# Estimation of Carbon Potential in Mangrove Vegetation of Bunaken and Manado Tua Islands, Manado City, North Sulawesi Province, Indonesia

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# Estimation of Carbon Potential in Mangrove Vegetation of Bunaken and Manado Tua Islands, Manado City, North Sulawesi Province, Indonesia

Keywords: Mangroves, biomass, carbon, Bunaken

## ABSTRACT

As important ecological functions in coastal areas, mangrove forests maintain the balance of the coastal environment by serving as a carbon absorber and storage. Hence, the research objective is to estimate the carbon stock potential in the mangrove vegetation on the small islands of the Bunaken National Park in Manado City (Bunaken and Manado Tua). The data were collected using a survey and direct observation approach in the field with a sample plot transect method. Sample plots were made to decide the total individuals, species distribution, as well as stem diameter of mangrove trees to estimate biomass value. Analysis on the biomass of the tree used allometric equations, while calculation on the total carbon stock was performed by analyzing the total weight of biomass with a carbon concentration of 47%. The results indicated that the estimated total carbon supply in mangrove vegetation on Bunaken and Manado Tua Islands was 108.27 tons C/ha from a biomass potential of 229.81 tons/ha. This indicated that the mangrove vegetation can absorb carbon of 396.41 tons/ha, with the *Sonneratia alba* species having the highest value in biomass potential, carbon stock, and $CO_2$ absorption.

## INTRODUCTION

Mangroves represent a carbon-dense tropical ecosystem (Donato *et al.*, 2011) that reduces carbon dioxide ($CO_2$) emissions through photosynthesis. During this process, mangroves absorb $CO_2$, convert it into organic carbon (carbohydrates), and store the carbon in biomass stocks, with some also sinking and accumulating in sediment/substrate (Donato *et al.*, 2011). Although relatively small in area, wetlands in coastal areas are also important for global carbon dynamics (Fourqurean *et al.*, 2012). In 2012, it was reported that mangrove ecosystems stored 4.19 billion tons of carbon, in which Papua New Guinea, Brazil, Indonesia, and Malaysia, contributed more than 50% of the global carbon stock from the ecosystems (Hamilton & Friess, 2018). These ecosystems play a crucial role in combating climate shifts caused by global warming by actively participating in the mitigation of $CO_2$ emissions through various sequestration mechanisms. These mechanisms facilitate the absorption of carbon dioxide from the atmosphere and its subsequent storage in different compartments, including vegetation, soil organic material, and waste (Hairiah dan Rahayu., 2007). In the photosynthesis process, $CO_2$ from the atmosphere is captured by vegetation and stored in biomass. Moreover, the amount of biomass in an area is closely related to carbon sinks and is estimated from the measurements of diameter, tall, and density of trees. Biomass and carbon sinks are forest services that exceed other biophysical potentials, which involve their ability to absorb and store carbon to reduce $CO_2$ in the air.

Mangroves absorb and store organic carbon in large amounts in vegetation and deposition biomass, which make them significant natural carbon sinks in coastal areas (Jennerjahn & Ittekkot, 2002; Bouillon *et al.*, 2008). A previous report has shown that mangrove ecosystems can store a moderate carbon stock of 956 Mg C ha−1, higher than peatlands, estuaries, coral reefs, and seagrass beds (Alongi, 2014). Preserving mangrove ecosystems is widely recognized as a valuable approach to mitigating climate change (Murdiyarso et al., 2015). Interestingly, in certain mangrove ecosystems, the concentration of organic carbon in the sediment is predominantly influenced by the root production capacity rather than the amount of leaf litter that falls. Meanwhile, these leaf litters and roots are an important source of organic matter (Chen & Twilley, 1999). The lagging degradation of dead mangrove roots combined with high root production levels is an important process that controls the accumulation of organic carbon in sediments (Robertson & Alongi, 2016). Although mangroves are dynamic ecosystems that cause uncertainty in assessing changes in their area, not all changes are negative (Friess & Webb, 2014). For instance, sediment deposition has led to an increase in the size of mangrove forests in delta systems (Shapiro *et al.*, 2015), and expanded naturally in reaction to climate shift (Friess *et al.*, 2020).

The majority of carbon stock in mangrove forests comes from tropical regions, but these areas also face increasing threats to their ecosystems. Maintaining this carbon stock, air temperature, and annual rainfall are needed for tropical and subtropical mangrove forests (Almahasheer *et al.*, 2017; Sanders *et al.*, 2016; Rovai *et al.*, 2018). Although the largest reduction in mangrove cover is caused by anthropogenic activities (Ong, 1995; Friess *et al.*, 2020), natural aspects such as storms and erosion also contribute to the global degradation of mangrove ecosystems (Thomas *et al.*, 2017). Despite their importance, the sustained degradation of these ecosystems globally has become a focus in recent years (Thomas *et al.*, 2017; FAO & UNEP, 2020; Goldberg *et al.*, 2020;). Since the early 1990s, the global mangrove cover has decreased by about 35% (Thomas *et al.*, 2017), with approximately 60% of degradation between 2000 and 2016 because of human activities such as land conversion for agriculture and aquaculture (Goldberg *et al.*, 2020; Spalding & Leal, 2021). This extensive loss has resulted in the release of approximately 2% of global mangrove carbon between 2000 and 2012, representing a potential maximum of 317 million tons of $CO_2$ emissions. This sustained degradation also contributes to carbon emissions and has significant economic impacts (Hamilton dan Friess, 2018).e

Deforestation refers to the transformation of forested areas into non-forest land, while degradation entails the loss of forests resulting in a decrease in the remaining above-ground biomass (Lund, 2009, 2014, 2015; IPCC 2006). The primary drivers behind the degradation and deforestation of mangroves are excessive exploitation and conversion to alternative land uses such as salt production, aquaculture, and agriculture (Wang et al., 2003; Mangora et al., 2016; Mayunga & Uhinga, 2018). The global deforestation and land use changes in mangrove ecosystems can contribute to approximately 10% of $CO_2$ emissions, which is roughly equivalent to 0.02 - 0.12 Pg C per year (Donato et al., 2011).

The considerable scientific and political focus on carbon stocks in mangroves highlights their potential as a promising strategy for mitigating greenhouse gas emissions. (Cameron *et al.*, 2019; Liu *et al.*, 2014; Schile *et al.*, 2017; Wang *et al.*, 2017; Wang *et al.*, 2013). This is because the conservation and restoration program is the best way to address greenhouse gas emissions. Although the process requires significant energy for prevention, it is the most influential approach to maintaining carbon stock in wetlands (Kauffman *et al.*, 2017).

Bunaken National Park is a representation of tropical aquatic ecosystems in Indonesia, encompassing several ecosystems such as seagrass, mangroves, coral reefs, and other terrestrial ecosystems. Geographically, the park is located in the North Sulawesi Province, with an area of 89,065 hectares, divided into the Northern and Southern parts. For the Northern part, the islands include Manado Tua, Bunaken, Siladen, Mantehage, Nain, and the coastal area of the northern shore, such as Molas, Meras, Tongkaina, and Tiwoho Villages. Meanwhile, the Southern part starts from Poopoh to Popareng Village. The mangrove ecosystems on the small islands of Bunaken National Park cover an area of 748.53 hectares. Bunaken Island has a mangrove area of 79.51 hectares, while Manado Tua has an area of 11.04 hectares. Other islands in Bunaken National Park with mangrove ecosystems are Mantehage and Nain, with areas of 654.84 and 3.14, respectively.

Due to the significant function of mangrove forests in carbon absorption, this research aims to estimate the carbon stock prospect in mangrove forests on the small islands of Bunaken National Park, Manado City, specifically on Bunaken and Manado Tua Islands. The analysis involves the accounting of the potential of aboveground biomass (trees), carbon, and $CO_2$ absorption.

## RESEARCH METHOD

This research was carried out in January 2023 on the small islands of Bunaken National Park, Manado City, namely Bunaken and Manado Tua Islands (Figure 1). There were 4 research stations on Bunaken Island and 2 stations on Manado Tua Island, which were determined based on the area of mangrove forests on each island.

[Figure 1]

### Data Collection Method

The data were collected using a survey approach and direct observation in the field, with a sample plot transect method. At each research position, 3 sample plots calculating 10 x 10 $m^2$ were created with the space between plots adjusted to the size of the mangrove forest. Each plot was placed parallel to the coastline, with a horizontal position to the coastline because the mangrove forest conditions at each station were not too thick or thin. The sample plots were made to determine the number of individuals, species distribution, and stem diameter of mangrove trees to estimate biomass values. The analysis was carried out through an objective assessment based on sample plots placed randomly to estimate the composition of mangrove forests, related structures, and carbon stock. One of the challenges in executing inventories of some mangrove forests was the lack of basic knowledge underlying research. Meanwhile, some investigations used remote sensing to estimate tree biomass through mangrove canopy height and its extent (Feliciano *et al*., 2017; Stringer *et al*., 2015). The humid tropical mangrove ecosystems stored carbon stock in their biomass above and below the ground surface, which was often analyzed through specific allometric equations of each species (Komiyama *et al*., 2008).

The measurement of tree trunk diameter was carried out at breast height (DBH = diameter at breast height = 1.3 m from the ground surface). Subsequently, each trunk was measured using a measuring tape, given a number or mark, and recorded for each species. The measurement was conducted by wrapping the measuring tape around the tree trunk, with the tape positioned parallel to all directions to obtain the circumference of the trunk (IPCC, 2003).

## Data Analysis

Mangrove biomass data were obtained based on tree DBH sizes (diameter at breast height) and entered into allometric equations for each species. The allometric equations utilized in this research was presented in Table 1.

[Table 1]

The carbon stock potential in tree biomass per unit area was converted into tons per hectare. The carbon concentration in organic matter was typically around 46-50%

(Hairiah and Rahayu, 2007; Dharmawan and Siregar, 2008). The estimated total carbon stock was calculated by breeding the total biomass weight with the carbon concentration, as shown in the equation below:

$$\text{Carbon Stock (tons/ha)} = W_{top} \times 0{,}47 \qquad (1)$$

Description:

Wtop = Tree biomass or dry weight (ton)

0,47 = Carbon concentration in organic matter

The allometric method was used to estimate biomass by measuring the diameter of the tree stem at breast height (DBH), located on the research plot. Furthermore, DBH was used as an independent variable in allometric equations that related biomass and DBH as dependent and independent variables, respectively. This method had been widely applied to assess carbon stock in various greenery species in Indonesia (van Noordwijk *et al.,* 2002; Roshetko *et al.,* 2002).

## RESULTS

### Carbon Potential on Bunaken Island

The biomass and estimated carbon stock values of mangrove vegetation in Bunaken Island were calculated. Based on the results presented in Table 2, the most elevated biomass and carbon potential was found in ST1 at 63.38 tons/ha or equivalent to 29.79 tons C/ha, while the lowest was ST4 at only 25.52 tons/ha or 11.99 tons C/ha. The average biomass of mangroves in Bunaken Island was 37.80 tons/ha, with an estimated mean carbon stock of 17.77 tons/ha and the ability to absorb $CO_2$ at 65.20 tons/ha.

[Table 2]

### Carbon Potential in Manado Tua Island

Table 3 showed the analysis for biomass and estimated carbon stock potential of mangrove vegetation in Manado Tua Island The results indicated that the highest biomass and carbon potential was in ST1 at 56.04 tons/ha or equivalent to 26.39 tons C/ha, while the lowest was ST2 at 22.47 tons/ha or 10.56 tons C/ha. The average biomass of mangroves in Manado Tua Island was 39.31 tons/ha, with a carbon stock potential of 18.47 tons C/ha, and the ability to absorb carbon dioxide up to 67.80 tons $CO_2$/ha.

[Table 3]

## Total Biomass, Carbon, and $CO_2$ Potential in the Small Islands of Bunaken National Park at Manado Area

### Biomass Potential

Based on the examination in Figure 2, the total potential biomass of mangrove vegetation in both islands was 229.81 tons/ha, with 151.20 tons/ha in Bunaken and 78.61 tons/ha in Manado. Most of the biomass in mangrove vegetation was carbon, which had the potential to sponge and store carbon. The value of carbon stock in mangrove vegetation was determined based on the formula by Murdiyarso *et al.*, (2015).

[Figure 2]

### Carbon Potential

Figure 3 showed that the total carbon stock potential of mangroves vegetation in both Islands was 108.01 tons C/ha, consisting of 71.06 tons C/ha in Bunaken and 36.95 tons C/ha in Manado Tua. The total of carbon range was affected by the ability of trees to absorb carbon from the conditions through the photosynthesis process, known as sequestration (Hilmi, 2003). The biomass and carbon sink in tropical forests were services provided by forests, as they absorbed and stored carbon to reduce $CO_2$ in the air (Murdiyarso *et al.*, 2015).

[Figure 3]

## $CO_2$ Absorption Potential

Figure 4 showed that the total $CO_2$ absorption potential of mangrove vegetation in Bunaken and Manado Tua islands was 396.41 tons $CO_2$/ha, with 260.81 tons/ha in Bunaken Island and 135.60 tons/ha in Manado Tua Island.

Mangrove ecosystems in coastal areas are very effective and efficient in reducing the $CO_2$ concentration in the atmosphere. This is because they can absorb $CO_2$ through photosynthesis by diffusing through stomata and storing carbon in the form of biomass (Donato *et al.*, 2011).

[Figure 4]

## Carbon Potential in Each Mangrove Species in the Small Islands of Bunaken National Park at Manado Area

The carbon stock potential in each mangrove species in Bunaken and Manado Tua Islands was presented in Table 4. S. Alba species on Bunaken Island had the highest value for each parameter, including biomass, carbon potential, and $CO_2$ absorption potential. The total biomass of S. Alba was 148.42 tons/ha or equivalent to 69.76 tons C/ha, followed by *R. apiculata* at 1.94 tons/ha, *A. officinalis* at 0.77 tons/ha, and the lowest was *R.mucronat*a at 0.07 tons/ha. Meanwhile, on Manado Tua Island, there were only two species, with *S. Alba* having the highest value of 78.50 tons/ha and *R. apiculata* with the lowest at 0.11 tons/ha. The higher carbon stock value of *Sonneratia alba* compared to other species was due to the species having a larger average DBH value of 34.10-40.06 cm. Schile *et al*., (2017) applied the *Avicennia marina* allometric equations in a humid tropical area in Australia to estimate the carbon source of mangrove trees. When compared with Dharmawan and Siregar (2008), the carbon stock value of Avicennia marina in Ciasem Purwakarta, Banten was twice as high as other species. The value of carbon stock in each mangrove species varied based on the calculation coefficients used for each species and tree size (Komiyama *et al*., 2005).

[Table 4]

## DISCUSSION

### Biomass Potential

The results of this research were higher than Bachmid et al. (2020) in the mangrove forest of Sarawet Village, Likupang Timur Sub-district, North Minahasa Regency at 112.55 tons/ha and Suryono *et al*., (2018) in Perancak, Jembrana Bali at 159.46 tons/ha. However, these values were lower compared to those obtained in the Subelen mangrove forest, Siberut, West Sumatra at 49.13 tons/ha or equivalent to 24.56 tons C/ha (Bismark *et al*., 2008). Furthermore, *S. Alba* had the highest value for biomass, which was different from the 364.9 tons/ha found in Ciasem Purwakarta for Avicennia marina, with a DBH range of 6.4-35.2 cm (Dharmawan & Siregar, 2008)

The percentage of carbon stock increased in line with an increase in biomass. This showed that the carbon stock was straight proportionate to the range of biomass, therefore, the more significant the content of biomass, the higher the carbon stock. According to Hairiyah and Rahayu (2007), the carbon concentration in organic matter was typically 47%. This indicated that the carbon stock potential of *Rhizophora stylos*a stands in stems, roots, litter, and necromass was 47% of its biomass potential.

Tree biomass is the amount of organic material produced by each tree through photosynthesis. During the photosynthesis process, $CO_2$ in the air is sponged by plants with the help of sunlight and transformed into carbohydrates, which are distributed throughout the body of the plant and stored in the form of leaves, stems, branches, fruits, and flowers. The difference in biomass acquisition is affected by vegetation density, the diversity of diameter sizes, and the distribution of vegetation density. For example, the use of land consisting of trees with species with high wood density values will have higher biomass compared to land with low values (Hariah & Rahayu, 2007).

The biomass value is also affected by the size of the tree diameter. This indicated that as the diameter of a tree increases, the biomass value becomes greater. The effect of the high stem diameter value on the biomass value of a tree stand was much greater than density. Similarly, Adinugroho, (2001) stated that there is a strong relationship between tree dimensions such as diameter and height, as well as biomass. As a tree stand grows, it will produce a large amount of biomass and carbon stock due to the absorption of $CO_2$ from the atmosphere through the photosynthesis process. This process produces biomass allocated to leaves, branches, stems, and roots, thereby increasing the diameter and height of the tree (Bismark *et al*., 2008). Carbon is absorbed by plants during photosynthesis and nutrients taken from the soil also produce raw materials for growth. The potential biomass of a tree stand increases with age because the diameter of the tree grows through continuous cell division, which slows down at a certain age. This growth occurs in the cambium in the radial direction, forming new cells that increase the stem diameter (Sjostrom, 1998).

### Carbon Potential

The results obtained in this research were higher compared to Bachmid *et al*., 2020 in the mangrove forest of Sarawet Village, East Likupang Sub-district, North Minahasa Regency at 52.90 tons C/ha and Rachmawati *et al*., (2014) in the coastal area of Muara Gembong, Bekasi Regency at 55.35 tons C/ha.

This research found that density had a relationship with biomass, carbon content, and $CO_2$ absorption. This was in line with Satoo and Madgwick in Tresnawan & Rosalina (2002) who stated that stand density is one of the factors influencing biomass. Therefore, a denser stand will have a larger amount of biomass, carbon, and $CO_2$ absorption (Heriyanto & Subiandono, 2012).

The biomass content in a forest was highly dependent on the results obtained during photosynthesis, as well as the age and history of the stand. Each species has a different contribution to the total biomass and carbon stock at each location. The biomass value was calculated by involving 2 parameters, such as density and stem diameter, which affected the size of the biomass. Therefore, the larger the stem diameter of a plant, the higher its biomass value, indicating a positive correlation between the 2 parameters (Suwardi *et al.*, 2013).

$CO_2$ Absorption

The results obtained in this research were higher compared to Bachmid *et al.*, 2020 in the mangrove forest of Sarawet Village, East Likupang, North Minahasa Regency at 194.14 tons of $CO_2$/ha and Sofyan *et al.*, (2016) in the coastal area of Rupat Island, Riau at 251.39 tons of $CO_2$/ha.

The presence of mangrove forests in coastal areas and small islands was highly effective and efficient in reducing $CO_2$ concentration in the atmosphere. This was because mangroves absorbed $CO_2$ through photosynthesis by diffusing through stomata and storing carbon in biomass (Rachmawati *et al.*, 2014).

One of the largest sources of anthropogenic $CO_2$ in the atmosphere was found to be caused by deforestation and forest degradation, followed by the burning of fossil fuels, which account for 8-20% of anthropogenic emissions (van der Werf *et al.*, 2009). This loss of mangroves contributed to the increase in greenhouse gas emissions, where approximately 38% of global mangrove resources are degraded, with a significant reduction in the deforestation rate (Thomas *et al.*, 2017; Hamilton & Friess, 2018). The increase in the degradation and deforestation rate of various mangrove forest reserves in several countries was mostly due to the lack of law enforcement and irresponsible policies on mangrove managing (Semesi, 1992; Mangora, 2011; Monga *et al.*, 2018).

Explicit spatial inventories are needed to manage and protect mangroves to accommodate carbon stock in these ecosystems (Locatelli *et al.*, 2014). According to (Duarte *et al.,* 1999), mangroves and seagrass ecosystems can accumulate carbon stock accumulates over several decades, which makes them crucial for reducing greenhouse gas effects and improving environmental quality. In this research, the data received from the survey results were examined quantitatively by calculating the carbon stock potential using several allometric equations.

The allometric method used in this research had several limitations. These included variations in species characteristics, such as shape and density, which affected the relationship between structural dimensions and biomass. Therefore, the allometric method based on specific species cannot be applied to different species and required specific allometric data for each species. Environmental aspects such as substrate conditions, soil moisture, salinity, and water conditions affected the growth and development of mangroves. This variation influenced the relationship between structural dimensions and biomass, leading to inaccurate estimation when environmental factors were not considered. Furthermore, the method had an inconsistency in the measurements of mangrove structural dimensions such as stem diameter or height. This resulted in differences in the relationship between structural dimensions and biomass, which led to errors in biomass estimation. Another limitation was the difficulty in measuring large mangroves because the allometric method typically measured structural dimensions such as stem diameter. However, some large mangroves might have irregular or bent stems, making it difficult to measure their diameter. The method also only estimated the potential above-ground biomass of mangroves and did not accommodate the ecosystem (Komiyama *et al*., 2008).

## CONCLUSION

The results showed that the estimated total carbon stock in the mangrove vegetation of Bunaken and Manado Tua Islands was 108.01 tons C/ha. The $CO_2$ absorption potential was 396.41 tons $CO_2$/ha and the mangrove species with the highest absorption was *Sonneratia alba* at 69.76 tons C/ha. The mangrove vegetation of Bunaken Island had a greater capacity based on the biomass, carbon, and $CO_2$ absorption potential compared to Manado Tua Island.

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## Tables

**Table 1.** Allometric equations for estimating biomass and carbon in mangroves

| No | Species | Allometric Equations |
|---|---|---|
| 1. | *Rhizophora apiculata* | $Wtop = \rho*0.1848DBH^{2.3524}$, Darmawan *et al*., (2008) |
| 2. | *Rhizophora mucronata* | $Wtop = \rho*0.235DBH^{2.42}$, Ong *et al*., (1993) ; $\rho*k*0.75D^{2.23}$ Hilmi *et al*., (2007) |
| 3. | *Sonneratia alba* | $Wtop = \rho*0.105DBH^{2.68}$, Dmax = 25cm, Clough *et al*., (1992) ; $\rho*k*0.50\ D^{2..32}$ Hilmi *et al*., (2007) |
| 4. | *Avicennia* spp | $Wtop = \rho*0.1848DBH^{2.3524}$, Darmawan *et al*., (2008) |

**Table 2.** The carbon stock potential of mangrove vegetation on Bunaken Island

| **Station** | **Biomass (tons/ha)** | **Carbon Stock (tons C/ha)** | **$CO_2$ Absorption (tons $CO_2$ /ha)** |
|---|---|---|---|
| ST1 | 6338 | 29.79 | 109.33 |
| ST2 | 32.65 | 15.35 | 56.32 |
| ST3 | 29.65 | 13.94 | 51.15 |
| ST4 | 25.52 | 11.99 | 44.01 |
| Average | 37.80 | 17.77 | 65.20 |

**Table 3.** The carbon stock potential of mangrove vegetation on Manado Tua Island

| Station | Biomass (tons/ha) | Carbon Stock (tons C/ha) | $CO_2$ Absorption (tons $CO_2$/ha) |
|---|---|---|---|
| ST1 | 56.04 | 26.39 | 96.85 |
| ST2 | 22.47 | 10.56 | 38.75 |
| Average | 39.31 | 18.47 | 67.80 |

**Table 4.** Carbon stock potential in each mangrove species in the small islands of Bunaken National Park at Manado Area

| **Species** | **Biomass (tons/ha)** | | **Carbon Stock (tons C/ha)** | | **$CO_2$ absorption (tons $CO_2$ /ha)** | |
|---|---|---|---|---|---|---|
| | Bunaken Island | Manado Tua Island | Bunaken Island | Manado Tua Island | Bunaken Island | Manado Tua Island |
| *S. Alba* | 148.42 | 78.50 | 69.76 | 36.90 | 256.01 | 135.41 |
| *R. mucronata* | 0.07 | - | 0.03 | - | 0.12 | - |
| *R. apiculata* | 1.94 | 0.11 | 0.91 | 0.05 | 3.35 | - |
| *A. officinalis* | 0.77 | - | 0.36 | - | 1.32 | 0.19 |

## Figures

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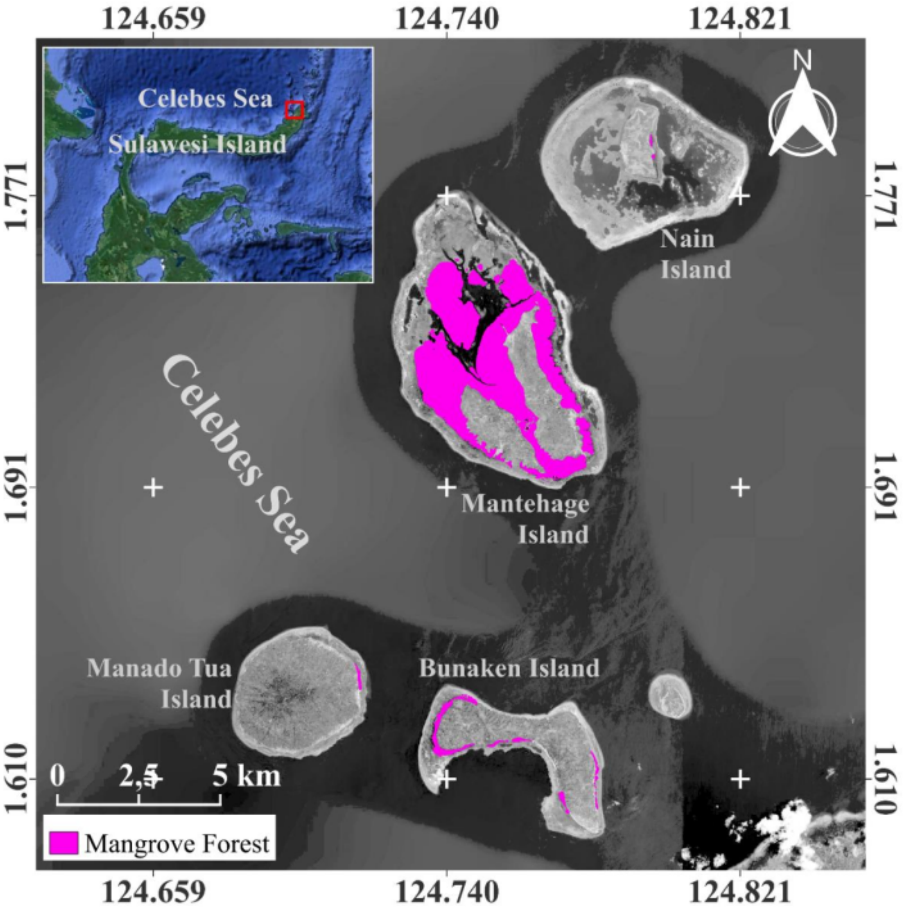

**Figure 1.** Research location of Bunaken and Manado Tua Islands

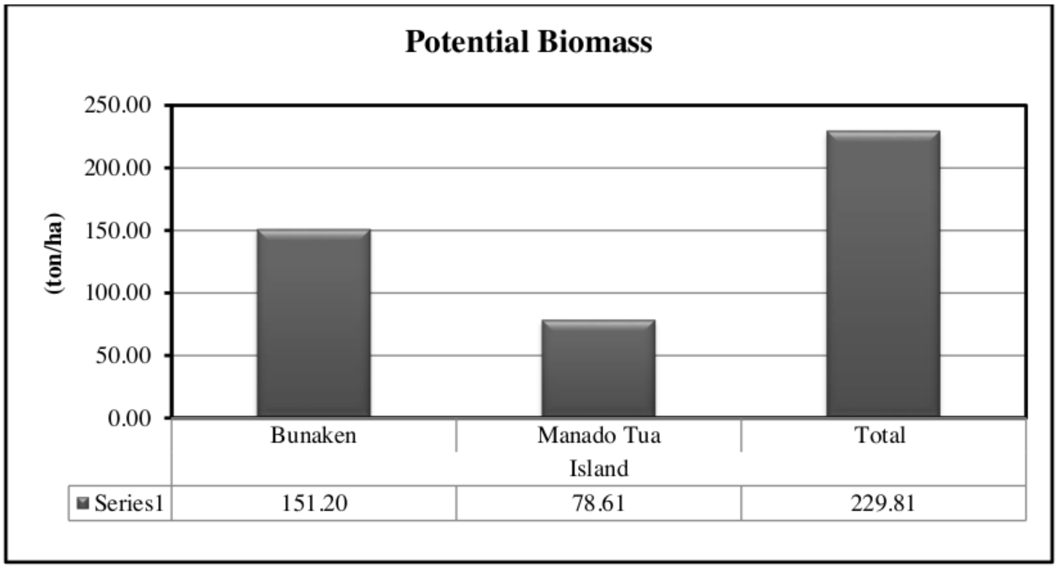

**Figure 2.** Diagram for the potential biomass of mangrove vegetation in the small islands of Bunaken National Park at Manado Area

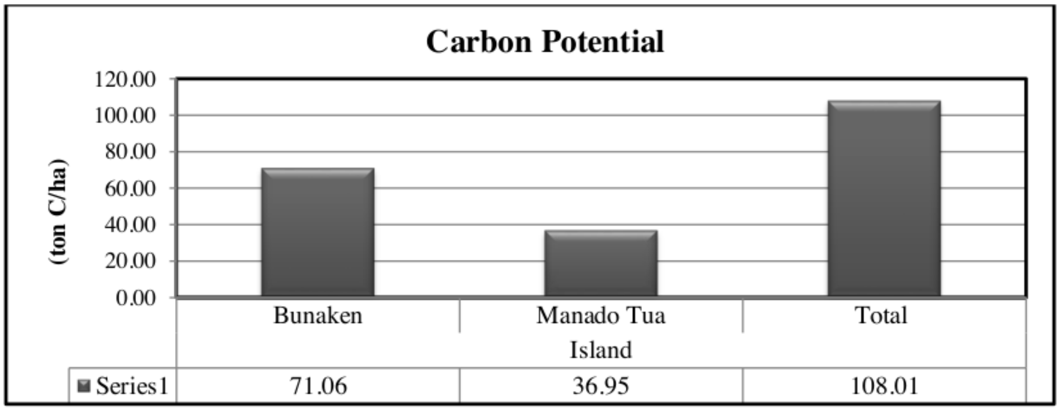

**Figure 3.** Diagram of the carbon stock potential in the small islands of Bunaken National Park at Manado Area

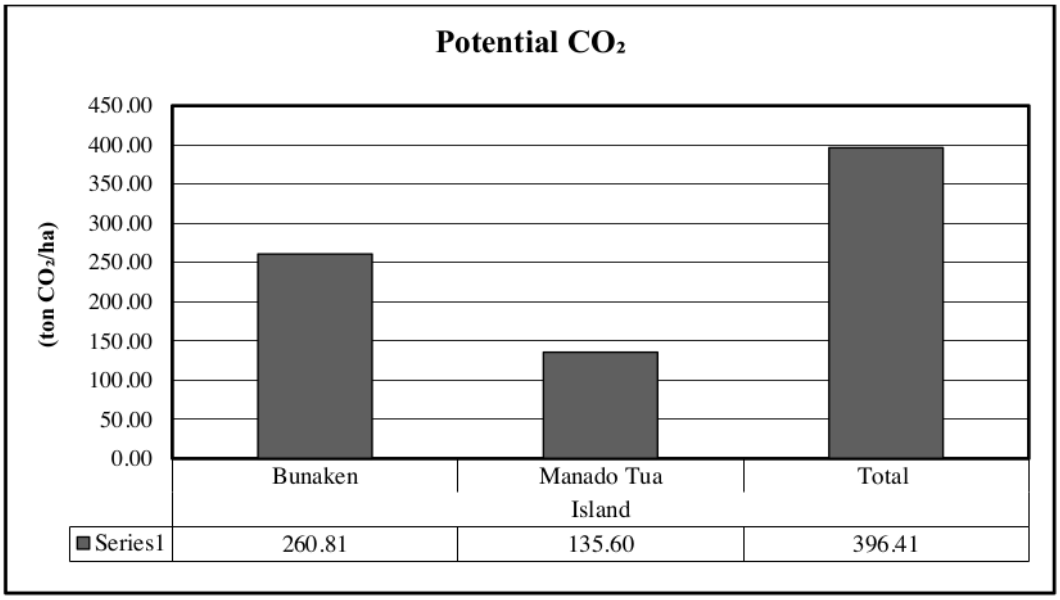

**Figure 4.** Diagram of the $CO_2$ absorption potential in the small islands of Bunaken National Park at Manado Area

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32