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Estimation of Carbon Absorption and Changes in Mangrove Area in 2017-2024 in Tugurejo Village Semarang

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ABSTRACT

Mangroves are one of the coastal productive ecosystems that have a role in absorbing CO2. Mangroves play an important role in the storage of blue carbon in the growth process, including standing plants and soil organic content so as to prevent the risk of sudden carbon loss. This study conducted in October 2023 - May 2024 aims to determine the estimated value of CO2 storage and CO2 absorption as well as to determine the changes in the area of mangrove ecosystems in Tugurejo Village Semarang. The method used in the study is descriptive explorative method with purposive method for determining the research location by paying attention to the distance between quadrants and the density of mangroves, mangrove data collection using non-destructive methods. The calculation of CO2 storage and absorption of mangrove stands was calculated by allometric equation, LOI (Loss on Ignition) method was used in the analysis of sediment CO2 upcycle. The mapping of mangrove land changes was processed using Arcmap 10.8 with sentinel satellite imagery 2A. The results of the study showed two types of mangroves found at the research site, namely Rhizopora mucronata and Avicennia marina. The value of carbon content in the stand is 199.68 tons/ha, equivalent to CO2 absorption of 732.84 tons/ha. The carbon content in the sediment is 134130.3 tons/ha with a CO2 absorption content value of 492258.1 tons/ha. The area of mangroves has changed, the area of mangroves in the Tugurejo area in 2017 is 77.613 Ha and in 2024 102,626 Ha, an increase in land area with a percentage of 25% influenced by mangrove planting activities by local communities and various institutions as an effort to conserve the environment.

Keywords: area change, CO_2 stock, CO_2 uptake, mangroves, Tugurejo Village

1. Introduction

Climate change is a pressing global challenge. One natural solution to address this problem is to increase carbon sequestration. The increase in carbon that occurs due to human activities and land-use change causes changes in mangroves. Activities such as burning, land clearing, and industrial and waste disposal reduce the mangrove area and its ability to sequester carbon.

Mangrove ecosystems, with their high biomass and ability to store carbon over long periods of time, have great potential for addressing global climate change. Mangroves are productive ecosystems in coastal areas and have high ecological and economic benefits. Ecologically, mangroves can store sediments through photosynthesis, the sediment accretion process, which is the process of adding sediments with organic matter content stored in the soil. Mangroves can also store carbon, which is known as carbon sequestration. Mangroves can store three–four times more carbon than terrestrial forests (Alviana *et al*. 2023). This affects the mangrove ecosystem as a blue carbon ecosystem because it can absorb CO_2 and convert it into organic carbon stored in its body biomass, including aboveground living biomass (AGB), below-ground living biomass (BGB), and leaves and twigs of mangrove trees that fall and are decomposed by microorganisms that become a source of organic matter in mangrove sediments (aboveground dead biomass), and organic soil, namely soil and sediment stands.

The Tugurejo Village mangrove ecosystem, located in Tugu District, Semarang, is one of the mangrove areas with damaged conditions due to abrasion and shoreline changes of up to 1.7 km in the site village area (Yaqin *et al.* 2022). Based on the data from the Central Java Marine and Fisheries Service (2012), Tefarani *et al.* (2019) Semarang City mangrove area has reached 94.39 ha or 3.84% of the total mangrove area in Central Java. The Tugu sub-district is a mangrove forest area that still has good conditions compared to the other three sub-districts, namely the North Semarang, West Semarang, and Genuk sub-districts. Mangroves in Tapak Village are artificial ecosystems with the aim of being a conservation area and resisting abrasion. Mangrove area reduction also affects the ability of mangroves to absorb carbon. The importance of mangroves as blue carbon storage to keep carbon from being lost, and it can be estimated that the storage must be done and preserved.

This research is expected to maintain mangrove ecosystems in a sustainable manner with the results of estimating CO_2 uptake in mangroves from the air, so that it can support mangrove ecosystem management activities in a sustainable manner and its relationship to reducing CO_2 concentrations in the atmosphere by calculating the estimated uptake and storage of CO_2 in mangrove stands and sediments, as well as mapping changes in mangrove areas digitized from 2017 to 2024.

Mangroves in Tugurejo Village are known to have increased in area; in 2017, the land area was 77.613 ha and in 2024 it amounted to 102.626 ha. Mangrove storage in stands of 199.68 tonsC/ha is equivalent to a CO_2 uptake of 732.84 tons/ha. The carbon content in sediments amounted to 134130.3 tonsC/ha with a CO_2 uptake content value of 492258.1 tons/ha.

The results of this study were compared with previous research conducted using remote sensing methods to observe changes in the area of mangroves in Tugurejo Village. Remote sensing techniques that utilize the results of satellite image analysis are effective for mapping mangrove ecosystems. Utilization of sentinel-2 satellite imagery can be easily accessed for free and has a fairly high spatial resolution quality, so that monitoring the condition and periodic changes in mangroves can be easily known (Hidayah *et al.* 2023).

2. Materials and Methods

2.1 Research Materials

The materials used in this study were the measurement data of Diameter Breast High (DBH) biomass, sediment, and density. DBH, density, and mangrove sediment data were collected directly in the field and through remote sensing management to observe changes in mangrove land area. The mangrove sediment carbon testing process was carried out in the laboratory, followed by data analysis. Tools and materials used in data collection in the field included ivory paper siteery to record observations in the field, sewing meters to measure DBH, PVC pipes for sediment collection, zip plastic for sediment sample containers, cool boxes for sediment storage containers, roller meters for quadrant plots of mangrove identification, refractomter for measuring water salinity, DO meter for measuring DO (Dissolve Oxygen) and water temperature, pH meter as a water pH measuring device, camera for documentation, GPS as a tool to determine the sampling point, and label paper as a marker of observation results. The tools used for laboratory analysis included an oven for drying samples, aluminum foil for sample containers, 50 ml porcelain cups as sample media, furnace as a tool for combining samples, desiccators as a medium for removing moisture and air samples, analytical scales to measure sample mass, and laptop to perform data processing.

2.2 Data Collection Method

The research was conducted from October to December 2023 with stages including making a research proposal, December-January 2024, including the data collection stage in the field, namely, in the Tugurejo Village area. Field data processing was conducted from February to May 2024 at the PSDIL Laboratory, Faculty of Fisheries and Marine Science, Diponegoro University. The research was conducted using a purposive sampling method, in which the process was carried out by systematically analyzing the predetermined objectives by considering the condition of mangroves in the research location. Data collection was conducted at three research sites, each consisting of two points. The research location was determined using GPS, and the location was determined by considering certain considerations that are considered to represent the overall condition of the data (Septiani *et al.* 2018). Site I is located close to the educational area and there is a Tapak River flow. Site II was close to the Tapak pond area and was a stream from the Tapak River. Site III is close to the sea coast; therefore, it is directly influenced by tides. An overview of the research locations is presented in Figure 1.

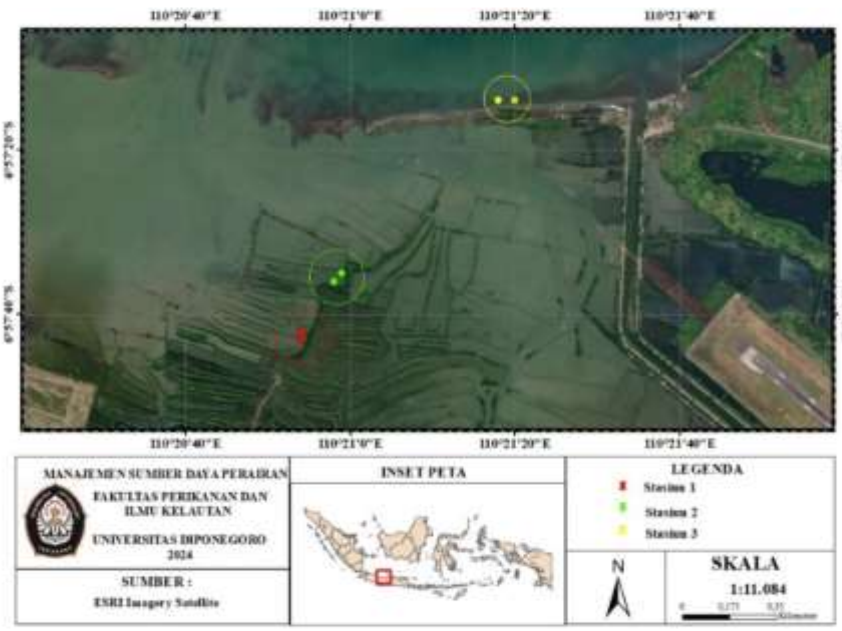

Fig. 1 - Research Location

2.3 Data Analysis Method

Stand Carbon Measurement

Carbon measurements in mangrove stands are carried out using non-destructive methods that do not damage mangroves. Measurements of stand carbon are performed by calculating Diameter Breast Height (DBH*)* at chest height or less than 1.3 m from the ground (Rahmattin and Hidayah, 2020). Mangrove DBH measurements were then processed using an allometric equation. The formula for the allometric equation for biomass in mangrove stands is presented in Table 1.

Table 1. *Above Ground Living Biomass* (AGB) Allometric Equation

Mangrove	Allometric Equation	Research Source
Rhizopora	$B = 0.1466*D^{2.3136}$	Dharmawan, 2010
Avicennia marina	$B = 0.1848*D^{2.3524}$	Harmawan and Siregar, 2008

Notes: B= Biomass (kg); D= DBH mangrove

Data analysis of mangrove carbon density contained in organic matter was 46%; therefore, the estimated amount of carbon stored was multiplied by 46% or 0.46 with the following equation:

Carbon Storage (tons/ha) = Biomass (tons/ha) x 0.46 (1)

Sedimentary Carbon Measurement

Sediment sampling was performed using a *sediment corer* tool that was modified from a 50 cm PVC pipe with a diameter of 5 cm. The mangrove sediment sampling step was conducted vertically. The PVC pipe was inserted into the ground and then pulled slowly while still rotating to obtain a fixed and full sediment. The samples obtained were split horizontally, inserted into a plastic *zipper,* and labeled for further analysis in the laboratory (Alviana *et al.* 2023). Furthermore, the samples were analyzed using the LOI *(Loss on Ignition)* method to measure the weight of the sample lost after burning for 48 h at 60 °C. Mangrove sediment carbon loading was measured in stages using the following equation:

1. *Bulk density* data is a unit of particle weight along with its porousness. *Bulk density* (BD) calculation formula is:

$$Bulk\ Density = \frac{dry\ soil\ weight\ (g)}{soil\ volume\ (cm^3)} \quad (2)$$

2. Carbon density (C) is calculated by the equation:

Soil C *density* (g cm^{-3}) = %C x *bulk density* (3)

3. The estimated carbon content of the soil was calculated using the equation:

Soil C (Mg ha^{-1}) = *Bulk density* x *soil deep interval* x % C (4)

4. Measurement of sediment organic matter that has previously gone through the combustion process for 48 hours at a temperature of 60 º C then mashed to make it homogeneous, then weighed ± 2 grams and put in a porcelain cup and in the *furnace* for 4 hours then weighed again. The calculation formula is as follows:

$$OC = \frac{[Wt\text{-}C) - (Wa\text{-}C)]}{Wt\text{-}C} \times 100\% \quad (5)$$

Description:

Wt : Total weight of porcelain and sample after drying

C : Weight of empty porcelain cup

Wa : Total weight of porcelain and sample before dryingz

Mangrove Community Structure

The structure of the mangrove community analyzed includes species density (K), relative density (KR), relative frequency (FR), relative dominance (DR), and important value index (INP). The formula for calculating the value of mangrove composition structure, refers to (Ati *et al.* 2014; Rachmawati *et al.* 2014) as follows:

1. Density (D) is the number of individual stands in a mangrove area. The formula for species density is:

D (ind/ha) = Number of individuals of a species / Plot area (6)

2. Relative density (RDi) is the sum of the ratio of the i-species type of stand and the total of all stand types. The relative density formula is:

RDi (%) = ni / ∑n x 100 (7)

3. Frequency (Fi) is the percentage of the number of mangrove is calculated based on equation. The frequency formula is:

F = Pi / ∑p (8)

4. Relative Frequency (FR) is the ratio between the frequency of species and the total frequency of all species (∑RFi). The formula for relative frequency is:

RFi(%) = Fi / ∑F x 100 (9)

5. Dominance (D) shows the influence of a species on the community in a quadrant plot. The dominance formula is:

D (m^2) = Total basal area of a species / Total all measured plots (10)

6. Relative Dominance (DRi) shows the sum of the ratio between the dominance of species (D) and the total dominance of all species (∑Da). Relative dominance formula:

DR (%) = Ci / ∑C x 100 (11)

7. Importance Value Index (INP) is the sum of the relative density of species (RDi), relative frequency of species (RFi), and relative closure of species (RCi). The INP formula is:

Tree-level INP (%) = RFi + RDi+ DRi (12)

INP at sapling level (%) = RFi + RDi

The standardized criteria for mangrove density values are presented in Table 2.

Table 2. Mangrove density standard criteria

Criteria	Density (ind/ha)
Dense	< 1.000
Moderate	≥ 1.000 - < 1.500
Sparse	≥ 1.5000

Source: State Ministry of Environtmenr (KEPMEN-LH) 2004

Data Capture

The process of monitoring changes in mangrove area can be recognized by remote sensing. Spatial monitoring, i.e. satellite imagery allows detailed area observations from around the world, while temporal, satellite data is historically available for analysis of change trends over several decades. The utilization of Sentinel 2A for mapping is practical because it combines image data and field survey data (Kawamuna *et al.* 2017). Sentinel 2A is able to provide maximum results in mapping in the tropics with the addition of the NDVI method and the right combination. NDVI is a combination process by comparingthe difference in reflectance values of red wave *(Red) and* near wave (*Near Infrared*) that can distinguish the condition of vegetation and non-vegetation. The NDVI equation formula is presented as follows:

$$NDVI= \frac{(NIR - Red)}{(NIR + Red)} \quad (13)$$

Table 3. Classification of NDVI Values

Classification	**Value**
Very good vegetation	0,72 - 0,92
Good Vegetation	0,42 - 0,72
Medium Vegetation	0,22 - 0,42
Poor Vegetation	0,12 - 0,22
Very Poor Vegetation	-0,1 - 0,12

Source: Endeleo (2020)

3. Results and Discussion

Mangrove Community Structure

Table 4. Mangrove species in Tugurejo Village

Spesies	**Famili**	**ST I**		**ST II**		**ST III**	
		Pengulangan					
		1	**2**	**1**	**2**	**1**	**2**
R. mucronata	*Rhizophoraceae*	√	√	√	√	√	√
A. Marina	*Acanthaceae*	-	-	√	√	√	√

Description: (√) = found; (-) = not found;

(a) (b) (c) (d)

Fig. 2 - Mangroves found in Tugurejo Village

Description: Mangroves found in Tugurejo Village (a) *Rhizopora mucronata* fruits and leaves, (b) *Rhizopora mucronata* roots, (c) *Avicennia marina* leaves and flowers, (d) *Avicennia marina* roots.

Based on the results of research that has been done mangroves identified at the research site there are two species, namely *Rhizopora Mucronata* and *Avicennia marinna*. Based on the research it is known that the mangrove species *R. mucronata* dominates the study area, this is known from the INP value of the highest tree category of 150.06%. While the lowest value is the species *A. marinna* which is 56.62%. As for the sapling category, the INP with the highest value was found in the *R. mucronata* species,which was worth 112.50% while the lowest INP was obtained in the *A. marinna* species 38.89%. INP indicates the relationship of a species to the ecosystem with the category of species importance ranging from 0-300%. The higher the INP value, the more important the species is in an ecosystem (Hanafi *et al.* 2021). The high INP value found in *R. mucronata* species can be influenced by its growing area near brackish areas, because it has low salinity and is only inundated at the highest tide of sea water and mangroves in the brackish water zone.

Based on the results of the study, the highest density was obtained at site I with an average of 1435 ind/ha which is included in the medium criteria, while the lowest average at site III with an average of 817 ind/ha which is included in the rare category. The high and low density is influenced by the adaptability of the species to environmental factors, seed dispersal and seedling growth. According to Nasution *et al.* (2017), The high and low density of mangrove species in an ecosystem is an indication that naturally the species is considered suitable for the vegetation environment of the area. It is known that the type of mangrove with the highest density value is *R. mucronata* is influenced because the study area has a substrate that is very suitable for the growth of mangrove species *R. mucronata* which can grow in muddy and sandy substrates in accordance with the conditions of site II area close to the pond bund area leading to the mouth of the Tapak river which causes a high organic nutrient content that supports mangrove density. Based on the density data obtained can be known site III with mangrove density value of sapling category as much as 1680 ind / ha which indicates that mangroves in the site III area in good condition to support mangrove growth, this is known from the mangrove category is still in the form of saplings that show good regeneration ability.

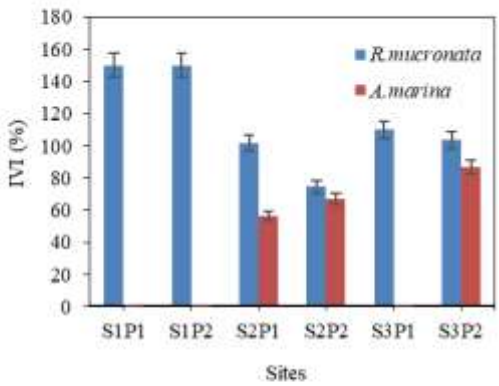

Fig. 3 - Tree Level Category INP

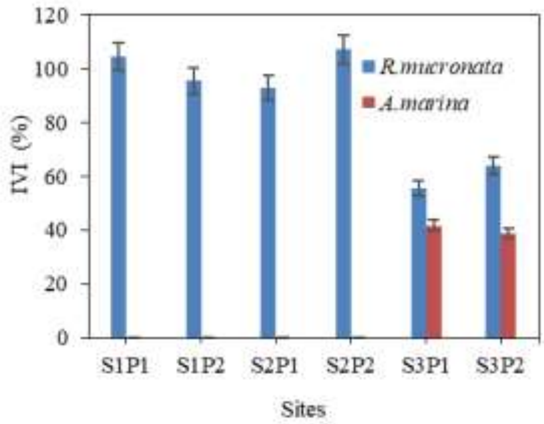

Fig. 4 - Sapling Level Category INP

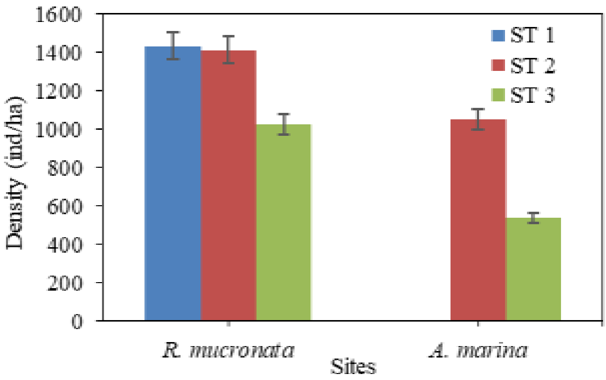

Fig. 5 - Mangrove density values

Water Quality Measurement Results

Environmental factors observed in the form of temperature, pH, salinity and DO sequentially obtained the highest value at site III of 33.9-34° C and the lowest value at site 33-33.5° C; pH 7-8.8 lowest at site II and the highest pH of 8.09-8.1 found at site III; The lowest DO at site II was 6-8.10 and the highest DO was found with a value of 11.35-12.13 at site I and is still classified as a threshold level for mangrove growth and if the concentration of physical parameters measured exceeds the threshold will interfere with mangrove growth, which can interfere with the ability of mangroves to absorb CO 2. The better the mangrove growth, the better the ability to absorb CO2 and the increasing content of CO2 stored by mangroves in the soil. This indicates that CO2 storage in the soil is influenced by anthopogenic activity, the activity of weathering organic materials such as litter decomposed by microorganisms and deposited in sediments.. According to Jamaludin *et al.* (2021), the content of organic matter in soils with muddy textures tends to store more organic matter than sandy ones. Sediments with muddy textures tend to have a slower decomposition process compared to sandy sediments because they have a finer texture that allows the accumulation of organic matter and reduces oxidation.

Table 5. Measurement Results of Environmental Quality Parameters

Variables	**Site I**	**Site II**	**Site III**	**Quality Standard**
Temperature (ºC)	33,5-34	33-33,5	33,9-34	Experience
Salinity (ppm)	30-32	32-33	31-32	Experience
pH	8,1- 8,3	7-8,8	8,09-8,1	7- 8,5
DO	11,35-12,13	6-8,10	8,72 - 10,75	⩾5
Substrate Type	Muddy	Muddy	Silty Sand	-

Carbon Content of the Stand

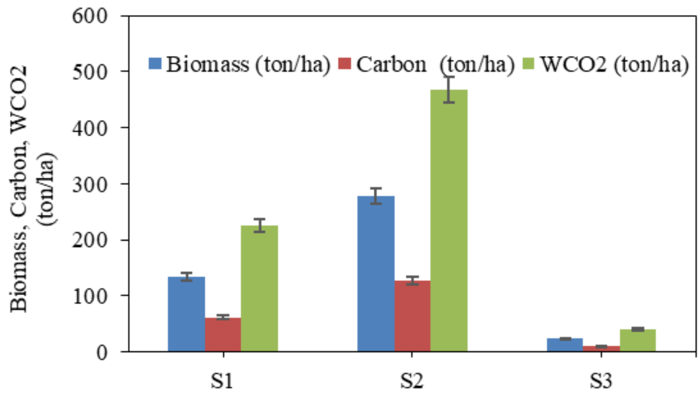

Fig. 6 - Estimated Value of Mangrove Standing Carbon Stocks

Based on the research conducted, the highest carbon stock value was obtained at site II, namely in the Tapak Village Mangrove Area with a biomass value of 277.27 tons/ha, carbon content of 127.55 tons/ha and can absorb CO 2 of 468.09 tons/ha. While the lowest carbon stocks were obtained at Site III in the Tirang Beach area. Carbon content in mangroves followed by an increase in biomass CO2 absorption capacity, therefore the higher the value of mangrove reserves, the higher the CO2 absorption. The low value of mangrove reserves at site III obtained a biomass value of 23.78 tons / ha and carbon 10.94 tons / ha and carbon uptake of 40.15 tons / ha. It can be seen that the difference in the value of CO 2 in the stand is influenced by mangrove DBH, where the wider the DBH size, the greater the carbon value. High and low carbon uptake in mangrove stands can be caused by differences in the size of the *diameter at breast height* (DBH). It is known that the diameter at site II is greater than the diameter of site III. The greater the diameter of the tree biomass, the greater the carbon storage that will affect the amount of carbon sequestration (Mutmainna *et al.* 2024)

Carbon Content of Sediments

Fig. 7 – The difference of BO and C-Organic content

Based on Figure 7, the highest percentage content of organic matter was found at Site III, equivalent to the value of organic carbon content with a value of 30.69%, equivalent to the value of organic content of 17.80%. While the lowest percent value of organic matter was found at site II with a value of 9.27% and an organic content value of 5.37%. Based on the results of the study, it can be seen that the high value of organic matter will affect the organic carbon content, which will affect the absorption process and carbon reserves in sediments. According to Jamaludin *et al.* (2021), the high value of C-organic content in sediment content is influenced by the activity of microorganisms and the decomposition process that settles in sediments, which increases the process of organic matter content in the soil.

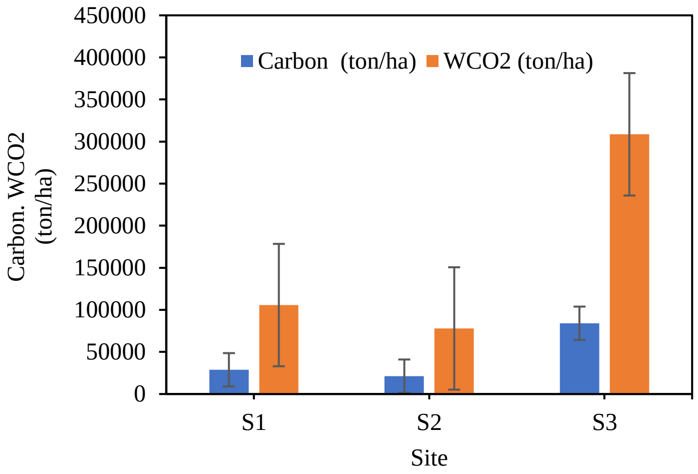

Fig. 8 - Estimated Value of Mangrove Sediment Carbon Stocks

Based on Figure 8, it can be seen that mangrove sediments with the highest CO2 value can be found at site III with CO(2) content of 84095.67 tons/ha, the estimated value of CO(2) uptake is 308631.1 tons/ha, while the lowest value is found at site II with CO(2) content of 21230.64, the estimated value of CO(2) uptake is 77916.45 tons/ha. It can be seen that the increasing value of CO2 storage, the estimated value of CO2 uptake is also increasing. The difference in the value of organic content in mangrove sediments is influenced by the type of substrate, where sediments that have a fine texture tend to have a higher content value compared to sediments that have a coarse texture. Research areas that have muddy substrates tend to have higher carbon content than sandy areas. Carbon content results are influenced by physical and chemical factors such as temperature, pH, salinity, *bulk density*, soil texture. Therefore, the better the mangrove growth, the better the carbon content in mangrove sediments. Mangroves that are included in the good category can store more organic matter which will increase the potential for soil organic content with the addition of biomass values (Sumarni *et al.* 2024).

Change in Mangrove Area

Based on the results of the study, it was found that there was an increase in mangrove area in the area of Tugurejo Village, Tugurejo, Semarang in the last 7 years (2017-2024). The increase in land area which was originally in 2017 of 77.613 ha and in 2024 of 102.626 Ha increased by 25.013 Ha (25%) Ha due to the condition of the mangrove area which is often used as an ecotourism area and as a mangrove planting site. The increase in land area is caused by mangrove planting carried out by community service groups. The research location of Kelurahan Tugurejo has environmental problems, is directly affected by abrasion and organic waste disposal from settlements, fishing ponds and industrial waste and is included in the medium *vulnerability* level zone even though it can be developed into an ecotourism area. The mangrove rehabilitation process is carried out by planting mangroves along the coast, especially in locations that have been damaged. According to Hutapea *et al.* (2023), mangrove forest planting activities have been carried out since 2009 until 2022 with the process of replanting, namely by replacing dead or damaged mangrove seeds with better quality to increase the survival of mangrove growth that will be planted. Mangrove planting activities carried out by the surrounding community and related parties such as PRENJAK *(Youth Care for the Environment)* and KSG *Social Adventure Club* have succeeded in increasing the mangrove area. It is known that the mangrove area in the northern part of Tirang Beach has increased, in 2007 the mangrove area in Tirang Beach was around 1.44 Ha, increasing to 2.15 Ha in 2015. In 2022 it will be 2.84 Ha. Mapping of mangrove area changes can be seen in Figure 9 and Figure 10 presented below.

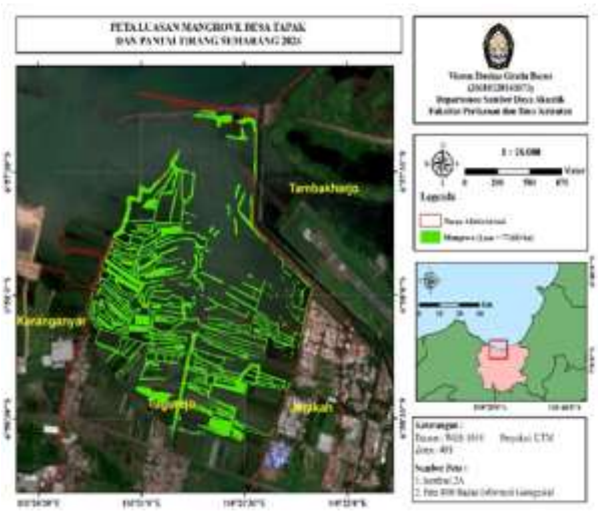

Fig. 9 - Map of Changes in Mangrove Area in 2017

Fig. 10 - Map of Changes in Mangrove Area in 2024

4. Conclusion

CO_2 storage and CO_2 estimation in the Tugurejo Village area, the value of carbon content in the stand of 199.68 tonsC/ha is equivalent to a CO_2 uptake of 732.84 tons/ha. Carbon content in sediments amounted to 134130.3 tonsC/ha with a CO_2 uptake content value of 492258.1 tons/ha with mangroves found in the study site there are two types, namely *Rhizopora mucronata* and *Avicennia marina* with an increase in mangrove area changes, in 2017 obtained by 77.613 Ha in 2024 amounted to 102.626 Ha.

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