International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Multi-Temporal Spatial Analysis of Mangorve Carbon and Land Change in the Wulan Delta, Demak Regency

Fiyan Triadi Kurniawan [a], Suryanti Suryanti [a], Sigit Febrianto[a]*

[a] *Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro*
Jl. Prof. Soedarto, SH. Tembalang, Semarang 50275 Indonesia
Email : sigitfebrianto40@lecturer.undip.ac.id
DOI: https://doi.org/10.55248/gengpi.5.0324.0733

A B S T R A C T

Mangrove ecosystems play a crucial role in life, including as a carbon sink in nature, thus contributing to climate change mitigation, high wave buffering, and abrasion and accretion control on the coast. This study aims to determine the carbon sequestration capacity and area change of mangroves from 2017 to 2022. The research was conducted in June 2023 in the Wulan Delta in Menco Village, Wedung District, Demak Regency. The method used was purposive sampling at 3 stations by identifying mangroves, measuring Diameter Breast High (DBH), taking sediment, measuring the physical and chemical properties of mangrove sediment, and spatial data of Landsat 8 satellite imagery. Carbon analysis used the allometric equation to calculate carbon stock in mangrove trees and stands, then for sediment using the Loss On Ignition (LOI) method, and satellite imagery analysis was processed using ArcMap 10.3. The results obtained were that the CO_2 separation value was 733.86 - 886.19 tons CO_2/ha. The spatial area in 2017, 2019, 2020, and 2022 was 1,003.93, 852.38, 853.25, and 935.29 hectares. The change in mangrove area in the Wulan Delta experienced changes every year due to abrasion in 2017 and 2019, while in 2020 to 2022 there was an increase due to replanting by the community and natural growth.

Keywords: Biomass; Wulan Delta; Landsat 8; Mangrove Carbon Stock; Remote Sensing

1. Introduction

Mangrove ecosystems are one of the forest ecosystems that have unique characteristics and can grow in coastal areas or river estuaries that have tides. (Prasetyo et al., 2017). The benefits of mangrove ecosystems that play a role in the environment include carbon storage, which can have an impact on preventing global warming (Dinilhuda et al., 2018). The ability of mangrove ecosystems to prevent global warming includes absorbing carbon dioxide and storing it in the form of biomass and sediment. The benefits of mangrove biomass and sediment lie in their ability as carbon absorbers and sinks, which can reduce the concentration of carbon dioxide in the air through the sequestration process. This process involves absorbing carbon from the atmosphere and storing it in the form of biomass (Rahman et al., 2017)

Carbon is related to standing biomass. Estimates of biomass in an area are obtained by calculating biomass production and density which is adjusted based on measurements of tree diameter, height and specific gravity (Rachmawati et al., 2014). The amount of biomass in mangrove forests is greatly influenced by climatic conditions such as rainfall and air temperature. The amount of biomass in the mangrove forest will influence the amount of carbon stored. Mangrove forests store carbon in four carbon pools, namely above-ground biomass (*Above ground biomass*), subsurface biomass (*Below ground biomass*), dead organic matter, and soil organic carbon. Upper biomass in mangroves is stored in the stems, leaves, branches and all parts of the mangrove above the ground surface. The lower part of the mangrove contributes the most to absorbing and storing carbon, namely sediment, this is because a lot of organic material is stored in it. (Pratiwi et al. 2023).

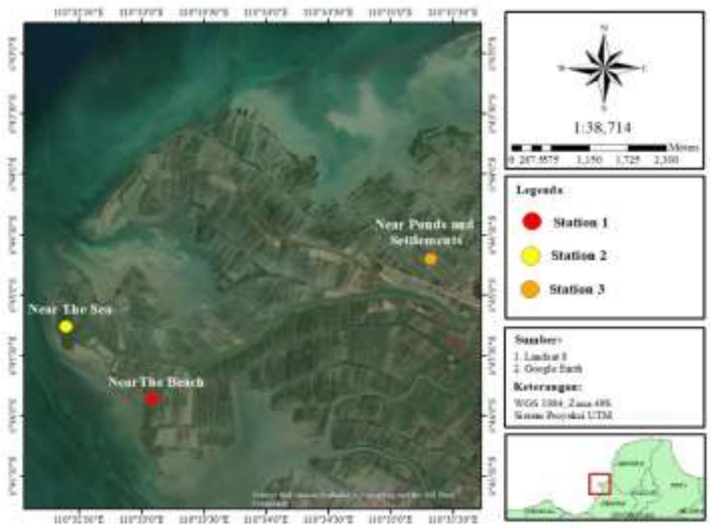
The area of mangrove forests in Indonesia is decreasing every year, almost 40% of mangrove forests in Indonesia have been damaged. Damage to the mangrove ecosystem can cause weak defenses on land areas in Demak Regency, especially in coastal areas, which are caused by factors such as tides, waves, currents, and wind. Demak Regency is one of the coastal areas on the north coast of Java that has a fairly extensive mangrove ecosystem, one of the mangrove areas in Demak Regency is the Wulan Delta, which is located at the headwaters of the Wulan River in Wedung District, Demak Regency, which has a forest. mangroves which have a significant area.

The Wulan Delta is an area adjacent to an industrial area that produces high carbon emissions which have the potential to pollute the surrounding environment. In addition, the Wulan Delta often experiences sea tides which can cause sea levels to overflow. Apart from that, in the Wulan Delta area, abrasion and accretion often occur. This can raise concerns regarding the decline in the role of mangroves in carbon absorption productivity. Therefore, to determine the carbon stock and carbon absorption capacity of mangroves in the Wulan Delta, considering the important role of mangroves in absorbing global carbon and providing other ecosystem services, as well as their vulnerability to changes in land use, it is important to estimate the carbon stock in the mangrove ecosystem. Based on this, it is hoped that this research location can provide more information regarding supporting data for mangrove rehabilitation efforts in Dela Wulan.

2. Materials and Methods

2.1 Location

The research was carried out from June 2023 to August 2023 in Menco Village, Wedung District, Demak Regency, Central Java Province. The research location map is presented in Figure 1.



The method used in this research is method*survey*. Method*survey* is a method that carries out observations and sampling directly in the field. Data were collected using a purposive sampling method carried out at 3 stations ((Apriliana et al. 2021)). These considerations include station 1, which is in an area close to the coast which has a high density and area of mangroves. station 2 is located in an area close to the sea with a high mangrove density, while station 3 is located in a pond area behind a settlement with a low mangrove density

2.2 Tools and materials

The tools used in this research to collect trunk diameter data from tree circumference, mangrove sediment and environmental parameters at each station are sediment core modification, soil pH test, refractometer, GPS, camera, digital scale, quadrant transect, roller meter, sewing meter, zipper, mangrove identification book and stationery.

Retrieval of image data for the Wulan Delta region was obtained using satellite image data from Landsat 8 for the time period 2017, 2019, 2020 and 2022 which was sourced from Landsat 8 with the website address*https://earthexplorer.usgs.gov/*. The data is then opened and processed using the ArcMap 10.3 application and then overlaid.

2.3 Community Structure

Analyze the structure of the mangrove community by making a sample plot measuring 10x10m for the tree category, within this plot a sub-plot measuring 5x5m for the sapling category is created. The data is then processed to obtain the structure of the mangrove community by calculating the values for Species Density (Di), Species Relative Density (RDi), Species Frequency (Fi), Species Relative Frequency (RFi), Species Dominance (Ci), Species Relative Dominance (RCi) and important value index (INP). The explanation of the calculation above is as follows:

1) The Importance Value Index (INP) is useful for providing an overview of the influence or role of a species in a community

$$INP = RDi + RFi + RCi \quad (1)$$

Information :

INP = Important value index

RDi = Relative density of species

RFi = Relative frequency of type

RCi = Relative dominance of type

2.4 Biomass, Carbon Stock and Mangrove Carbon Uptake

Analysis of measurements on mangrove biomass using the method*non-destructive* by making five sample plots measuring 10x10m for inventory of trunk diameter and number of tree categories, within these plots a sub-plot measuring 5x5m was created for the sapling category at each station. Standing biomass measurements are carried out using data*Diameter Breast Height* (DBH) diameter at breast height or approximately 1.3 m from the ground surface obtained from the stand circumference measurement using a sewing meter. Biomass calculations include the DBH value in the equation formula*allometric* to obtain biomass values for mangrove vegetation species which are then converted to obtain carbon stock values. Equation formula*allometric* on mangrove vegetation both above the surface and below the surface which is presented in table 1 as follows (Suryono et al. 2018).

Table 1 - *Allometric Above Ground Biomass* and*Below Ground Biomass* Mangrove

No.	Mangrove Species	AGB		BGB	
		Model *Allometrik*	Reference	Model *Allometrik*	Reference
1.	*Avicennia marina*	$B = 0{,}1848xD^{2{,}3524}$	Dharmawan and Siregar, 2008	$B = 1{,}28xD^{1{,}17}$	Komiyama *et al*., 2008
2.	*Rhizopora apiculata*	$B = 0{,}043xD^{2{,}63}$	Amira, 2008	$B = 0{,}00698xD^{2{,}15}$	Ong *et al*., 2004
3.	*Rhizopora mucronate*	$B = 0{,}1466xD^{2{,}3136}$	Dharmawan, 2013	$B = 0{,}00698xDBH^{2{,}61}$	Kauffman and Cole, 2010

Carbon stock analysis in mangrove vegetation can be obtained from biomass estimates. According to Howard et al (2014) the estimated amount of carbon stored for biomass above the surface can be calculated using the following formula

Above Ground Biomass = biomass x 0.46 (2)

Apart from that, estimating the carbon stock stored below the surface can be calculated using a formula

Blow Ground Biomass = Biomass x 0.39 (3)

The carbon stock calculation obtained can determine the value of carbon dioxide absorption by each mangrove species using the formula

$$Carbon\ dioxide\ uptake = \frac{Mr.CO_2}{ArC} x stok\ carbon \quad (4)$$

Information :

Mr CO2 = Molecular weight of compound (44)

Ar C = Atomic number C (12)

2.5 Sedimentary Carbon Stock

Sediment sampling was taken at a depth of 10 cm. The value of carbon stock in sediment can be calculated using the following equation

Soil C = Bulk density x soil deep interval x % C (5)

Information :

Soil C = Estimated carbon savings

Bulk density $= \left(\frac{time\ dry\ weight\ (g)}{volume\ sampel\ (m^3)}\right)$

Soil deep interval = sample depth interval

%C = presentase carbon $\left(\frac{1}{1{,}724}\ x\ \%BO\right)$

2.6 Normalize Difference Vagetation Index (NDVI)

NDVI is based on using reflections from remote sensing objects in the red and near infrared spectrum, namely for Landsat 8 it is*band* 5 and*band* 4 (Ratuamkin et al. 2023)

$$NDVI = \frac{NIR-R}{NIR+R} \quad (6)$$

Information:

NDVI = *Normalize Difference Vagetation Index*

R = digital value in the red channel of interest (*Band* 4)

NIR = Digital value in the near infrared channel image (*Band* 5)

2.7 Carbon Stock in Mangrove Areas

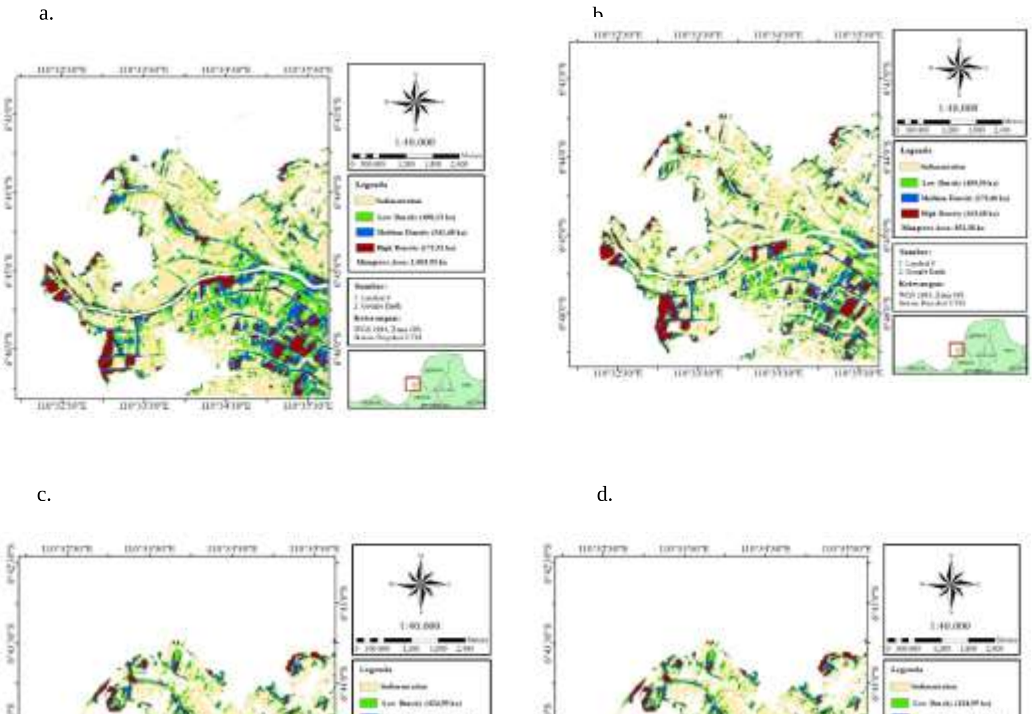
The equation for determining spatial estimates of mangrove carbon stocks in an area uses the following equation (Singh et al., 2023)

$$\text{Total Carbon Stock in Mangrove Area (Mg)} = \text{Total Carbon (Mg ha}^{-1}\text{)} \times \text{Area (ha)} \quad (7)$$

3. Results

3.1 Changes in Mangrove Area

Based on the results of data processing using Normalize Difference Vagetation Index (NDVI) analysis on Landsat 8 satellite images for 2017, 2019, 2020 and 2022, the changes in mangrove area in the Wulan Delta are as follows



Picture 1 - (a) Map of Changes in Mangrove Area in 2017; (b) Map of Changes in Mangrove Area in 2019; (c) Map of Changes in Mangrove Area in 2020; (d) Map of Changes in Mangrove Area in 2022

Based on the results of these calculations, the mangrove area in the Wulan Delta from year to year shows a decrease and increase in mangrove area. Based on the NDVI classification in 2017, 2019, 2020 and 2022, the areas obtained were 1,003.93, 852.38, 853.25 and 935.29 ha.

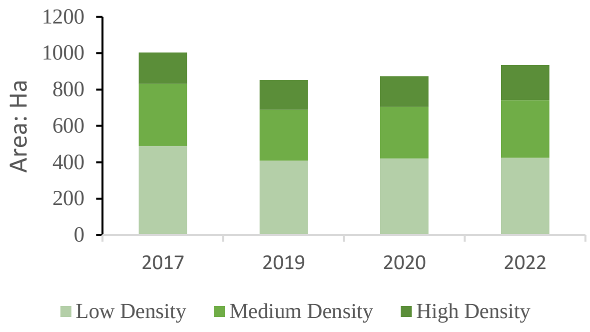


Figure 2 - Changes in Mangrove Area in 2017, 2019, 2020, and 2022

3.2 Mangrove Community Structure

Based on table 2, the results of calculating the Important Value Index (INP) of trees from the three mangrove species found at the research location show that the species*Avicennia marina* has the highest average INP value from the three research stations ranging from 21.84 – 297.18. The lowest INP value is found in species*Rhizopora mucronata* with a range of 2.82 – 42.94. The results of calculating INP values for mangrove stand types in the Wulan Delta, it was found that species*Rhizopora mucronata* has a higher INP value, namely with values ranging from 37.57 – 279.31. Meanwhile, the lowest INP value is found in species*Rhizopora apiculata* with a value range of 199.38 at station 3.

Table 2 - *Results of Calculation of Important Value Index (INP) for Trees and Stands*

Station	Species Name	Tree				Stand			
		KR	FR	DR	INP	KR	FR	DR	INP
I	*Avicennia marina*	98,85	98,85	99,48	297,18	73,17	73,17	78,71	225,05
	Rhizopora mucronata	1,15	1,15	0,52	2,82	26,83	26,83	21,29	74,95
	Rhizopora apiculata	-	-	-	-	-	-	-	-
II	*Avicennia marina*	76,47	76,47	71,7	224,64	5	5	10,69	20,69
	Rhizopora mucronata	13,24	13,24	16,47	42,94	95	95	89,31	279,31
	Rhizopora apiculata	10,29	10,29	11,83	32,42	-	-	-	-
III	*Avicennia marina*	6,82	6,82	8,2	21,84	30	39	3,05	63,05
	Rhizopora mucronata	13,64	13,64	12,76	40,03	10	19	17,57	37,57
	Rhizopora apiculata	79,55	79,55	79,04	238,13	60	60	79,38	199,38

3.3 Mangrove Biomass and Carbon Stock

The biomass value is obtained from using equation a*llometric* with tree diameter as the main data. The biomass obtained is divided into 2, namely*above ground biomass* and*bellow ground biomass*. The results of analysis of above-ground mangrove biomass data for each species whose allometric equations are known in the Wulan Delta mangrove area show that the highest above-ground mangrove biomass yield is at station 2 with a value of 52.65 tonnes/ha, while the lowest value of tree biomass content is at station 3 with a value of 6.47 tons/ha. Meanwhile, below ground mangrove biomass data for each species whose allometric equations in the mangrove area are known, it is known that the highest biomass yield is at station 1 with a value of 40.32 tonnes/ha, while the lowest value of mangrove biomass content is at station 3 with a value of 1.52 tonnes/ha.

Based on the results of analysis of mangrove carbon data, the carbon stock value consists of carbon stock above the surface and below the surface which is the result of the conversion of biomass yield multiplied by 0.46 for carbon above the surface and 0.39 for carbon below the surface of mangroves with a fixed carbon value. The results of analysis of mangrove carbon data show that the carbon stock value at the top of the surface is higher than the value at the bottom of the surface. The highest value at the top of the soil surface is at station 2 with a carbon value of 24.22 tonnes/ha. Meanwhile, the lowest carbon value was at station 3 with a carbon value of 2.98 tons/ha. The highest carbon value in the subsurface part of the soil is at station 1 with a value of 18.55 tonnes/ha, while the lowest value is at station 3 with a value of 0.70 tonnes/ha. The results of the estimated biomass and carbon stock values for mangroves in the Wulan Delta area can be seen in Figure 2

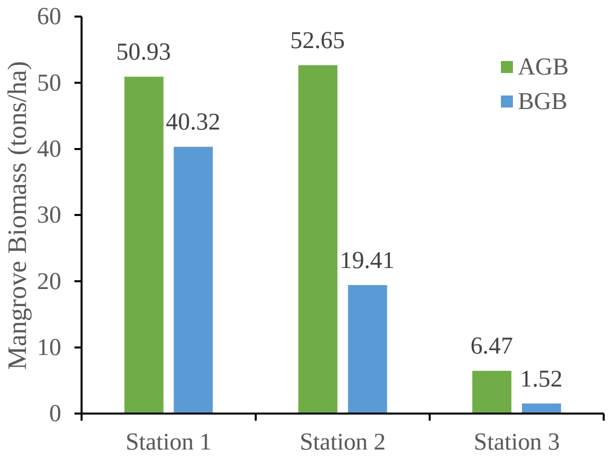


Figure 3 Estimated Mangrove Biomass and Carbon Stock

3.4 Mangrove Sedimentary Carbon Stock

The results of mangrove sediment carbon measurements at each research station showed the highest value at station 2 with a value of 844.81 tons/ha. while the lowest result was the amount of carbon in sediment at station 3 with a value of 720.38 tonnes/ha. The carbon value of mangroves in the Wulan Delta can be seen in Figure 3

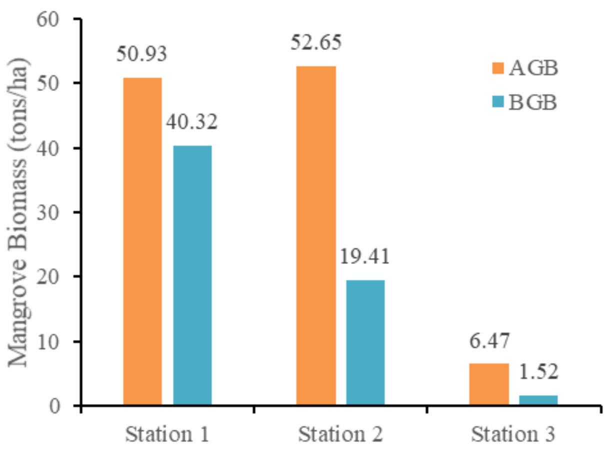


Figure 4 -*Mangrove Sedimentary Carbon Stock*

3.5 Total Carbon Stock and Total Carbon Uptake

The total carbon stock value is obtained by adding up the carbon stock of mangrove vegetation and the carbon stock of sediment. Meanwhile, the total value of carbon uptake is obtained from the sum of mangrove and sediment carbon uptake. The total carbon stock results at each station can be seen in Figure 4

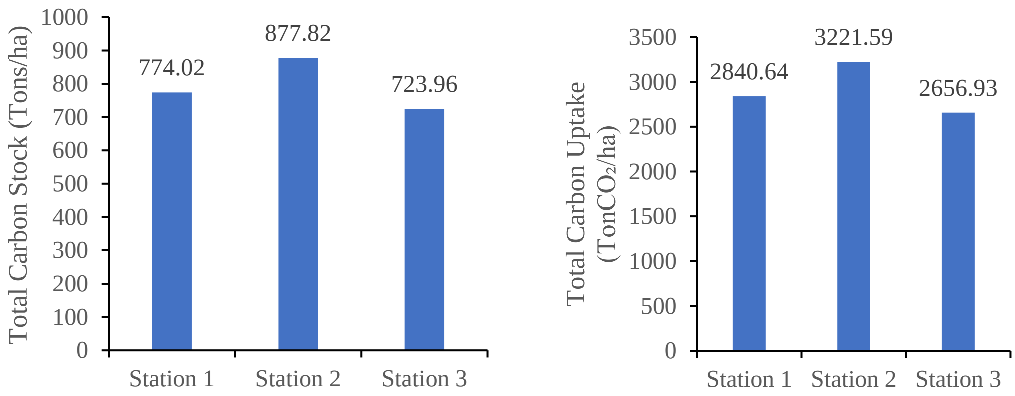


Figure 5 - Total Carbon Stock and Mangrove Carbon Uptake

The lowest amount of carbon stock at station 3 was 723.96 tons/ha, while at station 1 the amount of carbon was 774.02 tons/ha. Station 2 has the highest total carbon stock with a value of 877.82 tonnes/ha. The lowest amount of carbon absorption at station 3 was 2656.93 tonsCO_2/ha, while station 1 has a total carbon uptake of 2840.64 tonsCO_2/Ha. Station 2 has the highest total carbon uptake with a value of 3221.59 tonsCO_2/Ha. This is because station 2 has a high sediment carbon stock value compared to other stations and is supported by mangrove vegetation.

3.6 Spatial Estimates of Mangrove Carbon Stock in the Wulan Delta from 2017 and 2022

The spatial estimate of mangrove carbon stock was obtained by carrying out calculations by multiplying the total mangrove carbon stock by the mangrove area from 2017, 2019, 2020 and 2022. The results of the spatial calculation of mangrove carbon stock can be seen in table 3

Table 3 - ***Spatial estimates of Mangrove Carbon Stock in the Wulan Delta from 2017 and 2022***

Year	**Area (ha)**	**Total Stock Carbon Mangrove (Mg ha^{-1})**	**Spatial Estimation of Carbon Stocks (Mg)**
2017	1.003,93	10,28	10.323,60
2019	852,38	10,28	8.765,18
2020	853,25	10,28	8.774,13
2022	935,29	10,28	9.617,76

The results of the calculation of spatial estimates of mangrove carbon stocks showed that in 2017 the mangrove area was 1,003.93 ha with carbon storage of 10,323.60 Mg ha^{-1} whereas in 2019 there was a decrease in mangrove area caused by abrasion so that the mangrove area was 852.38 ha so it was able to store carbon of 8,765.18 Mg ha^{-1}. In 2020 there was an increase in mangrove area to 853.23 ha which was caused by the replanting of mangrove trees by the community so that they were able to store carbon of 8,774.13 Mg ha^{-1}. In 2022, the area of mangrove trees will increase due to mangroves growing naturally to 935.29 ha so that they can store carbon of 9,617.76 Mg ha^{-1}.

4. Discussion

The results showed that the changes in mangrove area in the Wulan Delta were different each year. This is due to the occurrence of abrasion and accretion in the area. According to Suwargana (2008), Darmawan and Hilmanto (2014), and Anurogo et al. (2018), the changes in mangrove area are caused by erosion (abrasion) and land accretion (accretion) which are characterized by the growth of mangrove forests in the accretion area and appear to be decreasing or disappearing in mangroves due to abrasion. This is related to this study with the difference in mangrove area change from year to year. 2017 to 2019 experienced a decrease in mangrove area due to abrasion in the mangrove area, while in 2020 to 2022 there was an increase in area due to the addition of mangrove vegetation area, resulting in mangroves being able to grow naturally and replanting by the community in the area.

The highest INP value for the mangrove tree species Avicennia marina and the highest stand INP value for the mangrove species Rhizophora mucronata in this study indicate that these species have a large role in the mangrove community structure in the Wulan Delta. This is because the Avicennia marina species is found on muddy substrates and is in a tidal habitat so that it can reproduce well. The results obtained are in line with Japa and Santoso (2019), Puspayanti et al. (2013), Susanto et al. (2013) explained that Avicennia marina has a fairly high tolerance limit for waters with extreme conditions such as high salinity, muddy substrate conditions. This statement is in accordance with the research results where Avicennia marina has a respiratory root system and its distribution can occur because the fruit floats in water and is spread by the tidal currents of seawater.

Based on the results of the biomass value calculation, the high and low biomass values of mangrove vegetation are influenced by the diameter of the vegetation. This is in line with Mandari et al. (2016), Mandari et al. (2021), and Suryono et al. (2018) who stated that the biomass value is not only influenced by the tree density but also by the diameter of the tree, this is because the larger the diameter of a tree, the greater the biomass value. also will be bigger. The influence of the high stem diameter value on the biomass value of a tree stand is much greater than the density. This statement is in accordance with the research results where at station 2 the mangrove vegetation has a wide tree diameter, while at stations 1 and 3 the diameter is relatively small.

The carbon stock value above the ground surface is higher because this part consists of stems that can act as a place to store food reserves from photosynthesis. This is in line with Dinilhuda et al. (2018), Lestariningsih et al. (2018) and Heriyanto et al. (2020) stated that mangrove vegetation can store more carbon than almost any forest on earth with the potential for carbon absorption which is influenced by the ability of trees to absorb carbon through the photosynthesis process which is absorbed through the air in the atmosphere which will be stored in the form of plant biomass on the stem. This study shows that station two has a large stem size so it can store more carbon.

The carbon content in the sediment can also be influenced by the type of sediment, where muddy sediment tends to have a higher organic matter content than sandy sediment. In relation to this, the high and low carbon values in mangrove sediments are influenced by several factors such as the organic matter content of the substrate, the age of the mangroves, and the type of substrate. The high carbon storage at station 2 is thought to be due to differences in the type of substrate and the age of the mangroves, where the older the mangroves, the more organic matter will be decomposed. In addition, station 2 has a mud type sediment, which generally has a higher organic matter content than sandy sediment. This is in line with Taqwa et al. 2014 Yolanda et al. 2019 and Wahyuningsih et al. (2020) stated that in general, muddy areas have a high organic carbon content. This is due to the ability of mud sediment to accommodate more organic matter than sand. The difference lies in the tighter pores in the muddy substrate, so that organic matter tends to be easier to settle than in sandy substrate.

The capacity of mangrove carbon storage is influenced by vegetation density. Higher vegetation density leads to higher carbon storage value. Mangroves with high density will have high biomass and carbon storage, whereas those with low density will have low biomass and carbon storage. As vegetation ages, its ability to store and absorb carbon increases. This aligns with Rifandi and Abdillah (2020) in Kathiresan et al. (2013) and Rahmah et al. (2015) who stated that optimal mangrove growth results in greater carbon reserves within the soil. Soil organic carbon content increases with rising plant biomass. The value of carbon stored in sediment will be greater than that stored in stands.

Annual changes in mangrove area are caused by abrasion and accretion, leading to increases or decreases in area. This is in line with Suwargana (2008), Darmawan and Hilmanto (2014) and Anurogo et al. (2018) who state that changes in mangrove forest area occur due to erosion (abrasion) and land addition (accretion). This can be observed from the growth of mangrove forests in areas experiencing accretion, while in mangroves experiencing abrasion, the growth appears to be reduced or even lost. Expanding the mangrove forest area can increase carbon storage capacity, where the larger or taller the mangrove vegetation, the higher the carbon storage capacity of the vegetation. Therefore, rehabilitation and expansion efforts are needed as a step to increase carbon absorption capacity.

5. Conclusion

The INP value of mangrove species that have an important value on community structure in the Wulan Delta area is*Avicennia marina*with a value of 21.84 – 297.18. The total biomass value has an average of 57.10 tons/ha, while the carbon stock value is 26.27 tons/ha, the carbon uptake value is 791.93 tons/ha, the carbon uptake is 2,906.39 tons of CO_2/ha. The spatial area in 2017, 2019, 2020 and 2022 is 1,003.93, 852.38, 853.25 and 935.29 ha.

6. Acknowledgements

In the preparation of this research, the author would like to thank the grant funds other than APBN Faculty of Fisheries and Marine Science Institute of Diponegoro University (FPIK Undip) for the fiscal year 2024 with contract number 569-04/UN7.D2/PP/VII/2024, for funding and assistance during the research.

References

Anurogo W., Lubis M. Z., Khakim N., Prihantarto W.J., and Cannagia L.R. 2018. "The Influence of Tides on the Dynamics of Changes in Mangrove Forests in the Banten Bay Area."*Marine Journal: Indonesian Journal of Marine Science and Technology* 11 (2): 130–39. https://doi.org/10.21107/jk.v11i2.3804.

Apriliana W.I., Purwanti F., and Latifah N. 2021. "Estimation of Biomass Content and Carbon Stores in Mangrove Forests, Mangunharjo, Semarang."*Life Science* 10 (2): 162–72. https://doi.org/10.15294/lifesci.v10i2.54447.

Barus B.S., Munthe R.Y., and Bernando M. 2020. "Total Organic Carbon and Phosphate Content in Sediments in the Waters of the Banyuasin River Estuary, South Sumatra."*Journal of Tropical Marine Technology* 12 (2): 395–406. https://medium.com/@arifwicaksanaa/pengertian-use-case-a7e576e1b6bf%0Ahttps://doi.org/10.1016/j.biteb.2021.100642.

Dinilhuda A., Akbar A.A., and Jumiati. 2018. "The Role of Mangrove Ecosystems in Mitigating Global Warming."*Journal of Civil Engineering* 18 (2): 1–8. https://doi.org/10.26418/jtsft.v18i2.31233.

Heriyanto, Teguh, Bintal Amin, Insaniah Rahimah, and Fitri Ariani. 2020. "Analysis of Biomass and Carbon Stocks in the Mangrove Ecosystem in the Sandy Beach Area of Kawal Village, Bintan Regency."*Maritime Journal* 2 (1): 31–41. https://doi.org/10.51742/ojsm.v2i1.104.

Japa L. and Santoso D. 2019. "Analysis of Mangrove Communities in Sekotong District, West Lombok, NTB."*Journal of Tropical Biology* 19 (1): 25–33. https://doi.org/10.29303/jbt.v19i1.1001.

Lestariningsih, Wiwid Andriyani, Nirwani Soenardjo, and Rudhi Pribadi. 2018. "Estimation of Carbon Stocks in Mangrove Areas in Timbulsloko Village, Demak, Central Java."*Marina Oceanographic Bulletin* 7 (2): 121. https://doi.org/10.14710/buloma.v7i2.19574.

Mandari D.Z., Gunawan H., and Isda M.N. 2016. "Estimation of Biomass and Carbon Stored in the Mangrove Forest Ecosystem in the Bandar Bakau Dumai Area."*Journal of Riau Biology* 1 (3): 17–23.

Maolani R.A., Dalimunthe A.S., Haryanto D., Bifa R., Azzahra Cornelia J., and Suryamika P.E. 2021. "Expansion of Mangrove Forests in Mitigating the Risk of Global Warming Disasters: PkM Activities in the Muara Angke Coastal Area, Jakarta."*Dinamisia: Journal of Community Service* 5 (6): 1380–88. https://doi.org/10.31849/dinamisia.v5i6.8096.

Prasetyo A., Santoso N., and Prasetyo L.B. 2017. "Damage to the Mangrove Ecosystem in Ujung Pangkah District, Gresik Regency, East Java Province."*Journal of Tropical Silviculture* 8 (2): 130–33. https://doi.org/10.29244/j-siltrop.8.2.130-133.

Pratiwi D., Hartoko A., and Febrianto S. 2023. "Carbon Uptake Potential of Mangrove Forests, Kulon Progo, Yogyakarta."*National Marine Journal* 18 (2): 99–112.

Puspayanti N.M., Tellu H.A.T., and Suleman S.M. 2013. "Types of Mangrove Plants in Lebo Village, Parigi District, Parigi Moutong Regency and Their Development as Learning Media."*E-Jipbiol* 1 (1): 1–9.

Rachmawati, Ditha, Isdradjad Setyobudiandi, and Endang Hilmi. 2014. "Potential Estimation of Carbon Stored in Mangorove Vegetation in the Muara Gembong Coastal Area, Bekasi Regency."*Omni-Aquatic Journal* XIII (19) (November 2014): 85–91.

Rahma F., Basri H., and Sufardi. 2015. "Potential for Carbon Stored in Mangrove Land and Ponds in the Coastal Area of Banda Aceh City."*Journal of Land Resource Management* 4 (1): 527–34.

Rahman, Effendi H., and Rusmana I. 2017. "Estimation of Carbon Stock and Uptake in Mangroves in the Tallo River, Makassar."*Journal of Forestry Science* 11 (1): 19. https://doi.org/10.22146/jik.24867.

Rifandi R.A., and Abdillah R.F. 2020. "Estimation of Carbon Stock and Carbon Uptake in Mangrove Tree Stands in the Trimulyo Mangrove Forest, Genuk, Semarang."*Journal of Environmental Sustainability* 1 (2): 63–70. http://e-journal.ivet.ac.id/index.php/envoist/.

Suryono, Soenardjo N., Wibowo E., Ario R., and Rozy E.F. 2018. "Estimation of Biomass and Carbon Content in the Perancak Mangrove Forest, Jembrana Regency, Bali Province."*Oceanographic Bulletin* 7 (1): 1–8.

Susanto A.H., Soedarti T., and Purnomobasuki H. 2013. "Mangrove Community Structure Around the Suramadu Bridge, Surabaya Side."*Biosciences* 10 (1): 1–10.

Suwargana N. 2008. "Analysis of Mangrove Forest Changes Using Remote Sensing Data in Pantai Bahagia, Muara Gembong, Bekasi."*Journal of Remote Sensing* 5 (2): 64–74.

Taqwa R.N., Muskananfola M.R., and Ruswahyuni. 2014. "Study of the Relationship between Basic Substrate and Organic Material Content in Sediment and the Abundance of Macrobenthos Animals at the Sayung River Estuary, Demak Regency."*Management of Aquatic Resources Journal (MAQUARES)* 3 (1): 125–33. https://doi.org/10.14710/marj.v3i1.4429.

Wahyuningsih, Asri, Warsito Atmodjo, Sri Yulina Wulandari, Lilik Maslukah, and Muslim Muslim. 2020. "Distribution of Total Carbon Content of Bottom Sediment in the Waters of the Kaliboyo River Estuary, Batang."*Indonesian Journal of Oceanography* 2 (1): 24–30. https://doi.org/10.14710/ijoce.v2i1.7177.

Yolanda Y., Effendi H., and Sartono B. 2019. "Concentration of C-Organic and Sedimentary Substrates in the Waters of Belawan Harbor, Medan."*Journal of Environmental Sustainability Management* 3 (2): 300–308. https://doi.org/10.36813/jplb.3.2.300-308.

Yuliasamaya, D. Arief and, and R. Hilmanto. 2014. "Changes in Mangrove Forest Cover on the Coast of East Lampung Regency."*Sylva Lestari Journal* 2 (3): 111. https://doi.org/10.23960/jsl32111-124.