>O. octodonta</i>	0.7	20	-	-	-	-	-	-
<i>S. alba</i>	1.0	30	0.3	20	1.0	50	0.7	60
<i>C. tagal</i>	0.3	10	0.7	40	0.3	17	-	-
<i>A. marina</i>	0.3	10	0.7	40	-	-	-	-
<i>R. apiculata</i>	-	-	-	-	0.3	17	1.0	40
TOTAL	3.3	100	1.7	100	2.0	100	1.7	100

Remarks: F (Frequency); FR (Relative Frequency).

The physical conditions of the waters of Pejarakan Village, most of which are very open or directly facing the sea, so the salinity of the waters is quite high. This condition is very suitable for the growth of *S. alba*. Noor *et al.* (2006) stated that the type of *S. alba* was able to live at high salinity levels in the open mangrove area, and adaptation from its post roots which were able to withstand wave currents the findings of the four stations, the *O. octodonta* can be found on one station with a relative frequency value of 20%. Contrary to *S. alba*, the *O. octodonta* species is quite rare, because the territorial waters of Pejarakan Village are longer inundated, and the condition is the opposite of the *O. octodonta* living area.

The dominance of mangrove forests can provide an overview of the control or dominance of a type of mangrove in an area. This dominance value is obtained from processing data from the mangrove data attachment, where the basal area or base area is divided by the total plot area.

The dominance values in each tree class mangrove type in the study location can be seen in Table 4 above. From the results of

the dominance value, the type of *S. alba* has the highest value with a total percentage of 196%. This is influenced by the ability of this type of competition in finding more nutrients and nutrients than other types, therefore *S. alba* is found with a relatively large size of stem diameter. So that it controls an area.

This condition is supported by a statement from Hotden *et al.* (2014) that the size of the stem of a species is getting bigger, then the species will control more certain areas, and dominate the other types of mangroves had the highest average density with a value of 233 ind ha⁻¹ since it is found in all observation stations and is almost found in all areas of mangrove zoning. Overall, the average condition of mangrove forest in Pejarakan Village, Gerokgak Subdistrict, Buleleng Regency categorized as damaged with a density of 634 ind ha⁻¹. This mangrove forest ecosystem in Pejarakan is now in captious position. Negative natural and anthropogenic impacts and over exploitation of natural resources have caused severe damage to the ecosystem. More specifically, the causes of the decline in

mangroves are due to the growing number of buildings supporting the activities of the harbor crossing towards West Bali National Park. In addition, the study area is often traversed by crossing vessels that cause waves that have an impact on mangrove damage, especially for seedlings and belta classes which are difficult to grow. *S. alba* at the four station were found in all stations with a total relative frequency value of 40%, followed by *C. tagal* with a relative frequency value of 16.75%. This is possibly due to the physical condition of the waters of Pejarakan Village which are mostly very open or directly facing the sea, so that the water salinity is quite high that is suitable for growing from *S. alba* (wrote *et al.*, 2006).

Mangrove value index is a manifestation of the role and importance of a type of mangrove in the ecosystem or its environment. The mangrove importance value index was obtained by summing the density (Table 3), relative frequency (Table

4), and relative dominance (Table 5). The important value index is represented by the percentage of a type of mangrove to the other types of mangrove can be seen in Table 6.

3.2. Carbon Sequestration and Stock on Mangrove

3.2.1. Carbon Sequestration by Litter

This study shows that litter from the Rhizophoraceae family had a high carbon stock. It was contributed by two species of mangroves i.e storing carbon of 0.1093 tons C ha⁻¹ and 1,009 tons C ha⁻¹, respectively (see Figure 2). These mangroves were almost observed in all stations and this could one of the main factors where litter of *R. stylosa* and *R. apiculata* types are dominant. Sedimentation in mangrove forests is rich in carbon and is often assumed to be a carbon burial process, and the sediment accretion rate is used as a proxy for overall C uptake. Sediment accretion increases from high to low intertidal zones.

Table 5. The dominance of mangrove.

Types	St I		St II		St III		St IV	
	D (m ² /ha)	DR (%)	D (m ² /ha)	DR (%)	D (m ² /ha)	DR (%)	D (m ² /ha)	DR (%)
<i>R. stylosa</i>	12192	27	-	-	4663	14	-	-
<i>O. octodonta</i>	6930	15	-	-	-	-	-	-
<i>S. alba</i>	16858	37	14533	48	23594	69	8827	42
<i>C. tagal</i>	3832	8	7676	25	2776	8	-	-
<i>A. marina</i>	5648	12	8318	27	-	-	-	-
<i>R. apiculata</i>	-	-	-	-	3312	10	12037	58
TOTAL	45461	100	30527	100	34345	100	5576	100

Remarks: D (Dominance); DR (Dominance relative).

Table 6. Mangrove important value index.

Types	Important Value Index (%)				Average
	St I	St II	St III	St IV	
<i>R. stylosa</i>	82	0	39	0	30.25
<i>O. octodonta</i>	52	0	0	0	13
<i>S. alba</i>	109	84	175	100	117
<i>C. tagal</i>	23	98	33	0	38.5

Types	Important Value Index (%)				Average
	St I	St II	St III	St IV	
<i>A. marina</i>	35	117	0	0	38
<i>R. apiculata</i>	0	0	52	200	63
TOTAL	300	300	300	300	

Table 7. Mangrove litter carbon stock.

Types	St I	St II	St III	St IV
	SK (ton C ha ⁻¹)	SK (ton C ha ⁻¹)	SK (ton C ha ⁻¹)	SK (ton C ha ⁻¹)
<i>R. stylosa</i>	0.0365	0.0329	0.0138	0.0262
<i>O. octodonta</i>	0.0086	-	-	-
<i>S. alba</i>	0.0091	-	0.0110	0.0047
<i>C. tagal</i>	0.0153	0.0331	0.0099	-
<i>A. marina</i>	-	0.0090	0.0112	0.0100
<i>R. apiculata</i>	-	0.0323	0.0120	0.0566
TOTAL	0.0694	0.1073	0.0579	0.0975

Remarks: CS (Carbon Stock).

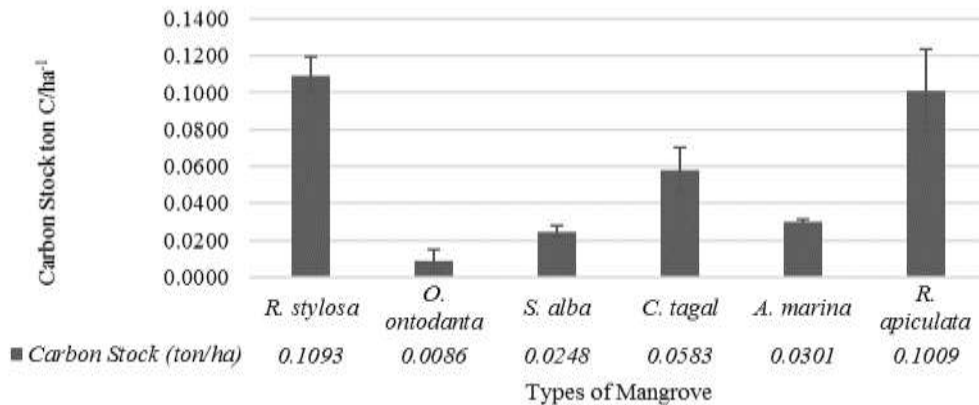


Figure 2. Litter carbon stocks in several types of mangroves in the mangrove forest of Pejarakan Village, Buleleng Regency, Bali.

3.2.2. Carbon Sequestration and Stock on Mangrove Stands

From the results of the litter research conducted, it was found that litter from the Rhizophoraceae family had a high carbon stock. Two mangroves from the Rhizophoraceae family found, *R. stylosa* and *R. apiculata* stored carbon at 0.1093 ton C ha⁻¹ dan 1,009 tons C ha⁻¹ (Figure 3). From the four existing observation stations, almost all stations were found litter from the Rhizophoraceae family, this is one of the main factors where more litter from *R.*

stylosa and *R. apiculata* species are highly produced.

From the results of processing stock and carbon uptake data in each type of mangrove (Table 8) found in the mangrove forest of Pejarakan Village, Buleleng Regency, Bali (Figure 3) shows the results that are directly proportional between the absorption and carbon stock of stands of each type of mangrove. If the absorption of carbon dioxide is high, the carbon stock stored from a type of mangrove will also be high when compared to other types.

Table 8. Carbon sequestration by mangrove stands.

Types	St I		St II		St III		St IV	
	CS	Sq.CO ₂	CS	Sq.CO ₂	CS	Sq CO ₂	CS	Sq.CO ₂
	(ton C ha ⁻¹)		(ton C ha ⁻¹)		(ton C ha ⁻¹)		(ton C ha ⁻¹)	
<i>R. stylosa</i>	4.65	17.05	0.51	1.85	6.52	23.90	-	-
<i>O. octodonta</i>	1.52	5.56	-	-	-	-	-	-
<i>S. alba</i>	4.27	15.67	3.31	12.13	5.87	21.52	2.26	8.28
<i>C. tagal</i>	2.13	7.83	0.80	2.93	1.58	5.79	0.44	1.61
<i>A. marina</i>	3.28	12.04	1.65	6.06	0.59	2.17	0.30	1.09
<i>R. apiculata</i>	-	-	0.84	0.84	3.43	12.57	5.51	20.22
TOTAL	15.86	58.16	7.11	23.82	17.98	65.94	8.51	31.19

Remarks: CS (Carbon Stock); Sq CO₂ (Sequestration carbondioxide).

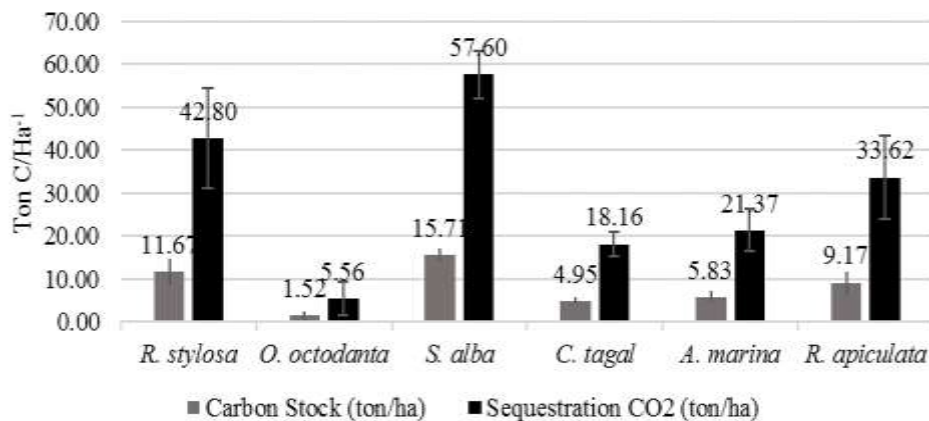


Figure 3. Carbon sequestration and stock on the surface of the mangrove.

3.2.3. Sequestration and Carbon Stock by Sediments

The sediment conditions in mangrove forests in the study area were mostly included in silt / clay sediments. The grain size of sediments ranged from 0.074 mm – 0.002 mm so that it is included in the type of silt/ clay, with a fine texture of the sediment. in Table 9, shows that the average carbon stock in sediments of the mangrove forest ecosystem in Desa Pejarakan is quite high. Station I has a carbon stock of 135.15 tons C ha⁻¹, station II has a carbon stock of 99.92 tons C ha⁻¹, station III has carbon 233.63 tons C ha⁻¹, and station IV has a total of 209.56 tons C ha⁻¹. Thus the total carbon stock in the sediment is 678.26 tons C ha⁻¹. The total value of carbon stock is 678.26 tons C ha⁻¹ due to conditions which are mostly types of mud (aqueous soil), where sediments with

the type of mud have fine grain size of sediment and contain higher organic carbon (Dewanti *et al.*, 2016). The density of mangrove trees also affects the wealth of sediments for carbon. This is due to the density of mangrove roots in the sediment also releasing organic compounds.

The stored carbon condition can also be read based on sediment depth as shown in Figure 4, with a depth of 10 cm, and a maximum depth of 30 cm. From the results obtained it is known that the more the depth of the sediment increases, the higher the value of the carbon deposits. The average carbon stock from the four observation stations showed that at a depth of 10 cm the carbon stock averaged 71.20 tons C ha⁻¹, at a depth of 20cm the carbon stock was 183.44 tons C ha⁻¹, and at a maximum depth of 30cm the carbon stock value was 254.06 ton C ha⁻¹.

Table 9: Total Stock Carbon in Sediments.

Depth (cm)	St I		St II		St III		St IV	
	DCS (ton C ha ⁻¹)	TSK (ton C ha ⁻¹)	SKK (ton C ha ⁻¹)	TSK (ton C ha ⁻¹)	TSK (ton C ha ⁻¹)	TSK (ton C ha ⁻¹)	TSK (ton C ha ⁻¹)	TSK (ton C ha ⁻¹)
10	63.43 ±14.3		39.94 ±3.3		120.04 ±4.1		61.39 ±33.9	
20	151.94 ±72.4	135.15	121.01 ±69.6	99.92	240.88 ±10.9	233.63	219.92 ±22.4	209.56
30	190.10 ±48.9		138.80 ±7.8		339.98 ±24.1		347.35 ±11.1	

Remarks: DCS (Deth Carbon Stock); TSK (Total Carbon Stock).

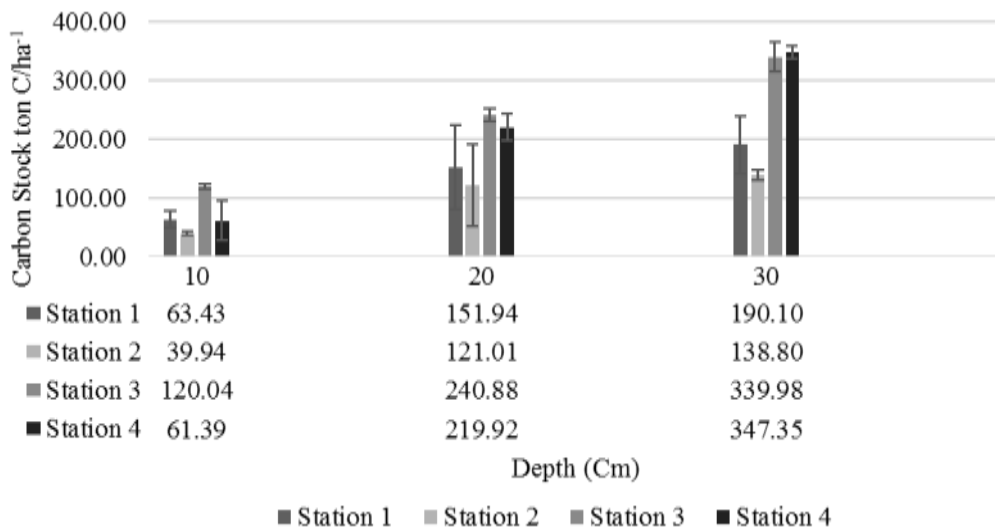


Figure 4. Carbon stock at every sediment depth of mangrove forest Pejarakan Village, Buleleng Regency, Bali.

This shows that the depth affects the carbon stock in the sediment, that the deeper the sediment location, the higher the carbon stock. This result was supported by a statement from Arif *et al.* (2018) that the sediments in the mangrove forest are more likely to store more organic carbon compared to the sediment on the surface itself.

3.3. Total Stock Carbon

3.3.1. Stock Carbon on Mangrove Ecosystem

The total carbon stock from the mangrove forest ecosystem in the study area was obtained by summing the carbon stocks in all carbon sources from the research

results (top surface, litter, and sediment). In Table 10, it is explained that the total carbon stock in the mangrove forest ecosystem is equal to 727.52 tons C ha⁻¹, which is largely contributed by the carbon stock of the sedimentary mangrove ecosystem. This is as stated by Howard *et al.* (2014), that land is indeed more dominant in carbon storage. The condition of each station shows a significant difference, especially at station II which has the lowest carbon stock of 106.52 tons C ha⁻¹. This is because the physical condition of station II is indeed slightly different from the other three stations, where station II has muddy sediment types, but there are also rocky and sandy sediments, as well as the

condition of mangroves with very low density.

3.3.2. Carbon Sequestration and Stock on Various Types of Mangroves

The total carbon stock in each type of mangrove found is obtained by summing the carbon stocks in each type of mangrove from the litter carbon source and living mangrove stands (above the surface) presented in Table 11 below.

From the calculation of carbon stocks in various types of mangroves found in the mangrove forests of Pejarakan Village, Buleleng Regency, Bali, (Figure 5). It is known that *S. alba* has the highest sequestration and carbon stock of 15.71 tons C ha⁻¹ and 57.60 tons C ha⁻¹. Subsequently followed by *R. stylosa* and *R. apiculata*, which were respectively 11.67 tons C ha⁻¹ and 42.80 tons C ha⁻¹ for *R. stylosa*, and *R. apiculata* 9.17 tons C ha⁻¹ and 33.62 tons C ha⁻¹, then *A. marina* species 5.83 tons C ha⁻¹ and 21.37 tons C ha⁻¹, for *C. tagal* of 4.95

tons C ha⁻¹ and 18.16 tons C ha⁻¹, while the species with the lowest total carbon stock were in *O. octodonta* at 1.52 tons C ha⁻¹ and 5.56 tons C ha⁻¹.

These results indicate that *S. alba* is in the highest position of sequestration and carbon stock in the mangrove forest of Pejarakan Village, Buleleng Regency, Bali. Then followed by two types from the Rhizophoraceae family. This is directly proportional to the density value of the mangrove species itself, where the type of *S. alba* is also the species that has the highest density, and also followed by families from Rhizophoraceae. The relationship between mangrove density and sequestration ability or mangrove carbon stock is also justified by research conducted by Irsadi *et al.* (2016), explaining that the density of mangrove trees has a positive correlation with biomass content. This means that the higher the density, the higher the biomass content, the addition of biomass content will be followed by the addition of carbon stocks.

Table 10. Total carbon stock in mangrove ecosystem in Pejarakan Village, Buleleng Regency, Bali.

Carbon Source	St I	St II	St III	St IV
Top of the Surface (ton C ha ⁻¹)	15.86	6.50	18.06	8.51
Litter(ton Cha ⁻¹)	0.069	0.107	0.058	0.097
Sediment (ton C ha ⁻¹)	135.15	99.92	233.63	209.56
TOTAL	151.08	106.52	251.75	218.16

Table 11. Total carbon stock karbon on various types of mangroves.

Types	Above the Surface (ton C ha ⁻¹)	Litter (ton C ha ⁻¹)	TOTAL
<i>R. stylosa</i>	11.67±3.18	0.109±0.010	11.782
<i>O. octodonta</i>	1.52±1.07	0.009±0.006	1.525
<i>S. alba</i>	15.71±1.53	0.025±0.003	15.734
<i>C. tagal</i>	4.95±0.76	0.058±0.012	5.010
<i>A. marina</i>	5.83±1.35	0.030±0.001	5.857
<i>R. apiculata</i>	9.17±2.66	0.101±0.022	9.271

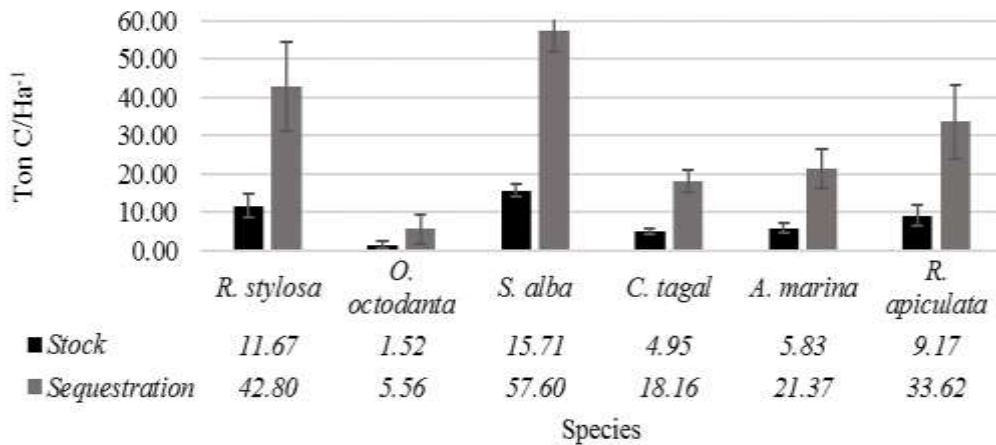


Figure 5. Comparison of sequestration and carbon stock in various types of mangroves in the mangrove forest of Pejarakan Village, Buleleng Regency, Bali.

IV. CONCLUSION

The results showed that of the six mangrove species found in the study area, it was found that the type of *S. alba* is the type that has the highest ability to absorb and store carbon, with carbon absorption and storage values of 57.60 tons C ha⁻¹ and 15.71 tons C ha⁻¹. The estimation of the total value of carbon dioxide uptake of mangrove forests in Pejarakan Village, Buleleng Regency, Bali is 179.11 tons C ha⁻¹, and has a carbon deposit value of 72.52 ton C ha⁻¹, which is sourced from sediments, litter, and living mangrove stands. The extent of the ability of mangroves to absorb carbon dioxide (CO₂) and store it in the form of biomass. To increase the absorption and storage of carbon in the research area, further intensive research is needed on the environmental parameters used for further research using humidity, soil temperature, soil pH and air temperature, because these parameters affect the decomposition process of mangrove litter by bacteria.

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