Estimation of carbon stock in seagrass communities in Central Tapanuli

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Abstract This study aims to determine the carbon stock in seagrass communities in Central Tapanuli, North Sumatera, Indonesia. The research was conducted from July to August 2020 in the coastal areas of Hajoran and Jago Jago. The parameters measured in this study were density, coverage, biomass, carbon content, and carbon stock in seagrass. Biomass analysis and carbon measurement are divided into the top (above-ground biomass) and the bottom substrate (below-ground biomass). Carbon measurements are conducted using the loss on ignition (LOI) approach. The results showed that the seagrass ecosystem on the coast of Central Tapanuli Regency, which was covered by monospecies Enhalus acoroides, was in a less healthy condition with a cover percentage of 30.3-33.3% and a density of 59-67 shoots/m². Above-ground and below-ground seagrass biomass reached 140.19-188.72 g/m² and 368.13-423.69 g/m² respectively, while carbon stock reached 70.57-94.86 g Corg/m² and 18731-19603 g Corg/m² and total standing stock range 257.87-290.90 Corg/m². The data obtained from this research can be used as a database to see the potential of seagrass beds as storage of CO₂ and as an effort to mitigate and adapt to climate change.

Keywords: biomass, carbon stock, Central Tapanuli, monospecies, seagrass

1 Introduction
The increase in carbon dioxide concentration has now exceeded the normal threshold in the atmosphere, reaching 400 ppm, which is expected to continue to rise every year [1]. There are many impacts caused by global warming on coastal and marine areas, such as acidification of seawater, coral bleaching, rising temperatures and sea levels. Climate change was causing spatial-temporal variability of the physicochemical parameter of coastal and oceans, driving to more frequent extreme climate events (e.g., altered upwelling and ocean circulation) [2]. Carbon sequestration potential is a key aspect of climate regulation, and seagrass meadows have shown high carbon sequestration potential as they accumulate from both in situ production and sedimentation of particulate carbon from the water column [3].

As an important coastal ecosystem, seagrass has many roles, including as a habitat for coastal and marine biota, feeding ground, nursery dan spawning ground, primary producers, trapping and stabilizing sediment, protecting coastal areas from abrasion and flooding, increasing fishery production, purifying water and captures and stores carbon dioxide [4-7]. Seagrass carries out a photosynthetic process as well
as terrestrial plants where carbon dioxide is absorbed and stored as biomass [8]. This process can help reduce carbon dioxide levels in nature when the area of terrestrial forest decreases each year due to natural or intentional factors. For coastal and marine vegetation, the process of carbon sequestration and storage is known as blue carbon [9]. In 2009, UNEP, FAO, and UNESCO coined the term Blue Carbon, while in Indonesia the term was first introduced on 24 February 2010 at the World Minister of Environment Forum in Nusa Dua, Bali [10]. The estimated carbon that can be stored in the seagrass network ranges from 0-13 mg CO$_2$/ha while the sediment below ranges from 880-6000 mg CO$_2$/ha [11]. Seagrass meadows have been determined as necessary sinks in the global carbon cycle, as a result of they are extremely productive systems that bury organic carbon. According to [12], at least 29% of the global seagrass area has been lost globally, implying that close to 1/3 of the associated carbon sink capacity of seagrass meadows has been lost. The loss of carbon sink capacity is probably greater since seagrass meadows lose biomass and gross primary production well before they are extirpated, so that extant seagrass meadows are also expected to have lost sink capacity relative to undisturbed seagrass meadows. Efforts to stop seagrass loss and to recover lost seagrass areas will, therefore, contribute to rebuilding some of the lost seagrass carbon sink capacity and help to mitigate climate change [13].

Based on a study of [14], there is still a discrepancy in the spatial distribution of carbon data in seagrass beds where from 946 sampling locations with 3460 observations, mostly in North America, Western Europe, and Australia, and there is still little data obtained from the tropical region of Indo-Pacific. Research on blue carbon in seagrass has been carried out in several regions in Indonesia [15-17], although the number is still less than research on blue carbon in mangroves. Therefore, it is necessary to conduct a study in the North Sumatra region, especially in Central Tapanuli which has a stretch of seagrass beds in its waters. This study aims to analyze the potential of carbon storage in seagrass to reduce carbon dioxide emissions. By knowing this function, it is hoped that destructive action on seagrass beds can be prevented, and sustainable rehabilitation or conservation efforts can be realized.

2. Material and Methods

2.1. Study area
The map of the research location is presented in Figure 1. This research was conducted from July to August 2020 on the coast of Central Tapanuli, North Sumatera.

![Figure 1. Study sites map.](image-url)
The located in two villages (Hajoran: 1°38’43.23”N; 98°50’18.20”E and Jago-Jago: 1°36’6.52”N; 98°49’5.03”E), each of which consisted of three stations (Figure 1). The carbon measurement was carried out at the Phytochemical Laboratory of the Faculty of Pharmacy, University of North Sumatra. Direct observations in the field were carried out on environmental parameters, while for seagrass data assessed were density, cover, biomass, and carbon content.

2.2. Analysis of seagrass cover and density
The assessment and data collection of seagrass density and percentage cover were carried out using line transect drawn straight from the coastline up to 100 m towards the sea using a 0.5 x 0.5 m² plot that was placed every 10 meters [18]. This method was executed at low tide, where the water depth a half meter on average, to make it easier to identify seagrass and collect samples. Seagrass coverage is the percentage of an area covered by a seagrass canopy. The assessment of the condition and cover of seagrass is based on visual observation and refers to [19] concerning the Standard Criteria for Damage and Guidelines for Determining the Status of Seagrass (Table 1).

Table 1. Criteria of seagrass cover.

| Condition | Coverage          |
|-----------|-------------------|
| Good      | Healthy           | ≥ 60%             |
| Moderate  | Less healthy      | 30% - 59.9%       |
| Bad       | Poor              | ≤29.9%            |

Density is the number of seagrass shoots in an area 25 x 25 cm plot grids was used to assess seagrass density. The calculation for density used the equation [20]:

\[ D = \text{number of shoot of a species over a given plot area} \times 16 \] (1)

where D is density (shoots.m²), 16 is the conversion factor to per square meter if the quadrant plot is 25x 25 cm.

2.3. Biomass
Biomass sampling was carried out on seagrass shoots which were then separated into two parts consisting of above-ground biomass (AGB) and below-ground biomass (BGB). Seagrass is dried using an oven at 60 degrees Celsius for 72 hours until it reaches a constant weight. The equation used to analyze the biomass content [20]:

\[ AGB = AGB_x \times DS_x \] (2)

\[ BGB = BGB_x \times DS_x \] (3)

where \( AGB \) is total above-ground biomass and \( BGB \) is total below-ground in unit g m\(^2\), \( AGB_x \) is above-ground biomass species x in unit g/shoots and \( BGB_x \) is below-ground biomass of species x and DSx is shoot density per species.

2.4. Seagrass carbon
Organic carbon analysis was carried out using the loss on ignition (LOI) approach. Calculation of organic carbon stock in seagrass is determined by multiplying the percentage of the organic carbon content of each species with the dry biomass [20] as follows:

\[ \% \text{LOI} = \frac{\text{weight before burning} - \text{weight after burning}}{\text{weight before burning}} \times 100\% \] (4)

\[ AG_x - OCS (g \text{ Cor g} m^2) = OCCxAGB_x \] (5)

\[ BG_x - OCS (g \text{ Cor g} m^2) = OCCxBGB_x \] (6)
where LOI is loss on ignition, OCC is organic carbon content, and OCS is organic carbon stock.

3. Result and Discussion

3.1. Environmental condition
Seagrass on the coast of Central Tapanuli grows on a stretch adjacent to mangroves and coral reefs so that their habitat is in a substrate that varies from the sandy substrate with coral fragments to sandy mud. In areas with sandy substrate with coral fragments, the water clarity level is relatively higher or clearer than in areas with sandy mud substrate. The measurement of aquatic parameters shows that the quality of the waters of Central Tapanuli is relatively good for seagrass habitat (Table 2).

### Table 2. Physico-chemical parameters of water.

| Location | Salinity (ppm) | DO (mg/l) | pH  | Temperature (°C) | Current (m/s) | TSS (mg/l) | N   | P   |
|----------|----------------|-----------|-----|------------------|---------------|------------|------|-----|
| Hajoran  | 36             | 3.26      | 7.4 | 31.26            | 0.23          | 25.00      | 3.37 | 0.003 |
| Jago-Jago| 35.67          | 5.3       | 7.53| 30.73            | 0.2           | 23.67      | 2.94 | 0.07  |

Based on the results of the study, the average salinity was between 35.67 - 36 ppm in the two study locations. Each type of seagrass has a different ability to tolerate salinity which can affect the number of shoots to its biomass [21]. For dissolved oxygen in the range of 3.26-5.3 mg/l, the low dissolved oxygen in the Hajoran area is most likely due to the sampling located near the jetty and community settlements where domestic waste goes directly to the sea. Regarding [22] concerning seawater quality standards, dissolved oxygen levels of more than 5 mg/l are in a good category. Water pH measurements carried out in this study ranged from 7.4 to 7.53, according to seawater's pH, which is generally not neutral but alkaline. The current value ranges from 0.20 – 0.23 m/s, that value of water movement is quite small because the current measurement is carried out at the low tide. Meanwhile, the TSS measurement varies between 23.6 - 25 mg/l, this value slightly exceeds the TSS threshold for seagrass habitat as stipulated in the Minister of Environment Decree No 51/2004, which is less than 20 mg/l. According to Yunitha [23], the existence and reproductive activity of seagrass are highly dependent on the environment so that the better the aquatic environment, the seagrass has a high chance of reproducing which affects its density. In addition, [24] stated that one of the physical factors affecting seagrass distribution is the availability of suitable substrates to grow.

3.2. Identification, cover, and density seagrass
The seagrass on the coast of Central Tapanuli are dominated by *Enhalus acoroides*, a species commonly found in tropical waters *E. acoroides* were known to have a widespread distribution in Indonesian waters [24, 25]. This species is easy to identify because of its larger size than other types of seagrass. Its large morphology allows it to grow to dominate a seagrass community and have a longer life span. This species is able to live in a variety of substrates ranging from the muddy substrate to coral fragments so that this species can be found in the two research locations with different substrate waters. Several studies found that several environmental factors significantly affected the growth of *Enhalus acoroides* that are turbidity, temperature, salinity, and nutrition [26].
Figure 2. Percentage of cover and density of *Enhalus acoroides*.

Assessment results on seagrass cover in the monospecies *Enhalus acoroides* ranged from 30.3-33.3%. Referring to [19] regarding the status of seagrass beds, this percentage of cover indicates that seagrasses located on the coast of Central Tapanuli are in poor and less healthy conditions. In general, the percentage of seagrass cover is directly proportional to its density so that the higher the percent cover, the higher the density and vice versa. At the research location, it was found that the density ranged from 59 to 67 shoots/m² (Figure 2). The low percentage of cover and density of *Enhalus acoroides* is possible because the water areas where seagrass grows in Hajoran are close to residential areas. Meanwhile, in Jago-Jago, seagrass grows side by side with mangroves so that, there is a possibility of competition for a place to live and nutrition. This is supported by research by [27] which found that there is interaction and competition for a place to grow between seagrass and mangroves that live side by side.

3.3. Seagrass biomass

Seagrass biomass is divided into two parts, namely above-ground biomass consisting of leaf blades and midrib and below-ground biomass consisting of roots and rhizome. The results of measurements of the biomass of *Enhalus acoroides* at the study location showed that the value of the below-ground biomass was much greater than that above-ground biomass with the average biomass above-ground the substrate ranging from 140.19 – 188.72 g/m² and the below-ground biomass ranging from 368.13 – 423.69 g/m² (Figure 3) Duarte et al. [28] and Tasabaramo et al. [29] revealed that in general the ratio of biomass at the bottom of the seagrass was greater than that of the upper part, this was due to the results of photosynthesis, and the nutrients absorbed by the roots were mostly stored in rhizomes to support the seagrass ability to withstand ocean currents and waves.

The level of density is generally directly proportional to the total biomass of seagrass where the higher the density, the higher the total biomass and vice versa. This can be evidenced by a higher density level in Jago-Jago followed by higher biomass than the density and biomass of seagrass at Hajoran. In addition, as a large seagrass, *Enhalus acoroides* can produce a higher biomass value than other types which are generally smaller and shaped like grass. This is supported by several previous studies which show that large species such as *Enhalus acoroides* tend to have a higher biomass value than other species so that they are often the largest contributor to total biomass in a seagrass bed community [30].
3.4. Seagrass carbon

The measurement of organic carbon in seagrass was carried out using the LOI method. The results of the average measurement of carbon stock ranged from 70.57 – 94.86 g Corg/m² at the top and 187.31 – 196.03 g Corg/m² at the bottom (Figure 4). The advantage of this condition is that when the fronds and seagrass leaves are broken due to natural or anthropogenic factors, whereas seagrass is still able to store a large amount of carbon at the bottom while waiting for the leaves to grow again. The total standing stock of carbon obtained from this study was 257.87 – 290.90 g Corg/m² (Figure 5). The top of the seagrass, such as the leaves, is a short-term carbon store because it is widely used in the food chain (consumed by herbivores) and is susceptible to exposure to aerobic conditions and chemicals [14].

![Figure 3. Enhalus acoroides density biomass](image)

![Figure 4. Above-ground and below-ground carbon stock.](image)
Each species has a different ability to absorb and store carbon. As well as its ability to produce biomass, the carbon stock contained in its tissues are stored larger at the bottom, namely the rhizome and roots. *Enhalus acoroides* that grow in tropical water have a high ability to absorb and store carbon because of the larger size of the stem, rhizome, and roots than other species so that it can produce large biomass and high carbon uptake [31]. Large species are also able to survive longer because of the slow turnover of roots and rhizomes compared to small species such as *Halophila ovalis* which affects their ability to accumulate total carbon storage [30, 32, 17].

Seasonal factors also affect the ability of seagrass as carbon storage. High waves in the rainy season are causing litter to increase and reduce its ability to store seagrass while in the dry season the sun's intensity is higher so that seagrass is more exposed to the sun during low tide which causes the ability to absorb and store carbon to be better [33]. The probability that the carbon value obtained is higher in this study because the measurement and sampling were carried out in the eastern or dry season period, but further research is needed to confirm this because there is no research result on seagrass carbon in Central Tapanuli which was carried out in the western season which can be used as a comparison.

The amount of carbon stored in seagrass is influenced by various factors so that there are differences in carbon stocks in seagrass in each region (Table 3). Seagrass is proven to be able to absorb and store carbon dioxide in its biomass, this shows that seagrass has an important role in climate change mitigation, so that it needs to preserve the seagrass ecosystem to be sustainable. However, when the seagrass beds are damaged, it eliminates their ecological function and releases the carbon stored back into the atmosphere [34-36].

**Figure 5.** Standing stock carbon.

| Location                        | Carbon Stock (g Corg m⁻²) | Source |
|---------------------------------|--------------------------|--------|
| Berakit (Bintan, Riau Islands)  | 233.67                   | [30]   |
| Pulau Kaposong (South Sulawesi)| 16.40                    | [15]   |
| Karang Tirta (West Sumatera)   | 12.99                    | [37]   |
| Pulau Befondi (Papua)          | 18.04                    | [38]   |

The table shows that each region in Indonesia has different potential carbon stock., when compared to the location of this study with other research in Table 3 illustrates that Hajoran and Jago-jago (Central Tapanuli) have the higher potential carbon stock than others which ranges 251.87-290.90 g Corg/m². Regarding [39] stated the total above-ground carbon, below-ground carbon, standing stock, and carbon
sequestration of seagrass meadows in Indonesia were ca 80–314 ktC, 196–696 ktC, 276–1005 ktC and 1.6–7.4 MtC/year, respectively. Considering their potential for carbon stock and carbon sequestration, Indonesia’s seagrass meadows play important roles in greenhouse gas reduction and climate change mitigation.

4. Conclusion

This study found the seagrass community on the coast of Hajoran and Jago-jago which is covered by the monospecific Enhalus acoroides is in a less healthy condition with a cover percentage of 30.3-33.3% and a density of 59 - 67 shoots/m². The percentage of biomass reached 140.19-188.72 g/m² at the top and 368.13-423.69 g/m² below-ground, while carbon stock reached 70.57-94.86 g Corg/m² at the top and 187.31-196.03 g Corg/m² at the bottom of substrate and the total standing stock range 257.87-290.90 g Corg/m². The data obtained from this research can be used as a database to see the potential of seagrass beds as storage of CO₂ and as an effort to mitigate and adapt to climate change. In addition, seagrass beds role can be taken into consideration in conservation efforts for the sustainability of the seagrass ecosystem in Central Tapanuli.

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References

[1] Chiba T, Haga Y, Inoue, M Madokoro H and Morino Isamu 2019 Measuring Regional Atmospheric CO2 Concentrations in the Lower Troposphere with a Non-Dispersive Infrared Analyzer Mounted on a UAV, Ogata Village, Akita, Japan Atmosphere 10(487) 1-17
[2] He Q and Silliman BR 2019 Climate change, human impact, and coastal ecosystem in the Anthropocene Curr. Biol. 29(19) R1021-R1035
[3] Ramesh R, Banarjee K, Paneerselvan A, Raghuraman R, Purvaja R and Lakshmi A 2019 Importance of seagrass management for effective mitigation of climate change, in RR Krishnamurty, M P Jonathan, S Srinivasalu and B Glaeser (eds), Coastal Management Global Challenge and Innovations (Elsevier) pp 283-299
[4] Dawes C J 1981 Marine Botany (New York: John Wiley and Sons Inc) 628 p
[5] Mellors J, Marsh H and Tim J B 2002 Testing the sediment-trapping paradigm of seagrass: do seagrasses influence nutrient status and sediment structure in tropical intertidal environments? Bull. Mar. Sci. 71(3) 1215-1226
[6] Unsworth R F K, McKenzie L J, Collier C J, Cullen-Unsworth L C, Duarte C M, Eklof J S, Jarvis J C, Jones B L and Nordlund L M 2019 Global challenges for seagrass conservation Ambio 48: 801-815
[7] Jiang Z, Huang D, Fang Y, Cui L, Zhao L, Liu S, Wu Y, Chen Q, Ranvilage C I P M, He J and Huang X 2020 Home for Marine Species: Seagrass Leaves as Vital Spawning Ground and Food Source Front. Mar. Sci. 7 1-9
[8] Rustam A, Kepel T L, Afiati R N, Salim H L, Astrid M, Daulat A, Mangindaan P, Sudirman N, Rahayu Y P, Dwiyanti D, and Hutahaean A A 2014 The role of seagrass as blue carbon in climate change mitigation, a case study of Tanjung Lesung, Banten Segara 10(2) 107-117 (in Bahasa Indonesia)
[9] Herr D and Landis E 2016 Coastal blue carbon ecosystems Opportunities for Nationally Determined Contributions Policy Brief. Gland. Switzerland: IUCN and Washington, DC, USA: TNC 28 p
[10] Lawrence A 2012 Blue carbon a new approach for reducing the impacts of climate change by conserving coastal ecosystem in the Coral Triangle (Australia: WWF) 21 p
[11] Sifleet S, Pendleton L and Murray B C 2011 State of the Science on Coastal Blue Carbon: Science Summary for Policy-Makers Duke University, Durham, USA 42 p

[12] Waycott M, Duarte C M, Carruthers T J B, Orth R J, Dennison W C, Olyarnik S, Calladine A, Fourqurean J W, Heck K L, Hughes A R, Kendrick G A, Kenworthy W J, Short F T, Williams S L 2009 Accelerating loss of seagrasses across the globe threatens coastal ecosystems Proc. of the National Academy of Sciences 106(30)12377–12381

[13] Nellemann C, Corcoran E, Duarte C M, Valdes I, De Young C, Fonseca I, Grimsditch G (Eds) 2009 Blue Carbon A Rapid Response Assessment United Nation Environment Programme, GRID-Arendal, Birkeland Trykkeri AS, Birkeland, Norway 80 p

[14] Fourqurean J W, Duarte C M, Kennedy H, Marba N, Holmer M, Mateo M A, Apostolaki E T, Kendrick G A, Krause-Jensen D, McGlathery K J and Serrano O 2012 Seagrass ecosystems as a globally significant carbon stock Nature Geosci 5 505-509

[15] Rustam A, Sudirman N, Afi Ati R N, Salim H L and Rahayu Y P 2017 Seagrass ecosystem carbon stock in the small island: case study in the Spermonde Island, South Sulawesi Indonesia Segara 13(2) 97-106 (in Bahasa Indonesia)

[16] Rahayu Y P, Solihuddin T, Kusumaningtyas M A, Afi Ati R N, Salim H L, Rixen T M and Hutahean A A 2019 The Sources of Organic Matter in Seagrass Sediments and Their Contribution to Carbon Stocks in the Spermonde Islands, Indonesia Aquat Geochem 25, 161–178 (2019)

[17] Rahmawati S 2011 Estimation of carbon stock at seagrass community lamun in Pari Island, Taman Nasional Kepulauan Seribu, Jakarta Segara 7(1) 1-12 (in Bahasa Indonesian)

[18] Short F T and Coles R G 2001 Global Seagrass Research Method (Amsterdam: Elsevier) 482 p

[19] Ministry of Environment of Indonesia Republic 2004 Ministry of Environment No200 of 2004 Raw Damage Criteria and Guidelines for Determination of Status of Seagrass Jakarta: Indonesia

[20] Rahmawati S, Hernawan U E, McMahon K, Prayudha B, Prayitno H B, Wahyudi A J and Vanderklift M 2019 Blue carbon in Seagrass Ecosystem: Guideline for Assessment of Carbon Stock and Sequestration in Southeast Asia (Yogyakarta: UGM Press) 112 p

[21] Oscar M A, Barak S and Winters G 2018 The tropical invasive seagrass, Halophila stipulacea, has a superior ability to tolerate dynamic changes in salinity levels compared to its freshwater relative, Vallisneria Americana Front. Plant Sci. 9 950

[22] Ministry of Environment of Indonesia Republic 2004 Ministry of Environment No51 of 2004 on Marine water quality standards for marine tourism Jakarta: Indonesia

[23] Yunitha A, Wardiatno Y and Yulianda F 2014 Substrates diameter and seagrasses species in Bahoi Coastal North Minahasa: a correlation analysis Jurnal Ilmu Pertanian Indonesia 19(3) 130-135 (in Bahasa Indonesia)

[24] Ramili Y, Bengen D G, Maduppa H H and Kawaroe M 2018 Morphometric characteristics of two seagrass species (Enhalus acoroides and Cymodocea rotundata) in four small islands in North Maluku, Indonesia Biodiversitas 9(6) 2035-43

[25] Kawaroe M, Nugraha A H, Juraïj and Tabusaramo I A 2016 Seagrass biodiversity at three marine ecoregions of Indonesia: Sunda Shelf, Sulawesi Sea, and Banda Sea Biodiversitas 17(2): 585-591

[26] Supriadi, Soedharma D and Kaswadji R F 2006 Some aspects seagrass growth of Enhalus acoroides (Linn F) Royle on Barranglompo Island Makassar Biosfera 23(1) 1-8 (in Bahasa Indonesia)

[27] Mendoza A R R, Patalinghun J M R and Divinagracia J Y 2019 The benefit of one cannot replace the other: seagrass and mangrove ecosystems at Santa Fe, Bantayan Island J. Ecol. Environ. 43 18

[28] Duarte C M, Kennedy H, Marba N and Hendriks I 2013 Assessing the capacity of seagrass meadows for carbon burial: current limitation and future strategies Ocean and Coastal Management 83 23-8
[29] Tasabaramo I A, Kawaroe M and Rappe R A 2015 Growth rate, cover, and survival rate (Enhalus acoroides) transplanted in monospecies and multispecies JITKT 7(2) 757-70 (in Bahasa Indonesia)

[30] Khairunnisa, Setyobudiandi I and Boer M 2018 The estimation of seagrass carbon stocks in the east of Bintan Regency JITKT 10(3) 639-650 (in Bahasa Indonesia)

[31] Duarte C M, Narba M, Gracia E, Fourqueuran J Q, Beggins J, Barron C and Apostolaki E T 2010 Seagrass community metabolism: assessing the carbon sink capacity of seagrass meadows Global Biogeochem 24 1-8

[32] Kaewsrikhaw R, Ritchie R J and Prathep A 2016 Variations of tidal exposures and seasons on growth, morphology, anatomy and physiology of the seagrass Halophila ovalis (RBr) Hook f at a seagrass bed in Trang Province, Southern Thailand Aquatic Botany 130 11-20

[33] Supriadi, Kaswadj R F, Bengen D G and Hutomo M 2014 Carbon stock of seagrass community in Barranglombo Island, Makassar Jurnal Ilmu Kelautan 19(1) 1-10 (in Bahasa Indonesia)

[34] Russel B D, Connel D S, Uthicke S, Muhlenhelmer N and Hal-Spencer J M 2013 Future seagrass beds: can increased productivity lead to increased carbon storage? Journal Marine Policy 73(2) 463-469

[35] Wawo M, Wardianto Y, Adrianto L and Bengen D G 2014 Carbon stored on seagrass community in marine nature tourism park of Kotania Bay, Western Seram, Indonesia Jurnal Manajemen Hutan Tropika 20(1) 51-57 (in Bahasa Indonesia)

[36] Lovelock C E, Atwood T, Baldock J, Duarte C M, Hickey S, Lavery P S, Masque P, Macreadie P I, Ricart A M, Serrano O and Steven A 2017 Assessing the risk of carbon dioxide emissions from blue carbon ecosystems Front. Mar. Sci. 15 257–265

[37] Azzahra, Chairul and Zakaria I J 2020 Carbon stock of seagrass in Karang Tirta’s coastal area, Padang Bioscience 4(1) 73-78

[38] Nugraha A H, Tasabaramo I A, Hernawan U E, Rahamawati S, Putra R D and Idris F 2020 Estimation of Carbon Stocks in Seagrass Ecosystems in Northern Papua Waters (Case Study: Liki Island, Befondi Island and Meossu Island) Jurnal Kelautan Tropis 23(3) 291-298 (in Bahasa Indonesia)

[39] Wahyudi A J et al. 2020 Assessing Carbon Stock and Sequestration of the Tropical Seagrass Meadows in Indonesia Ocean Sci J 55 85–97