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Mangrove biomass sequestration in Benoa Bay

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Abstract. Mangrove ecosystems are coastal ecosystems that can store carbon three times higher than all other forests on earth. Current conditions show a decrease in mangrove forests and damage to mangrove ecosystem conditions that impact reducing mangrove carbon sequestration. Data relating to the potential of sustainable mangrove biomass is currently lacking, so research is needed. The purpose of this study was to determine changes in the amount of mangrove biomass at permanent stations temporally. This research was conducted at 10 sample points in the Benoa Bay area using a stratified purposive sampling method with a quadrant transect measuring 10 meters x 10 meters. Data were collected by measuring DBH on each mangrove stand within the transect. Data analysis was conducted using the common allometric equation by including the wood-specific gravity per species. In general, there was an increase in the average biomass in each plot with an average of 1.315 tons/ha at six months different. This shows that the larger the diameter of the stand, the greater the biomass produced.

1 Introduction

Global warming is a form of ecosystem imbalance due to an increase in the earth's average temperature due to an increase in the amount of greenhouse gas emissions [1]. CO_2 emissions have doubled over the last decade from 1,400 million tons/year to 2,900 million tons/year [2]. The increase in carbon emissions is caused by land use change, fossil energy combustion, forest burning, and transportation activities. One of the climate change mitigation efforts can be done by optimizing the role of mangrove ecosystems to absorb CO_2 and store it in biomass [3]. The Indo-Pacific coastal region has only 0.7% forest area but holds 10% of all emissions, including carbon [4].

Mangrove ecosystems are transitional ecosystems between land and ocean that grow in tropical and subtropical coastal areas [5]. Mangrove ecosystems have the ability to store carbon three times greater than all other forests on earth [6]. Over time, the degradation rate

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of mangrove areas continues to increase due to natural and anthropogenic factors. Mangrove areas experience global annual losses ranging from 0.7% - 3% [7]. Indonesia has a mangrove area of 22.6% or 3.1 million ha of the world's mangrove area [8]. However, 1.8 million ha of Indonesia's mangrove area is categorized as degraded [9]. In general, the degradation of mangrove ecosystems in Indonesia tends to be caused by excessive forest utilization, such as for fisheries, industry, agriculture, and logging activities. The condition of the degradation area that continues to occur will affect the potential of mangrove ecosystem services, one of which functions as a carbon sink [10]. Therefore, ecological monitoring of mangrove ecosystems is needed to determine the condition of the ecosystem in a sustainable manner.

Mangroves store carbon in tree biomass, divided into aboveground and belowground biomass, with the highest proportion of tree biomass above ground [11]. 50% of the total biomass is carbon absorbed by plants through photosynthesis [12]. Potential carbon storage can be seen from the value of standing biomass [3]. Several factors influence the level of carbon sequestration. Spatially, the factors that influence the level of carbon sequestration are species composition, biomass, tree diameter, height, density, and canopy cover. Meanwhile, temporally, the factors that affect carbon storage are climate and season [13-14].

Bali has three large mangrove areas, one of which is the Benoa Bay mangrove forest. This mangrove area is located in the center of Bali's business and tourism growth. It is, therefore, vulnerable to environmental degradation due to high anthropogenic activities that continue to increase over time. So far, research in the Benoa Bay mangrove area has been limited to the relationship between mangrove community structure parameters and aboveground carbon storage, natural regeneration of mangrove seedlings, and methane gas concentrations in three mangrove communities [15-17]. Currently, research in the Benoa Bay mangrove area has been limited to the potential for carbon storage in the rehabilitated area [18], organic carbon below the soil surface [19], and the relationship among mangrove stand structure parameters in estimating the community scale of aboveground carbon stock [15]. The results of research in the mangrove rehabilitation area in Kedaburapat Village show that the diameter growth of *Avicennia alba* mangroves ranges from 1.53 - 1.85 cm/month [20] and Muara Angke research shows that the diameter growth of *Sonneratia caseolaris* ranges from 1.75 cm/month to 3.45 cm/month [21]. No research examines changes in mangrove biomass on a temporal scale on an ongoing basis at the same location over a long period. This is interesting to study as an effort to monitor the condition of the mangrove ecosystem, especially on changes in mangrove stand biomass on a certain time scale. The purpose of this study was to determine changes in the amount of mangrove biomass at permanent stations temporally.

2 Materials and methods

2.1 Research area

This research was conducted in the Benoa Bay mangrove area located in two districts, namely Badung Regency and Denpasar City (Fig. 1). This research was conducted in August 2022 - March 2023. Data collection time was divided into two, namely in August 2022 and March 2023, to obtain changes that occurred in the diameter of the stand. Determination of research points using purposive sampling method by considering accessibility.

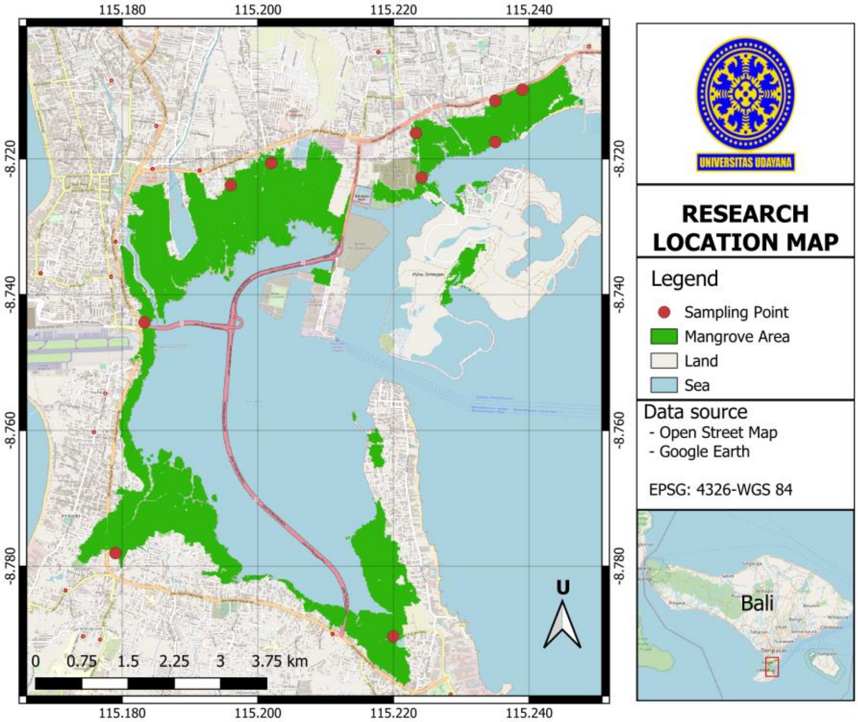

Fig 1. Map of the research area.

2.2 Research Methodology

In determining the sampling location, the indicators to be considered are accessibility and mangrove species that grow. The research site in Benoa Bay was divided into ten permanent points that will be monitored every six months. The coordinates of each data collection point were recorded using GPS (Global Positioning System).

Data were collected on a 10 m x 10 m square plot. Each measured stand was identified based on the identification book [22]. Each measured stand was given a marker at breast height (1.3 m) as a reference in subsequent data collection in the next monitoring. Parameters analyzed included sapling density (diameter < 5 cm with height > 1 m) and tree density (diameter ≥ 5 cm), stand diameter, and canopy cover. Determination of the percentage of canopy cover was carried out using the Hemispherical Photography method. The number of photos taken for determining the percentage of canopy cover was five photos using a 16 MP resolution smartphone camera with an output ratio of 1:1. ImageJ software was used to obtain the percentage of canopy cover. Biomass values were obtained from processing stand diameter data [23].

2.3 Data Analysis

Girth at the breast height of each tree and sapling stand was measured to obtain the chest-high stand diameter (Fig. 2), following Equation 1.

$$DBH = \frac{GBH}{\pi} \quad (1)$$

Where DBH (diameter at breast height) is the diameter of the stand at breast height (cm); GBH (girth at breast height) is the trunk circumference or stem circumference measured at breast height (cm); π is phi (3.14).

Fig 2. Measurement of mangrove Girth at Breast Height (GBH).

The biomass of each stand can be estimated by non-destructive methods using the aboveground common allometric equation 2 [24].

Equations should be centered and numbered with the number on the right-hand side.

$$Wtop = 0.251\ \rho\ D^{2.46} \tag{2}$$

Where W_{top} is mangrove aboveground biomass, D is the diameter at breast height (DBH), and ρ is wood-specific gravity per species.

Univariate data, including tree density, sapling density, percentage canopy cover, stand diameter, and biomass, were analyzed to obtain mean and standard deviation values. The normality of the data distribution was tested using Shapiro-Wilk; variables with an abnormal distribution of data will be transformed according to the condition of the data distribution obtained. After the data is normally distributed, the variance and real difference of the mean of each univariate parameter are analyzed by ANOVA using SPSS.

3 Results and Discussion

At the research site in the Benoa Bay area, six mangrove species were found, including *Sonneratia alba, Bruguiera gymnorhiza, Rhizophora apiculata, Rhizophora mucronata, Xylocarpus granatum,* and *Rhizophora stylosa*. In the first monitoring IVI respectively *Bruguiera gymnorhiza* (IVI: 94.66%), *Rhizophora apiculata* (IVI: 81.49%), *Sonneratia alba* (73.56%), *Rhizophora mucronata* (IVI: 38.01%), *Rhizophora stylosa* (IVI: 6.21%) and *Xylocarpus granatum* (IVI: 6.07%). Monitoring II IVI highest to lowest were respectively *Bruguiera gymnorhiza* (IVI: 90.73%), *Rhizophora apiculata* (IVI: 79.54%), *Sonneratia alba* (IVI: 76.31%), *Rhizophora mucronata* (IVI: 37.09%), *Xylocarpus granatum* (10.69%) and *Rhizophora stylosa* (IVI: 5.66%) (Table 1, Fig. 3). The importance index (IVI) indicates the significance of the species' role in an area [25]. The species found in the monitoring plots are common in the Benoa Bay mangrove area [26]. Areas dominated by *S. alba* tend to have less mangrove species diversity compared to zones dominated by other mangrove species, such as in Plot 1 and Plot 10. This is due to *S. alba,* which can release substances formed from its root system, namely allelopathic substances that can inhibit the growth of surrounding mangrove stands [27-28]. Similar conditions were also found in other studies in Benoa Bay, where mangrove sites dominated by *Sonneratia alba* tend to have the least species diversity [15-17]. In addition, other conditions with similar conditions were also found, such as in the Sancang Forest Waters, West Java [29], and Middleburg-Miossu Island, West Papua [30].

Table 1. Mangrove community structure data in Benoa Bay.

No.	Parameters	Monitoring Results	
		I	II
1.	Tree density (stands/ha)	3,170 ± 1,293	3,570 ± 1,294
2.	Sapling density (stands/ha)	2,260 ± 2,434	2,230 ± 2,409
3.	Total diameter *tree sapling (cm)	9 ± 3.24	9.05 ± 3.84
4.	% Canopy coverage	79 ± 15.08	71.52 ± 20.70
5.	Importance value index (IVI)* tree sapling	SA: 73.56% BG: 94.66% RA: 81.49% RM: 38.01% XG: 6.07% RS: 6.21%	SA: 76.31% BG: 90.73% RA: 79.54% RM: 37.09% XG:10.69% RS: 5.66%

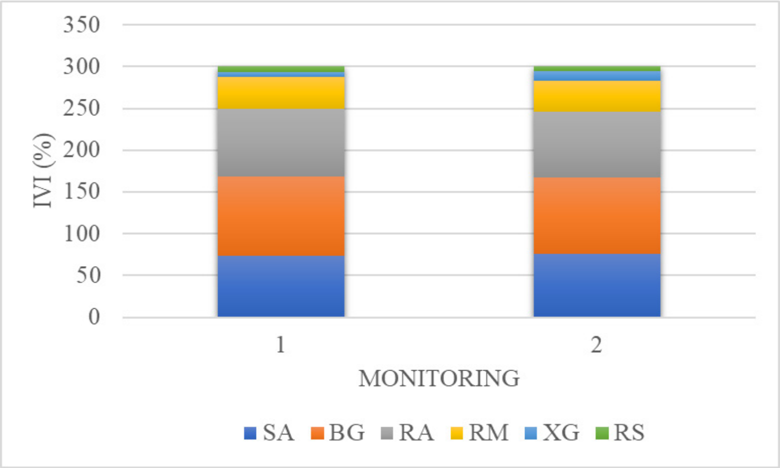

Fig 3. Comparison of Importance Value Indexes (IVI) from each monitoring.

The average tree density in monitoring I was 3,170 ± 1,293 stands/ha; the plot with the highest tree density was Plot 6 at 5,100 stands/ha, and the plot with the lowest tree density was Plot 8 at 900 stands/ha. The average tree density in monitoring II was 3,570 ± 1,294 stands/ha; the highest tree density was in Plot 7 at 5,400 stands/ha, and the lowest was in Plot 8 at 1,400 stands/ha. Tree density in the two monitoring sites did not differ significantly (ANOVA: $p > 0.05$). The tree density found in this study is much higher than the tree density in the Makassar mangrove area of 2,375 stands/ha [31], the mangrove area in Merauke of 1,798 stands/ha [32], and in Wakatobi mangrove area of 2,225 stands/ha [33].

The density of saplings in monitoring I at the research site was 2,260 ± 2,434 stands/ha. The highest density of saplings was found in Plot 8, which was 8,000 stands/ha, while the lowest density of saplings was found in Plot 6 and Plot 9, which was 400 stands/ha. Meanwhile, in the second monitoring, the average density of saplings was 2,230 ± 2,409 stands/ha; the highest density of saplings was found in Plot 8, namely 6,800 stands/ha, and the lowest was found in Plot 1, where no saplings were found. The density of saplings in the two monitors was not significantly different (ANOVA: $p > 0.05$). The sapling density in this study was much higher than the research in Ternate of 731 stands/ha [34].

The average stand diameter in monitoring I was 9 ± 3.24 cm, the highest average diameter was 13.92 cm in Plot I, and the lowest average diameter was 3.06 cm in Plot 8. In monitoring II, the average stand diameter increased ± 0.05 cm, which was 9.05 ± 3.84 cm; the highest average diameter was 16.34 cm in Plot 1, and the lowest average diameter was 3.49 cm in Plot 8. The diameter of the stands in both monitoring did not differ significantly (ANOVA: $p > 0.05$). Zones with low stand density, such as Plot 1, tend to have large stand diameters and vice versa. This is because high density will be related to canopy competence, which impacts lateral growth, namely slow diameter growth [35]. Plot 1, which is dominated by *Sonneratia alba* species, has the lowest total density and the largest average diameter. The same conditions were also found where the area dominated by *Sonneratia alba* species had a low density but had a large stand diameter [32]. The denser the stand, the lower the stand diameter, and vice versa [37].

The percentage of canopy cover in the two monitoring conducted decreased, where in monitoring I, the average canopy cover was 79 ± 15.08%. In monitoring II, the average canopy cover was 71.52 ± 20.70%, a decrease of ± 7.48%. In monitoring I, the plot with the highest percentage of canopy cover was Plot 6 (92.20%), and the lowest percentage of canopy cover was found in Plot 10 (52.44%). Meanwhile, for monitoring II, the highest percentage of canopy cover was found in Plot 4 (89.74%) and the lowest percentage of canopy cover in Plot 10 (31.45%). The percentage of canopy cover in both monitors was not significantly different (ANOVA: $p > 0.05$). The lowest percentage of canopy cover in monitoring I and II was found in Plot 10, dominated by *Sonneratia alba* species. The percentage value of canopy cover tends to be influenced by the species that dominate in an area because it is related to the leaf morphology of the species. The leaf morphology of *Sonneratia alba* is 5-12.5x3-9 cm, which is smaller than the leaf morphology of *Rhizophora mucronata* and *Rhizophora apiculata,* which have leaf morphology of 11-23x5-13 cm and 7-19x3.5-8 cm respectively [35]. In addition, the *Sonneratia alba* species tends to have a spreading crown type of growth so that it has a low canopy cover but a much larger stem diameter than other species [23].

Biomass is the total amount of aboveground living organic matter in trees expressed in units of weight per unit area [12]. When viewed from the comparison of the amount of biomass, the aboveground biomass is greater than the belowground biomass [38]. The biomass calculation uses an allometric equation that refers to the allometric equation [24]. The potential for carbon storage can be seen from the biomass value [3]. Based on the monitoring results, the lowest average biomass for the two monitors was found in plot 8, 46.327 tons/ha, and 59.709 tons/ha, respectively. Meanwhile, the highest biomass for two consecutive monitoring was Plot 6 at 580.375 tons/ha and Plot 1 at 976.534 tons/ha. The average total biomass was higher in monitoring II (421.650 tons/ha) than in monitoring I (341.546 tons/ha) (Table 2). The average increase in biomass value in 6 months in the Benoa Bay mangrove area is 1.315 tons/ha. The biomass value in this study is not significantly different from the average biomass value in 2020 in the mangrove area of Tahura Ngurah Rai, which is 413 tons/ha. [15].

The lowest biomass was found in Plot 8 (Fig.4), which was dominated by sapling stands with a much smaller girth at breast height (GBH) than those dominated by tree stands [35]. Plot 8, with the lowest biomass value compared to other points, had a lower average stand diameter compared to other points. Plot 8 is also dominated by the *Bruguiera gymnorhiza* species, which tends to have a conical crown growth type, so it has a smaller trunk but dense canopy cover [23]. Plot 6 had the highest biomass value in monitoring I, where this plot was dominated by *Rhizophora mucronata* and *Rhizophora apiculata* species. In the research location, plots dominated by *Rhizophora mucronata* and *Rhizophora apiculata* species have higher stand height than other plots. Areas dominated by Rhizophora tend to have higher stand sizes [15]. Comparable to the diameter of the stand, the height of the stand also affects the biomass value, which, along with the growth of the stand, will produce a large biomass value as well [35]. Plot 1 has the highest biomass value compared to other plots because the stands in this plot are dominated by the tree category and have a larger average diameter than other plots. Tree biomass will increase proportionally with an increase in stand diameter [40]. The same condition was also found in previous research, which showed that areas dominated by Sonneratia had higher biomass compared to other areas [15].

Table 2. Biomass calculation in monitoring I and monitoring II.

Plot	Monitoring I				Monitoring II			
	Average of DBH	Wtop (ton/ha)	Average of Wtop (ton/ha)	Average Total Wtop (ton/ha)	Average of DBH	Wtop (ton/ha)	Average of Wtop (ton/ha)	Average Total Wtop (ton/ha)
1	13.919	513.964	23.362	341.546	16.336	976.534	28.722	421.650
2	8.502	312.582	7.624		8.584	352.541	8.199	
2	11.993	519.335	14.794		12.055	556.272	16.361	
4	6.477	252.393	3.411		6.570	326.178	3.883	
5	6.165	218.264	3.578		5.534	229.011	2.974	
6	9.848	580.375	10.552		10.245	623.516	11.764	
7	5.678	245.561	2.728		5.717	311.503	2.967	
8	3.060	46.327	0.521		3.492	59.709	0.728	
9	10.417	327.709	10.571		11.661	338.414	13.016	
10	9.130	398.951	8.866		10.312	442.821	10.543	

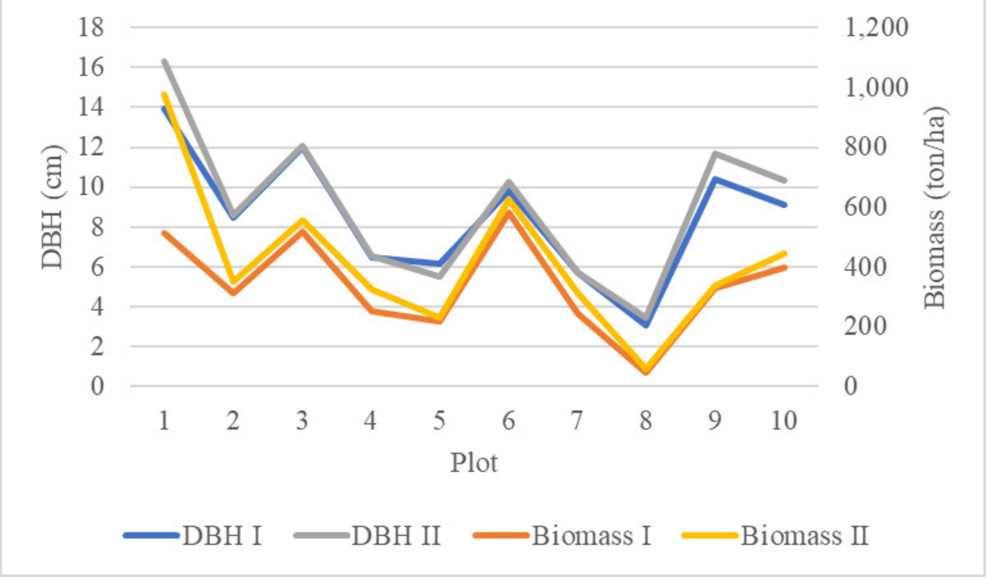

Fig 4. Comparison of DBH and biomass from each monitoring.

4 Conclusions

Common mangrove species found in the study site consist of *Sonneratia alba, Bruguiera gymnorhiza, Rhizophora apiculata, Rhizophora mucronata, Xylocarpus granatum*, and *Rhizophora stylosa*. Based on the monitoring results, a higher average total biomass was found in the second monitoring at 421.650 tons/ha compared to the first monitoring at 341.546 tons/ha. The average 6-month increase in biomass value in the Benoa Bay mangrove area was 1.315 tons/ha. This increase in biomass is directly proportional to the increase in diameter at breast height (DBH).

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