The role of seagrass ecosystem in small islands as a blue carbon in climate change mitigation in Indonesia (case study: Lembeh Island, Bitung Regency)

A Rustam, D D Suryono, A Daulat and N Sudirman

Marine Research Center, Agency for Marine and Fisheries Research and Human Resources, Ministry of Marine Affairs and Fisheries, the Republic of Indonesia

Email: august.daulat@gmail.com

Abstract. Climate change phenomenon has occurred equally and globally all over the world during the last century, including Indonesia, which known as an archipelagic country with more than 17,000 islands, where most of the island considered as small islands. Lembeh Island known by its high biodiversity in marine resources, especially coral reef which associated with other coastal ecosystems such as mangrove and seagrasses and create a healthy environment. Seagrasses as a blue carbon ecosystem can be functioned as a carbon absorber from the atmosphere and storage in the sediment, and supported the climate change mitigation act in Indonesia. Based on field observation, Lembeh Island region has seven species from possible twelve seagrass species found in Indonesia. Enhalus acoroides and Thalassia Hemprichii dominated the seagrass existence in Lembeh Island with certain characteristics live in a sandy substrate, muddy area or coral reefs. Seagrass in Lembeh Island has potency on biomass carbon as much as 0.96±1.327 MgCha⁻¹ (mostly autochthonous), which lower than the potency of carbon stored in sediment reached more than 40 MgCha⁻¹ (mostly allochthonous). Seagrass ecosystem play an important role in climate change mitigation act and should be supported, developed and collaborated with other coastal ecosystems such as coral reefs and mangroves.

1. Introduction
Seagrass has several ecosystem services for the adjacent environment not only as a producer, and biota habitat (spawning grounds, nursery grounds, and foraging areas) [1] but also as a sediment catcher, water purifier, and a nutrient recycler [2]. According to Phillips and Menez [3], the seagrass ecosystem known as a productive marine ecosystems in shallow waters which has functions as following: a) Stabilizing and trapping sediments carried by currents and waves pressure (sediment trap); b) Reducing currents and waves through it leaves, which also increasing sedimentation; c) Providing protection for animals and adults near the seagrass beds; d) Helpful for the epiphytes organism; e) High in productivity and growth; f) Fixing CO₂ in the water column, which partly enters the food chain recycling system, while others stored in biomass and sediment.

The ability of seagrass to do the CO₂ fixation in the water body, which is used for photosynthesis process will reduce CO₂ in the water column and be stored in biomass and sediment. The amount of seagrass ability to store carbon in biomass varies, where large seagrass has the ability to store CO₂ in biomass longer than the small one caused by its leaf turnover rate, which associated with the amount of carbon stored (carbon sink) in the epiphytes attached to the seagrass leaves. Seagrass sediments stored the biggest portion of carbon pool, which divided into two types namely allochthonous carbon that comes from other ecosystem (based on seagrass function as a sediment trap) and autochthonous carbon which deposited in the seagrass ecosystem by natural decomposition [4].

Small islands defined based on two main criteria, namely the size of the islands (with extent less than or equal to 10,000 km²) and the number of inhabitants (population of less than or equal to 200,000 people), which is adopted nationally according to the Minister of Marine Affairs and Fisheries Decree No. 41/2000 Jo the Minister of Marine Affairs and Fisheries Decree No. 67/2002. Furthermore,
small islands also have its own characteristics particularly physically, ecologically, socially, economically and culture compared to the mainland.

Lembeh Island, Bitung considered as a small island located in the tip of Sulawesi Island, specifically in the North Sulawesi Province, which is famous with its coral biodiversity as part of Coral Triangle region and well-known diving spot in the world [5]. This study aims to obtain and examine the existing conditions of the seagrass presence and its environmental conditions in correlation to the climate change mitigation action mandated by the government of Republic of Indonesia.

2 Methodology

2.1. Location

The study site located in Lembeh Island, administratively under the authority of Bitung City and geographically lies between 124° 30' 24" - 124° 56' 24"E and 10° 08' 19" - 00 50' 46"N (Figure 1). Lembeh Island has an area of 5,155.84 hectares and situated near Bitung Port right to the mainland (Sulawesi Island).

2.2. Data collection

The research method was carried out by purposive sampling which is expected to represent the island based on the presence of seagrass whether by boat or walk. SeagrassWatch method used to collect information of seagrass using line transect and modified following the condition of the seagrass bed [6]. The transect line is drawn perpendicular to the coastline and then a square measuring 50 x 50 cm² placed systematically with a distance between squares of 10 meters, depending on the length of the
seagrass bed. The distance between transects ranging from 50-100 meters depending on the width of the seagrass bed.

Parameters taken from each station were the percentage of seagrass canopy cover in 50 x 50 cm² squared frame visually based on SeagrassWatch method [6], encompassing the total percentage coverage and from each species. The number of seagrass shoots for large seagrass species such as *Enhalus acoroides* was counted inside the 50 X 50 cm² frame, while for other species and specimens were collected in smaller frame 25 x 25 cm². The specimens were placed in labeled plastics for further treatment. Each type of seagrass found in the site was also taken as a specimen for re-identification.

2.3. Data analysis

To find out the species composition, it was done by comparing the number of individuals of each species with the total number of individuals found.

Specific density (Ki), which is the total number of species in a measured unit area. The species density of seagrass calculated with reference to Fachrul [7], as follows:

$$K_i = \frac{N_i}{A}$$

where:

- Ki = density of the i species
- Ni = Total number of individuals of type i
- A = Total sampling area (m²)

The carbon content on biomass was calculated based on the formula from Fourqurean *et al.* [8]:

$$\text{Carbon biomass} = \frac{\text{Dry weight (kg)/area (m}^2\text{)} \times C\%}{\text{Conversion in Mg C/ha} = \text{Carbon biomass (kg C/m}^2\text{)} \times (\text{Mg/1,000kg}) \times (10,000m^2/ha)}$$

The total biomass carbon stock is the summary of all species found in the sampling plot.

Stock carbon sediment was calculated after bulk density analysis, which obtained by calculating using formula from Kauffman and Donato [9]:

$$\text{Bulk density} = \frac{\text{dry weight sample (g)}}{\text{volume sample (cm}^3\text{)}}$$

Furthermore, the calculation of carbon concentration in sediments is carried out with the following formula by Kauffman and Donato [9]:

$$\text{Sediment carbon (Mg/ha)} = \text{bulk density (g/cm}^3\text{)} \times \text{depth interval (cm)} \times \text{C\%}$$

Sifleet *et al.* [10] stated that the carbon content obtained under units of gC/cm³ with a depth of up to the first 1 m (top soil) can be equalized to the amount of CO₂ used or stored by using the following formula:

$$\text{CO}_2 \times \frac{10^4 \text{ cm}^3}{1 \text{ m}^2} \times \frac{10^4 \text{ m}^2}{1 \text{ ha}} \times \frac{44 \text{ g CO}_2}{1 \text{ Mg C}} \times \frac{1 \text{ Mg}}{10^6 \text{ g}} = \frac{\text{MgCO}_2}{\text{ha} \times \text{m}}$$

3. Results and Discussion

Lembeh Island is a small island located in front of Bitung Port in Bitung City, with two sub-districts namely North Lembeh and South Lembeh, which is part of Sulawesi Island (mainland). The water
quality condition in Lembeh Island visually is still in a good condition with all activities surroundings, including the presence of Bitung Port and traditional capture fisheries by fishermen. Lembeh Island known as tourism destination in North Sulawesi, especially for snorkeling and diving activities with more than 43 dive points and 352 types of fish that can be found in the Lembeh Strait, besides the historical Trikora monuments, and various of ship wreck from the World War II.

3.1. Species composition
The results of research on seagrass in Lembeh Island found seven species of seagrass consisting of two families, namely Hydrocharitaceae and Cymodoceaceae. Three types from the Hydrocharitaceae family, namely Enhalus acoroides, Thalassia hemprichii and Halophila ovalis. The four types of the Cymodoceaceae family are Cymodocea serrulata, C. rotundata, Halodule uninervis and Syringodium isoetifolium. The types of seagrass found in nine locations can be seen in Table 1. Indonesian waters have 12 species of seagrass, although according to Kiswara [11] Indonesia has 14 types of seagrass based on the herbarium at the Botanical Museum, Bogor, namely Ruppia maritime and Halophila beccarii and according Kuo [12] has 15 types with the new endemic species Halophila sulawesii.

Table 1. Seagrass species found in Lembeh Island, Bitung, North Sulawesi

| Seagrass species | 14TL1 | 14TL2 | 14TL3 | 14TL4 | 14TL5 | 14TL6 | 14TL7 | 14TL8 | 14TL9 |
|------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Hydrocharitaceae  |       |       |       |       |       |       |       |       |       |
| Enhalus acoroides | X     | X     | X     | X     | X     | X     | X     | X     | X     |
| Halophila decipiens | -     | -     | -     | -     | -     | -     | -     | -     | -     |
| Halophila ovalis  | -     | -     | -     | X     | X     | X     | X     | X     | -     |
| Halophila minor   | -     | -     | -     | -     | -     | -     | -     | -     | -     |
| Halophila spinulosa| -     | -     | -     | -     | -     | -     | -     | -     | -     |
| Thalassia hemprichii | -     | -     | -     | X     | X     | X     | X     | -     | -     |
| Cymodoceaceae     |       |       |       |       |       |       |       |       |       |
| Cymodocea serrulata| -     | -     | -     | X     | X     | X     | X     | -     | -     |
| Cymodocea rotundata| -     | -     | -     | X     | X     | -     | X     | -     | -     |
| Syringodium isoetifolium | -     | -     | -     | X     | X     | X     | X     | -     | -     |
| Thalassodendron ciliatum | -     | -     | -     | -     | -     | -     | -     | -     | -     |
| Halodule uninervis | -     | -     | -     | X     | X     | -     | X     | X     | -     |
| Halodule pinifolia | -     | -     | -     | -     | -     | -     | -     | -     | -     |

Note: X = exist
- = not exist

Table 1 shows that seven types of seagrass were found at station 14TL7 and the least number was found at stations 14TL1 to 14TL3 which were monospecies location for E. acoroides with a coverage percentage ranging from 10 to 40%. Based on observation, it can be seen that E. acoroides found in all stations in the study site, which means that Lembeh Island environment suits the requirement for E. acoroides habitat. The existence of E. acoroides also display the ability of this species to live on a variety of substrates, from sand, coral to mud and resistant to competition with other species (Figure 2).
Seagrass composition found in Lembeh Island relatively distributed evenly, ranging from 5% to 20%, where there were no dominance of specific species as shown in Figure 3.

3.2. Density
The density of seagrass species at the study site based on shoots or individual extension of seagrass (individuals/m²) using a frame with an area of 0.0625 m² as shown in Figure 4. There were three species of seagrass which have high density, namely *S. isoetifolium*, *H. uninervis* and *C. rotundata*. Although *E. acoroides* seagrass is found in all observation stations it does not have a high density compared to other species. This is because *E. acoroides* seagrass is a large seagrass so that the density...
in the same container will be different from other types of seagrass. However, *E. acoroides* plays an important role in the Lembeh Island seagrass ecosystem as indicated by its presence in all stations and the presence of *E. acoroides* monospecies seagrass beds in three stations.

**Figure 4.** Seagrass density by species in Lembeh Island and Tanjung Merah

### 3.3. Carbon biomass

The amount of biomass in the image above shows that based on species, the largest carbon biomass value is in the *E. acoroides* and *T. hemprichii* species which are large seagrass with a long life span. Even though small seagrasses have lower biomass, this all depends on the density and the seagrass beds formed. If seagrass beds are formed on a large scale, the complex and interconnected root systems of seagrass (rhizomes and roots) will be able to store carbon both allatochonous with the function of seagrass as a sediment trap and autochonous carbon derived from the seagrass itself, both fresh biomass, litter and that is decomposed.

**Figure 5.** Seagrass carbon biomass in all stations and average in Lembeh Island

The value of carbon biomass in Lembeh Island was $1.04 \pm 1.333$ MgC / ha, smaller than the value obtained in Tanjung Lesung, Banten [13] but greater than in Derawan Island [14] and Kema waters.
The amount of biomass is also greater in the below ground, which reinforced by the amount of carbon allocation in the below ground area of 63% of the total biomass carbon. The potency of carbon content stored in sediment of seagrass ecosystem in Lembeh Island, Bitung can be seen in the Figure 6 below.

![Figure 6. Sediment carbon content of seagrass by stations in Lembeh Island](image)

The Figure above shows the magnitude of sediment carbon content in Lembeh Island seagrass, where the layer depth of 6-10 cm has high carbon content particularly at stations 14TL3 to 14TL7, compared to the carbon content at stations 14TL1 and 14TL2. Low content of carbon in sediment especially in station 14TL1 and 14TL2, where the dominant species is *E. acoroides* caused by its location towards land, which predicted to have more influence from the mainland (terrigenous sediment) with low carbon content, but still bigger compared to the organic carbon whether from autochthonous nor allochthonous carbon. The role of seagrass as a sediment trap especially *E. acoroides* with its leaves like a ribbon will catch sediments during the high tide, and place for ephytes which also contributed in storing carbon. Healthy seagrass commonly live in habitat with high carbon content in its sediment, and will continue its ability to store carbon and restrain it due to a complex root system.

Overall, the function of seagrass as a dissolved CO$_2$ absorber in the water for photosynthesis purpose will reduce the dissolved CO$_2$ content in water, causing the CO$_2$ flow from the atmosphere to the water known through the CO$_2$ partial pressure difference. This function will work well just if supported by healthy and massive seagrass ecosystem and its adjacent environment. The existence of seagrass plants stores less organic carbon than mangroves, but its function as a sediment trap was huge, not only storing autochthonous carbon but also allochthonous carbon from other ecosystems such as from the sea and from mangroves or estuaries greater and longer. Several research on carbon stock in seagrass biomass and sediment showed a contrast carbon content based on its location, such as in Miskam Bay, Tanjung Lesung with 1,32 Mg C/ha equivalent to 4,85 Mg CO$_2$e/ha in biomass, while in the sediment about 475,21 Mg C/ha equivalent to 1,742,43 Mg CO$_2$e/ha [13] compared to Spermonde Island, where the carbon stored in seagrass biomass is 0,57 Mg C/ha equivalent to 2,07 Mg CO$_2$e/ha and in sediment is 186,15 Mg C/ha equivalent to 682,54 Mg CO$_2$e/ha [16], while the above carbon stock, below carbon stock and carbon sequestration capacity of seagrass ecosystem in Indonesia based on coverage reached 80-314ktC, 196-696 ktC, and 1.6-7.4 MtC/year respectively [17].
Moreover, the benefits of the seagrass ecosystem as blue carbon in mitigating climate change in addition to reducing and storing CO₂, which is a greenhouse gas (GHG), will also avoid the vulnerability of small islands regarding sea level rise issue [18]. The existence of healthy and massive seagrass will prevent and slowdown the effect of sea level rise on small islands. The role of the blue carbon coastal ecosystem will reduce CO₂ in the atmosphere which will have an indirect impact on decreasing CO₂ content in the atmosphere and help to control the earth’s temperature and considered as the contribution of coastal ecosystem through it services, particularly seagrass ecosystem.

4 Conclusion
There are 7 species of seagrass found on Lembeh Island, where the *Enhalus acoroides* species are found in all locations, while the highest density is *Syringodium isoetifolium*. *Enhalus acoroides* species have the potential to mitigate climate change on Lembeh Island by existing in all stations and are large in size compared to other species. The highest carbon stock in biomass located at station 14TL1, which is a monospecies *Enhalus acoroides* seagrass bed. The highest carbon stock potential in the surface layer sediment was at station 14TL7, which is a mixed seagrass bed with the highest density of *Syringodium isoetifolium*. The seagrass ecosystem on Lembeh Island, apart from having the potential to mitigate climate change, also plays a role in protecting the surrounding ecosystem, especially coral reefs where Lembeh Island is located in a coral triangle area with beautiful diving spots worldwide.

Acknowledgment
Thank you to Mr. Riyanto Basuki M.Si, as the Head of Marine Research Center, Agency for Marine And Fisheries Research and Human Resources for the assistance and facilities provided in this research. Last but not least, the entire Blue Carbon Indonesia Team of Marine Research Center who have done such an excellent research in North Sulawesi Province.

References
[1] Jiang Z, Huang D, Fang Y, Cui L, Zhao C, Liu S, Wu Y, Chen Q, Ranvilage CIPM, He J and Huang X 2020 Home for Marine species: seagrass leaves as vital spawning grounds and food source. Front. Mar. Sci. 7:1-9.
[2] Mtwana Nordlund L, Koch EW, Barbier EB, Creed JC 2016 Seagrass Ecosystem Services and Their Variability across Genera and Geographical Regions. PLoS ONE 11(10): e0163091. doi:10.1371/journal.pone.0163091
[3] Phillips R C and Menez E G 1988 Seagrasses. Smithsonian Contribution to The Marine Sciences. Number 34 (Washington DC:Smithsonian Institution Press) p 116
[4] Howard J, Hoyt S, Isensee K, Pidgeon E, and Telszewski M 2014 Coastal Blue Carbon: Methods for Assessing Carbon Stocks and Emissions Factors in Mangroves, Tidal Salt, and Seagrass Meadows (Arlington, Virginia USA: International Union for Conservation of Nature, IUCN) p 180
[5] Veron J E N, Devantier L M, Turak E, Green A L, Kininmonth S, Stafford-Smith M, Peyersen, N 2009 Delineating the Coral Triangle *Galaxea, J. Coral Reef Stud* 11:91–100
[6] McKenzie L J, Campbell S J, and Roder C A 2003 Seagrass-Watch: Manual for Mapping & Monitoring Seagrass Resources by Community (Citizen) Volunteers, 2nd Edition. (Townsville: The State of Queensland, Department of Primary Industries)
[7] Fachrul M F 2007 Metode Sampling Biokologi (Jakarta: Bumi Aksara)
[8] Fourqurean, J W, Johnson B, Kauffman J N, Kennedy H, Emmer I, Howard J, Pidgeon E, Serrano O 2014 Conceptualizing the project and Developing a Field Measurement Plan. ed J Howard *et al* Coastal Blue Carbon: Methods for Assessing Carbon Stock and Emissions factor in Mangrove , Tidal Salt Marsh and Seagrass Meadow. The Blue Carbon Initiative. pp 39-107
[9] Kauffman J B and Donato D C 2012 *Protocols for the Measurement, Monitoring and Reporting
of Structure, Biomass and Carbon Stocks in Mangrove Forest (Bogor: CIFOR) p 40

[10] Sifleet S, Pendleton L, and Murray B C 2011 State of the Science on Coastal Blue Carbon A Summary for Policy Makers,” Nicholas Inst. Report. NI, no. May 2011, p. 43, 2011, doi: 10.1108/13665620210427294.

[11] Kiswara W 2009 Studi Pendahuluan: Potensi Padang Lamun Sebagai Karbon Rosot dan Penyerapan Karbon di Pulau Pari, Teluk Jakarta. *Jurnal Oseanologi dan Limnologi* 36(3): 361-76.

[12] Kuo J. 2007. New monoecious seagrass of Halophila sulawesii (Hydrocharitaceae) from Indonesia. Short communication. *Aquatic Botany* 87(2):171-5

[13] Rustam A et al 2014 Peran ekosistem lamun sebagai blue carbon dalam mitigasi perubahan iklim, studi kasus Tanjung Lesung, Banten. *J Segara* 10(2): 107-17

[14] Kepel T L, Ati, R N A, Rustam A, Amri S N, Hutahaean A. 2015 Ekosistem Karbon Biru Lamun di Pulau Pulau Kecil Kepulauan Derawan Kalimantan Timur *Ekonomi Biru Sumberdaya Pesisir* ed W S Pranowo and I S Brodjonegoro (Jakarta: Pusat Penelitian dan Pengembangan Sumber Daya Laut dan Pesisir) pp 61 - 78.

[15] Rustam A et al 2015 Ekosistem lamun sebagai bioindikator lingkungan di pulau lembeh, bitung, sulawesi utara, *J. Biol. Indones* 11(2): 233–41.

[16] Rustam A, Sudirman N, Ati R N A, Salim H L, and Rahayu Y P 2017 Seagrass Ecosystem Carbon Stock in the Small Islands: Case Study in Spermonde Island, South Sulawesi, Indonesia.” *J. Segara* 13(2): 97–106.

[17] Wahyudi A J et al 2020 Assessing carbon stock and sequestration of the tropical seagrass meadows in indonesia, *Ocean Sci. J.* doi: 10.1007/s12601-020-0003-0.

[18] Duarte C M, Losada I J, Hendriks I E, Mazarrasa I and Marba N 2013 The role of coastal plant communities for climate change mitigation and adaptation. *Nature Climate Change* 3:961-68