Estimation of Carbon Reserves of Seagrass *Enhalus acoroides* in Balikpapan Bay Waters of East Kalimantan Province

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ABSTRACT

The research was conducted from October 2022 – January 2023 in the waters of Balikpapan Bay, East Kalimantan Province. The purpose of this study was to determine the estimated carbon content of seagrass E. acoroides in the Balikpapan Bay Waters. The results showed that the density of E. acoroides ± 501 stands/m^2 belonged to the very tight category. Biomass stored in the waters of Balikpapan Bay is the above substrate part of 592.54 g/m^2, and the biomass in the below substrate part is 1218.57 g/m^2. The estimated carbon storage at the above of the substrate is 264,32 gC/m^2 and the value at the below of the substrate has a carbon value of 608,50 gC/m^2.

INTRODUCTION

Global warming, also known as climate change, is a phenomenon characterized by the increase in the average temperature of the Earth's atmosphere, oceans, and land surfaces (Triana, 2008). Global warming is primarily caused by the escalation of greenhouse gas emissions, with carbon dioxide being a major contributor (Ramadona et al., 2021). According to Rawung (2015), carbon dioxide is the largest contributor to the global warming phenomenon, accounting for more than 75% of the total greenhouse gas emissions. Rachmayanti and Mangkoediharjo (2020) state that carbon dioxide is the most significant contributor to greenhouse gas emissions due to its direct association with human activities that utilize fossil fuels in industrial and transportation sectors.

The phenomenon of global warming has led to unpredictable climate changes, the melting of polar ice resulting in rising sea levels, increased rainfall and flooding, the extinction of several species of flora and fauna, and socioeconomic impacts on communities (Triana, 2008). These effects pose a threat to the sustainability of life in the future. Therefore, there is a need for mitigation of CO_2 emissions, one of which involves utilizing vegetation on land and in the oceans as absorbers and stores of carbon in the form of biomass.

Seagrass meadows are one of the marine ecosystems with significant potential for carbon absorption and storage. The role of seagrasses in carbon sequestration begins with the process of photosynthesis, followed by the storage of captured carbon as biomass (Maramis et al., 2020). Seagrasses can store carbon for millions of years, surpassing tropical forests, which only store it for a few years (Zurba, 2018). Furthermore, seagrass meadows can store carbon 35 times faster than other tropical rainforests (Nellemann et al., 2009). The carbon absorbed and stored as biomass in coastal ecosystems like seagrass meadows is referred to as blue carbon (Aji et al., 2020).

Indonesia boasts a vast expanse of seagrass meadows, totaling 293,464 hectares (Sjafrie et al., 2018). The potential carbon stock stored within these areas is estimated to be around 1,005 kilograms of carbon, with a carbon sequestration potential of approximately 7.4 megatons per hectare (Wahyudi et al., 2020). Meanwhile, in the province of East Kalimantan, specifically in the waters of Balikpapan Bay, the extent of seagrass meadows covers approximately 201.18 hectares (Zulfikar, 2021).

Balikpapan Bay is a small bay located in East Kalimantan, Indonesia, known for its relatively high diversity of seagrass species (Pane et al., 2021). According to Budiarsa et al. (2021), the seagrass meadows in Balikpapan Bay consist of various species, including Halodule, Thalassia, and Enhalus sp. This bay serves as a shipping route for various commodity-carrying vessels and other activities, which poses a potential threat to the seagrass ecosystem. Recognizing the ecological importance of seagrass ecosystems in climate change mitigation efforts and ecosystem stability, this research becomes crucial to ensure that the seagrass meadows in Balikpapan Bay receive adequate attention, care, and proper management from the community.

This research was conducted to estimate the carbon content of seagrass *E. acoroides* in the waters of Balikpapan Bay. Through this study, it is anticipated that valuable information and data about the significant carbon sequestration potential of seagrasses will be provided. This knowledge is crucial for mitigating the impacts of global warming and addressing climate change through the efficient absorption of carbon by seagrass ecosystems.

METHODOLOGY

This research was conducted in the waters of Balikpapan Bay, East Kalimantan Province, from October 2022 to January 2023.

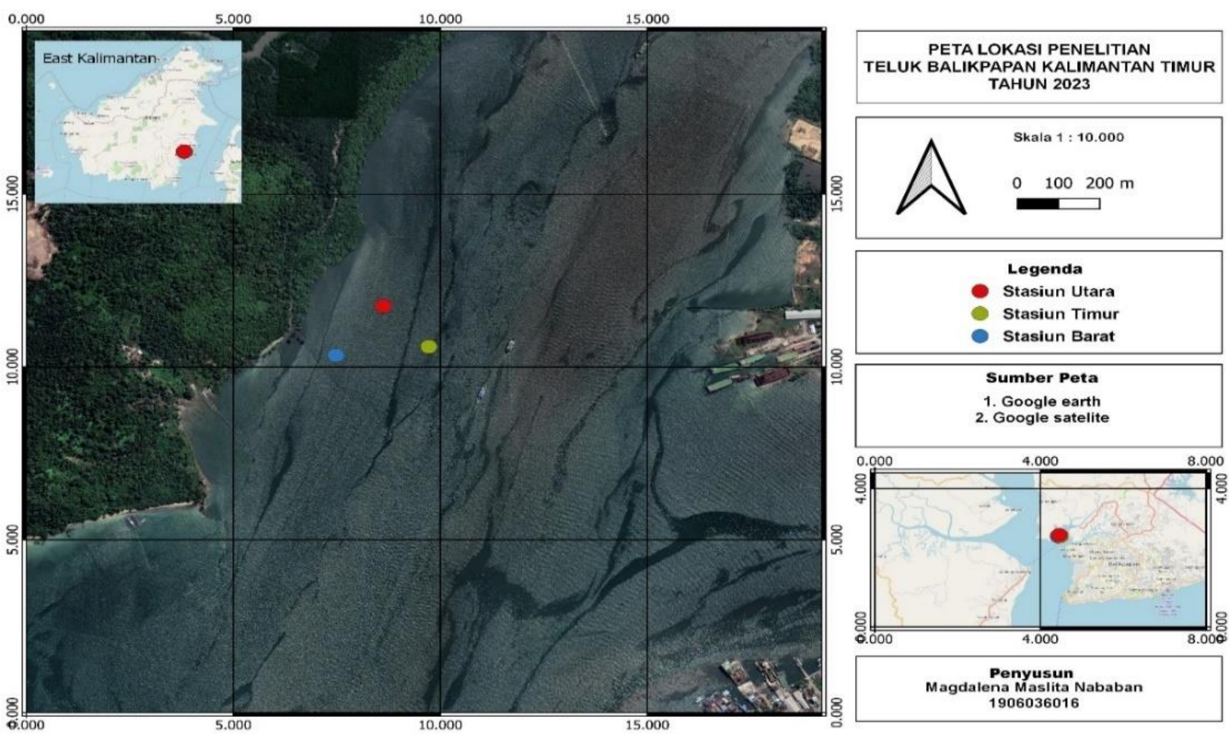

Figure 1. Research Location Map

1. Materials and Research Tools

The materials and tools used in the research are listed in Table 1 and Table 2.

Table 1. Research Materials

Number	Research Materials	Utility
1	*E. acoroides* Sample	As the research subject
2	Water Sample	For measuring water quality parameters
3	Substrate	For observing substrate types

Table 2. Research Tools

Number	Research Tools	Utility
1.	Thermometer	Thermometer for measuring water temperature
2.	DO meter (Dissolved Oxygen meter)	Dissolved Oxygen Meter for measuring dissolved oxygen levels
3.	Refractometer	Salinity Meter for measuring salinity
4.	pH meter	pH Meter for measuring water pH
5.	Plastic bags	Containers for storing seagrass samples for examination
6.	Scoop	Sampling tools for collecting seagrass and substrate samples
7.	GPS (Global Positioning System) device	GPS device for determining location coordinates
8.	Cool box	Sample containers for storage
9.	0.5 x 0.5 m Quadrat frame	Quadrats for estimating seagrass density
10.	Label paper	Tags or labels for identifying collected samples
11.	Writing tools	Field notebook for recording important sampling details
12.	Camera	Camera for documenting research activities
13.	Aluminum foil	Drying trays for air-drying samples before being placed in a muffle furnace
14.	Oven	Drying oven for drying seagrass samples
15.	Analytical balance and digital scale	Weighing scale for measuring sample weight
16.	Desiccator	Cooling rack for cooling samples after removing from the furnace
17.	Porcelain crucible	Sample containers for storage during drying in the muffle furnace
18.	Muffle furnace	Muffle furnace for sample combustion

2. Sampling Technique

Sampling of seagrass is conducted after visual observations and counting of seagrass stands. Visual observations and counting of the number of seagrass species stands at each station are carried out using transect approaches, where each station consists of 3 quadrant transects measuring 0.5 x 0.5 m (English et al., 1994). Subsequently, sampling of *E. acoroides* seagrass biomass is conducted outside the nearest quadrant plots and is expected to represent the existing *E. acoroides* seagrass type within the plot. The collected *E. acoroides* samples include the entire upright structure, from leaves to rhizomes and roots. These samples are then cleaned with freshwater, stored in sample bags, and labeled.

3. Laboratory Analysis

The measurement of seagrass carbon content utilizes the Loss of Ignition (LOI) method, which involves eliminating organic matter through combustion in a furnace. In this research, a furnace is used to combust organic matter, including leaf, rhizome, and root samples from seagrass. This combustion process is performed to determine the ash content in seagrass, which is then analyzed for its stored carbon content.

Before being placed in the furnace, the samples are dried and separated into leaves, rhizomes, and roots. They are then weighed and air-dried at room temperature. After sufficient drying, they are placed in aluminum foil and further dried in an oven at 60°C for 24 hours. Subsequently, they are weighed using an analytical balance. The samples are then homogenized by grinding them in a mortar or using a blender.

For combustion, porcelain crucibles are first sterilized in the furnace at 500ºC for 15 minutes, cooled, weighed, and their weight recorded (weight "a" in grams). The dried and homogenized samples are placed in the porcelain crucibles, weighed (weight "b" in grams), and then subjected to combustion in the furnace at 500ºC for 3 - 6 hours. After combustion, the samples are cooled in a desiccator and then weighed (c grams).

4. Data Analysis

a. Water Quality

The determination of the environmental quality status of seagrass beds refers to Government Regulation No. 22 of 2021 regarding the Implementation of Environmental Protection and Management.

b. Density

Seagrass density, also known as lamun density, refers to the number of shoots of a particular seagrass species per unit area, expressed in shoots m-2 (Graha, 2015). Density signifies the count of individuals of a specific species within a defined area. The calculation of density employs a formula utilized by Supriadi et al. (2014), as follows:

$$D = \frac{\sum Ni}{A}$$

Explanation:
D : Density of the seagrass species i
Ni : Number of shoots
A : Total sampled area (m^2)

c. Biomass

Seagrass biomass is calculated using the equation provided by Duarte et al. (2013) as referenced in Hartati et al. (2017):

$$B = W \times D$$

Explanation:
B : Seagrass biomass ($gram/m^2$)
W : Dry weight of seagrass (gram)
D : Seagrass density ($individuals/m^2$)

d. Seagrass Carbon Content

The carbon content in seagrass can reflect the ability of a seagrass species to capture CO2 from the atmosphere. One of the outcomes is in the form of biomass, both above-ground (Ag) and below-ground (Bg) (Supriadi et al., 2014). The formula used to calculate the carbon content in seagrass tissue using the combustion method can be calculated using the equation provided by Helrich (1990):

$$\text{Ash content} = \frac{c - a}{b - a} \times 100\%$$

Explanation:
a : weight of the crucible
b : weight of the crucible + weight of dried seagrass tissue
c : weight of the crucible + weight of ashed seagrass tissue

The organic matter is calculated using the combustion method, which involves subtracting the weight after combustion from the initial weight, as described by Helrich (1990):

$$\text{Organic matter content} = \frac{[(b - a) - (c - a)]}{(b - a)} \times 100\%$$

Explanation:
a : weight of the crucible
b : weight of the crucible + weight of the sample
c : weight of (crucible + ash)

The value of carbon content in seagrass tissue is calculated using the Helrich equation (1990):

$$\text{Carbon content} = \frac{\text{Organic matter content}}{1{,}724} \times 100\%$$

Explanation
1.724 : constant value for organic matter

The resulting carbon content values are then averaged to obtain the value of seagrass tissue carbon content (Graha, 2015).

e. The estimated seagrass carbon stock value

The carbon stock or carbon reserve of seagrass is calculated by multiplying the biomass with the carbon content for each seagrass type, using the formula as provided by Sulaeman et al. (2005):

$$Ct = \sum (Li \times Ci)$$

Explanation:
Ct : total carbon (tons)
Li : area of seagrass bed for class i (m^2)
Ci : average carbon stock of seagrass for class i (gC/m^2)

RESULT AND DISCUSSION

1. Oceanographic Conditions

In general, the condition of the waters in Balikpapan Bay is considered to meet the standard quality criteria for the survival of seagrass. Below are the results of oceanographic parameter measurements in Balikpapan Bay waters:

Table 3. Water Quality Parameters

Number	Parameter	Station			Average	*Water Quality Standards
		East	North	West		
1	Suhu (°C)	31	32	33	32	28-30
2	Salinitas (‰)	21	20	19	20	33-34
3	pH	8	8	8	8	7-8,5
4	DO (ppm)	7	8	9	8	>5

Source: Processed Primary Data (2023)
* PP No. 22 tahun 2021 (water quality standards for marine organisms)

2. Density

Based on the research conducted in the waters of Balikpapan Bay, two species of seagrass were found: *E. acoroides* and T. hemprichii. *E. acoroides* seagrass is the most widely distributed species in Balikpapan Bay, as it was found in significant numbers at each station. Table 4 shows that at the Northern station, only one species of seagrass, *E. acoroides*, was present with a density of 559 shoots/m^2. At the Eastern station, two species of seagrass were found: *E. acoroides* and T. *hemprichii*, with average densities of 483 shoots/m^2 and 160 shoots/m^2, respectively. Similarly, at the Western station, two species of seagrass were identified: *E. acoroides* with an average density of 460 shoots/m^2 and *T. hemprichii* with an average density of 333 shoots/m^2.

Based on the calculated seagrass densities presented in Table 4, the average density of *E. acoroides* seagrass in Balikpapan Bay is approximately 501 shoots/m^2, while the average density of T. hemprichii seagrass is approximately 164 shoots/m2. Referring to the seagrass density categories according to Rahadiarta et al. (2019), the density value of *E. acoroides* in Balikpapan Bay falls under the category of dense, whereas the average density value of *T. hemprichii* seagrass falls under the category of sparse. Feryatun et al. (2012) explained that seagrass species density is influenced by the growth habitat of the seagrass, salinity, pH, depth, currents, water clarity, and substrate type. The density plays a role in determining seagrass biomass, where higher biomass leads to higher estimates of stored carbon (Nugraha et al., 2016).

Table 4. Seagrass Species Density in Balikpapan Bay Waters

Species	Density (stand/m^2)			Average
	North	East	West	
E. acoroides	559	483	460	**501**
T. hemprichii	0	160	333	**164**
Total	**559**	**643**	**793**	**665**

Based on Figure 2, the dominant seagrass species in the waters of Balikpapan Bay is *E. acoroides*. This seagrass species constitutes up to 75% of the total stands, while the remaining 25% consists of T. hemprichii seagrass. A study conducted by Khairunnisa et al. (2018) also found that *E. acoroides* is the most abundant seagrass species along the East Coast of Bintan Regency, Riau Islands. This is due to its adaptability to various substrate types and its larger size and morphology compared to other species, enabling it to thrive in diverse conditions.

3. Biomass

Estimation of *E. acoroides* biomass is divided into two groups: above-ground biomass (ag) and below-ground biomass (bg). Above-ground biomass includes leaves, sheaths, and vertical stems, while below-ground biomass consists of roots and rhizomes (Fourqurean et al., 2014).

Based on the calculated *E. acoroides* biomass presented in Table 5, it can be observed that the Northern station has the highest total biomass value, which is 2,152.19 g/m^2, comprising 735.04 g/m^2 above-ground biomass and 1,417.15 g/m^2 below-ground biomass. The Eastern station has the second-highest total biomass value, which is 1,815.35 g/m^2, consisting of 628.08 g/m2 above-ground biomass and 1,187.27 g/m^2 below-ground biomass. Meanwhile, the Western station has the lowest total biomass value, which is 1,465.77 g/m^2, with 414.48 g/m^2 above-ground biomass and 1,051.29 g/m^2 below-ground biomass.

Table 5. Average Seagrass Biomass (g/m^2)

Stations	Biomass of *E. acoroides* Seagrass		
	Ag (g/m^2)	Bg (g/m^2)	Ag + Bg (g/m^2)
North	735,04	1.417,15	2.152,19
East	628,08	1.187,27	1.815,35
West	414,48	1.051,29	1.465,77

Source: Processed primary data (2023)

Caption: Explanation: Ag = above ground; Bg = below ground

The calculation results indicate that the biomass of *E. acoroides* seagrass in the Northern station is higher than in the other stations. This difference is due to the larger morphology of the *E. acoroides* species in the Northern station compared to the Eastern and Western stations. Additionally, the density value of *E. acoroide*s in the Northern station is also higher than in the other stations. The calculated density and biomass results in this study show a directly proportional relationship, where the station with higher density, which is the Northern station, also has a higher biomass value compared to the other stations. This is in line with the perspective of Phillips and Milchakova (2015), who observed that seagrass density is directly proportional to biomass value.

In general, the range of above-ground biomass of *E. acoroides* seagrass in the Balikpapan Bay seagrass bed is between 414.48 - 735.04 g/m^2, with an average of 592.54 g/m^2. The range of below-ground biomass of *E. acoroides* seagrass is between 1,051.29 - 1,417.15 g/m^2, with an average of 1,218.57 g/m^2. The analysis results in Figure 3 show a difference in biomass values between the above-ground and below-ground parts of the seagrass. The below-ground part of *E. acoroides* (rhizome and roots) has higher biomass compared to the above-ground part. This finding is similar to the research conducted by Bagu et al. (2020) in the Langala Dulupi Beach area of Boalemo Regency, where they found that the below-ground biomass of seagrass had the highest value compared to the above-ground part in the two researched stations. The researchers mentioned that this was influenced by the morphology size of the rhizomes and roots of the seagrass. Rhizomes are seagrass tissues with larger morphology, which leads to higher biomass compared to other tissues (Ningrum et al., 2020). Tasabaramo et al. (2015) stated that the high biomass storage in the below-ground part is due to the fact that roots absorb nutrients from sediments, and a significant portion of the organic material produced through photosynthesis is stored in the below-ground substrate.

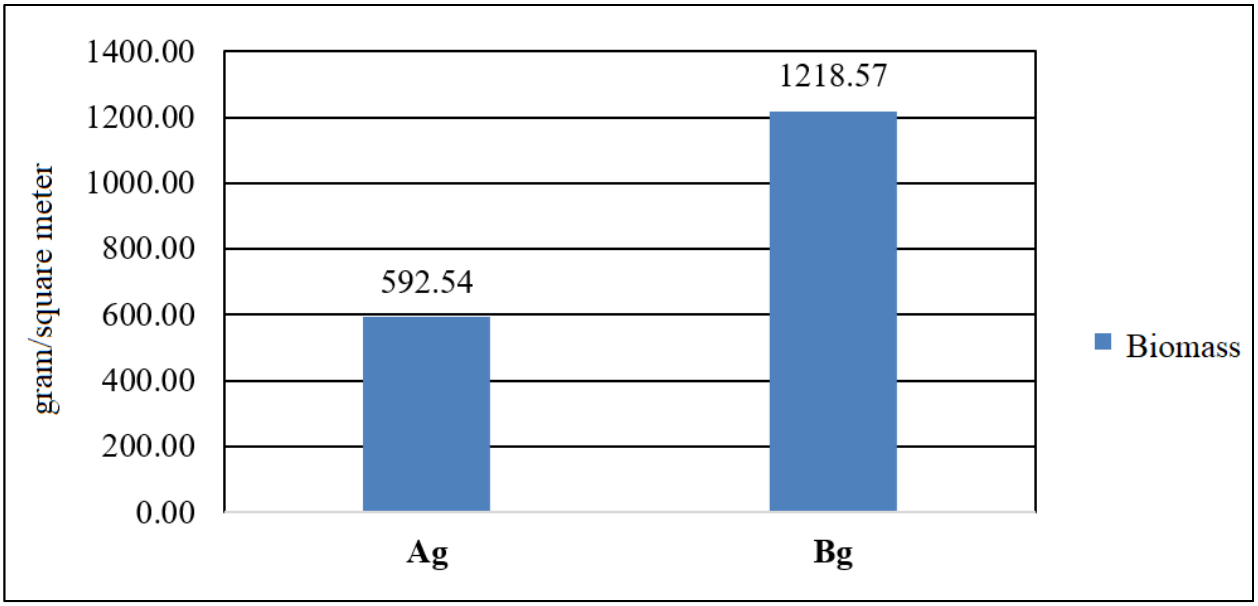

Figure 3. Biomass of Seagrass Above and Below Ground
Caption: Ag = above ground; Bg = below ground

4. Estimation of Carbon in *Enhalus acoroides*

The estimated carbon reserves of *E. acoroides* in Balikpapan Bay waters are higher at the Northern station compared to other stations. The carbon content at the Northern station is 328.28 gC/m^2 in the above ground substrate and 702.73 gC/m2 in the below ground substrate. The carbon content at the Eastern station is 284.56 gC/m^2 in the above ground substrate and 591.21 gC/m^2 in the below ground substrate. Meanwhile, the carbon content at the Western station is 180.11 gC/m^2 in the above ground substrate and 531.55 gC/m^2 in the below ground substrate. The variation in carbon content estimation is influenced by several factors such as the amount of lamun biomass, environmental factors like temperature, and substrate type (Hartati et al., 2017).

Table 6. Estimation of Carbon Reserves in *E. acoroides* (g C/m2)

Station	Carbon Stock Estimation of Seagrass *E. acoroides*		
	Ag (g C/m²)	Bg (g C/m²)	Ag + Bg (g C/m²)
North	328,28	702,73	1031,01
East	284,56	591,21	875,78
West	180,11	531,55	711,66
Average	**264,32**	**608,50**	**872,81**

Source: Processed primary data (2023)
Caption: Explanation: Ag = above ground; Bg = below ground

The carbon content in seagrasses is influenced by inter-species or inter-tissue biomass variations (Graha, 2015). Table 6 indicates that in the waters of Balikpapan Bay, the carbon content at the bottom substrate is higher compared to the upper part. Generally, the total carbon content estimation of *E. acoroides* in the waters of Balikpapan Bay is 264.32 gC/m^2 for the upper part and 608.50 gC/m^2 for the bottom part. In line with the study conducted by Aji et al. (2020) on Nyamuk Island and Kemujan Island, the results obtained on Nyamuk Island (Station 1) show that the average weight of carbon in sub-sediment biomass is about 4.3 times larger than the biomass above the sediment. Furthermore, Supriadi et al. (2014) emphasize that below-ground carbon significantly contributes to the total carbon stock of seagrass biomass, averaging 76.3%, ranging from 74.2% to 78.9%. Above-ground carbon contributes an average of 23.7%, ranging from

21.1% to 25.8%. According to Graha (2015), the carbon content in seagrasses is closely related to the magnitude of the biomass value. Similarly, Yuniawati (2014) states that the higher the biomass content, the higher the carbon content as well. The high carbon reserves of *E. acoroides* in Padang Lamun, Balikpapan Bay, indicate that *E. acoroides* in the waters of Balikpapan Bay has significant potential for carbon absorption and storage.

CONCLUSION

The stored biomass in *E. acoroides* within the waters of Balikpapan Bay is 592.54 g/m^2 for the upper substrate and 1218.57 g/m^2 for the lower substrate. The estimated carbon stock of *E. acoroides* seagrass on the upper substrate is 264.32 gC/m^2, while the value for the lower substrate indicates a carbon content of 608.50 gC/m^2.

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