BIO Web of Conferences **92**, 01007 (2024) https://doi.org/10.1051/bioconf/20249201007
4th ICMMBT 2023

Estimation of Carbon Stock in The Seagrass Meadows of Jelenga Bay, West Sumbawa, Indonesia

Muhammad Hizrian Irda[1*], *Devi Nandita* Choesin[2], *Muhamad Salamuddin* Yusuf[3], *Jorina* Waworuntu[1], Aslan[1], *Agus* Setianto[1], *Sephy* Noerfahmy[1]

[1]Environmental Department, PT Amman Mineral Nusa Tenggara (AMMAN), Jalan Bung Karno, 83126, Mataram, Indonesia
[2]School of Life Sciences and Technology, Institut Teknologi Bandung (ITB), Jalan Ganesa No. 10, 40132, Bandung, Indonesia
[3]ECOLINE – Center for Resource Study and Development, Jalan Industri, 83112, Mataram, Indonesia

Abstract. Blue carbon is a term used to describe the carbon stored in coastal and marine ecosystems. Research and conservation of blue carbon sinks like seagrass meadows are important in mitigating global climate change. This research aimed to estimate blue carbon stored in the seagrass meadows ecosystem of Jelenga Bay, West Sumbawa, Indonesia. Carbon stock in the seagrass community was estimated based on correlation analysis of density, biomass, and organic carbon content. Meanwhile, the correlation analysis of dry bulk density and organic carbon content was used to estimate the susbtrate carbon stock. Four seagrass species were found in Jelenga Bay, i.e., Enhalus acoroides, Thalassia hemprichii, Cymodocea rotundata, and Halodule pinifolia. Carbon stock estimation of the seagrass community within 107.1 hectares area showed that aboveground biomass stored 19.1 Mg of carbon (0.18 Mg C/ha), whereas belowground biomass stored 28.4 Mg of carbon (0.26 Mg C/ha). Carbon stock estimation in seagrass meadows substrate (in 1 meter depth) stored 4,590.0 Mg C (42.86 Mg C/ha). The substrate at 70-100 cm depth contributed the highest amount of carbon stock, i.e., 14.9 Mg. However, for the organic carbon content, depth of 15-30 cm showed the highest result (0.341 % of Dry Bulk Density).

1 Introduction

Climate change is a global issue that needs special concern from stakeholders from all around the world. Global climate change causes weather anomalies, melting of polar ice, rising sea levels, ocean acidification, changes in behaviour and migration routes of organisms, and other issues that threaten the survival of life on Earth [1]. Therefore, immidiate and collective actions are needed to overcome this global phenomenon.

---

[*] Corresponding Author: muhammad.hizrian.irda@amman.co.id

The global temperature increase must be maintained below 2°C (from the pre-industrial era) to minimize global climate change effects [2]. Countries worldwide ratified the Paris Agreement in 2015 as a commitment to mitigate climate change [3]. The mitigation can be done by conserving carbon storage ecosystems or carbon reservoirs, such as forests. Recent research also identifies marine and coastal ecosystems, namely mangroves, brackish swamps, and seagrass meadows, as extremely prospective carbon storage ecosystems in addition to forests [4]. Carbon stored in these ecosystems is called "Blue Carbon".

Research has shown that coastal and marine ecosystems can store substantially higher carbon per unit area than terrestrial ecosystems [5]. The extremely anaerobic substrate conditions of coastal and marine environments enable optimum organic carbon preservation [6]. The carbon absorption capacities of mangroves and other coastal and marine habitats, like brackish marshes and wetlands, have been extensively investigated, but less is known in seagrass meadows (Figure 1). Therefore, research on the potential of seagrass carbon stores is necessary [7].

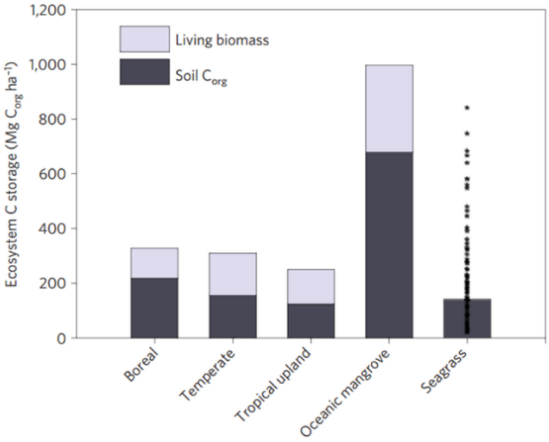

Fig. 1. Carbon storage potential per hectare of coastal and marine and terrestrial ecosystems [7].

Seagrass is the only group of Angiospermae which can live submerged in high salinity water (± 30 $^{0}/_{00}$). Seagrass has roots, true stems and leaves, and stem modification as a rhizome. It reproduces by bearing fruit and shoots. Seagrasses can grow from the coast to shallow waters at 0.5 to 8.5 meters depth. Some species can live in deep water. Broad seagrass bed, consisting of a single species or a mixture of some species, is called seagrass meadows. Seagrass meadows play a substantial function in marine ecosystems, namely as a foraging and nurturing place for marine biota, sediment traps and carbon storage [8]. Despite these, seagrass areas are continuously degraded due to anthropogenic pressure [9]. Research on seagrass carbon stocks can be used as further consideration in ecosystem valuation as a seagrass conservation effort.

Geographically, six bioregional groups make up the world's seagrass ecosystems: The Temperate North Atlantic Coast, The Temperate North Pacific, The Mediterranean, The Temperate Southern Ocean, The Tropical Atlantic, and The Tropical Indo-Pacific. The Indo-Pacific bioregion has vast areas and a high diversity of seagrass species. Indonesian coastal waters are some with the highest diversities and the largest in this bioregion [10]. The coast of West Sumbawa is known to have a fairly healthy seagrass ecosystem [11]. Jelenga Bay has the healthiest seagrass meadows ecosystem with more than 50% coverage. This condition makes Jelenga Bay a potential location as a carbon sink in the West Sumbawa region. For this reason, this study was conducted in Jelenga Bay in West Sumbawa, Indonesia, to calculate and determine factors influencing the carbon stocks at the top (aboveground), low part (belowground), and seagrass meadows substrates. This research also aims to enrich the global datasets, in particular recent researches in South East Asia, which has a potential seagrass carbon reserves [24-27].

2 Materials and Methods

Jelenga Bay is located on the west coast of Sumbawa Island. Administratively, Jelenga Bay is located in Jereweh District, West Sumbawa Regency, West Nusa Tenggara, Indonesia. Jelenga Bay stretches 4.6 km from the coordinates 8°50'20.06" South Latitude and 116°46'11.03" East Longitude to 8°51'47.19" South Latitude (SL) and 116°45'17.10" East Longitude (EL) (Figure 2). The sampling area is focused on the southern part of Jelenga Bay from coordinates 8°51'23.9" SL and 116°45'56.6" EL to 8°51'46.24" SL and 116°45'26.05" EL. The components measured in this study were the area of seagrass meadows, carbon stocks of seagrass communities, carbon stocks of seagrass meadows substrates (in 1 meter depth), and physiochemical parameters of the water.

2.1 Sampling Point Configuration

The sampling point configuration used was LIT (*line intercept transect*). Seagrass density was measured at nine transects with five points per transect or 45 points total. The transect stretches 250 m perpendicular to the coastline with a distance between points of 50 – 100 m parallel and 50 m perpendicular to the coastline. Seagrass sampling per species was done randomly using the hand-collecting method. Substrate sampling was carried out at three points with a distance of 50 m perpendicularly and 150 m parallel to the shoreline. Physicochemical parameters were measured twice at three points, 50 m perpendicular to and 150 m parallel to the coastline, during the maximum high and low tide. Figure 2 and Figure 3 describes the research area and sampling points configuration.

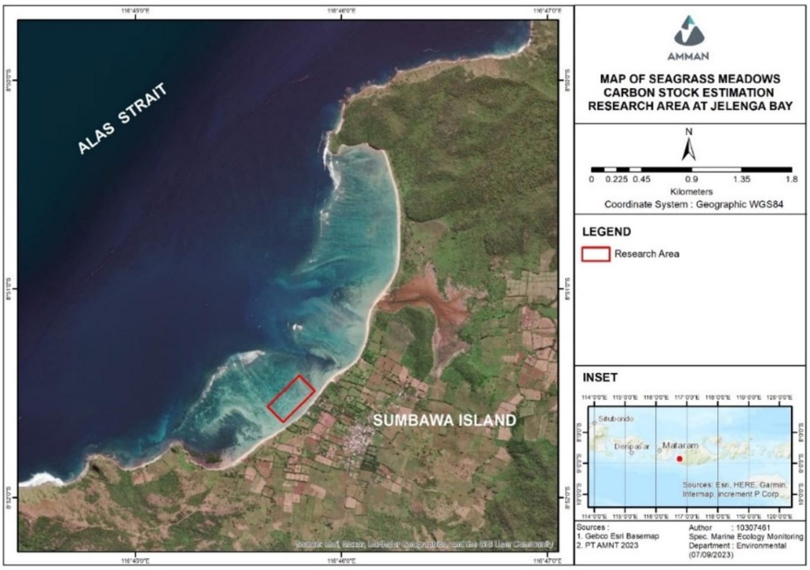

Fig. 2. Research area location at Jelenga Bay, West Nusa Tenggara, Indonesia.

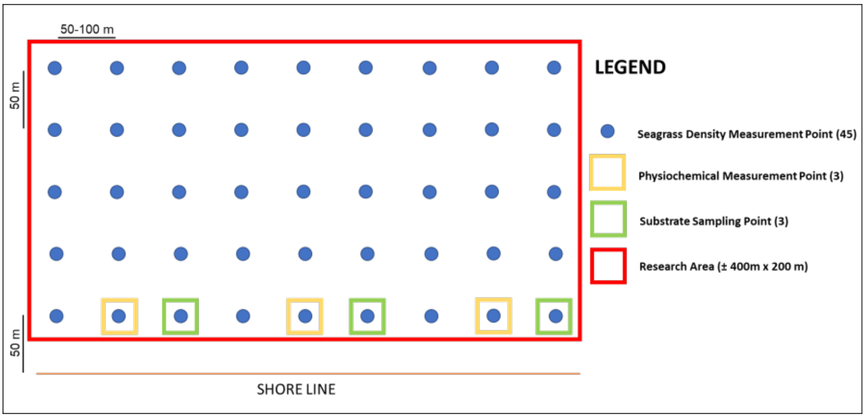

Fig. 3. Sampling point configuration.

2.2 Seagrass Meadows Area Determination

Seagrass meadows area was determined using Landsat 8 OLI image and was further processed using QGis 2.8 software. The image processing method referred to Wabnitz *et al.* [12]. Radiometric and atmospheric corrections were done before processing. The image was classified into six classes namely; shore, (submerged) sand substrate, land (terrestrial vegetation, rice fields, gardens and urban areas), waters, reefs (coral reefs and dead coral/rubble substrate), and seagrass. It was done with three repetitions using the minimum distance approach. Seagrass meadows area was measured by calculating the pixels for seagrass classes using the zone statistics plugin, and then the number of pixels was multiplied by the spatial resolution of the Landsat 8 OLI imagery (30 x 30 m).

Classification accuracy was determined through ground checks or field reviews conducted at a total of 100 points with a total of 67 seagrass class points using GPS. Accuracy calculations were carried out using the equation according to Congalton [13] following;

$$\mathrm{As} = (\mathrm{Cs} \div \mathrm{Ts}) \times 100\%$$

As = Seagrass class accuration
Cs = Number of correctly classified segrass meadows class sample point
Ts = Number of seagrass meadows sample points

$$\mathrm{At} = (\mathrm{Ct} \div \mathrm{Tt}) \times 100\%$$

At = Total accuration
Ct = Number of all correctly classified classes points
Tt = Total number of sample points

2.3 Estimation of Seagrass Community Carbon Stock

Estimation of seagrass community carbon stocks was carried out by referring to Howard *et al.* [5], Rahmawati & Kiswara [14], and Supriadi [15]. Seagrass community carbon stocks were obtained using the correlation between seagrass density per species, dry weight of seagrass per individual species, and percentage of seagrass biomass carbon content per species. Other recent seagrass carbon estimation references can also be considered in designing research methods [24-27].

Seagrass density was measured using a quadrate plot of 0.5 m × 0.5 m (Figure 4). Seagrass samples per species were obtained using hand-collecting method for several individuals of large seagrass species and several individual clumps for seagrass with smaller species

(Rahmawati & Kiswara, 2012). Individual seagrass was defined as one stems along with the leaves and sheaths, rhizome from one bud to the next, and roots along the rhizome [21].

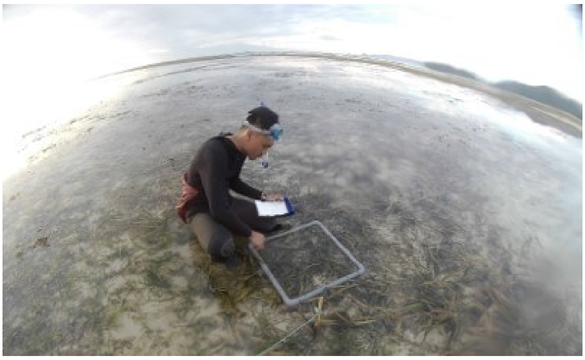

Fig. 4. Seagrass density measurement using a quadrate plot of 0.5 m × 0.5 m.

Whole seagrass samples were selected, cleaned, and divided into upper and lower parts. The above/aboveground seagrass sample consists of leaves, sheaths and stems, while the lower/belowground consists of roots and rhizomes. The division was done as the top and bottom of seagrass have different carbon content percentages [5][14]. After that, the seagrass samples were oven-dried at 60 °C for ± 24 hours until the weight was constant and the water content reached 0%. Next, several individual seagrasses were weighed using analytical scales and the average dry weight was determined. These preparation phase was conducted at The Environmental Department Laboratory of PT Amman Mineral Nusa Tenggara (AMMAN). Several individual of seagrass samples were combined and grounded. Analysis of the organic carbon content was carried out using the Walkley & Black method at the SEAMEO BIOTROP Bogor Laboratory.

The equations used in estimating the carbon stock of seagrass communities were as follows according to Howard *et al.* [5];

$$\mathrm{Ci} = \mathrm{DWi} \times \%\mathrm{Ci}$$

Ci = Carbon weight of seagrass species i (g)
Dwi = Dry weight of seagrass species i (g)
%Ci = Carbon content percentage of seagrass species i (%DW)

$$\mathrm{Ca} = \Sigma\, \mathrm{Di} \times \mathrm{Ci}$$

Ca = Seagrass carbon weight per area
(g C/m^2)*
Di = Species i density (individuals/m^2)
Ci = Carbon weight of seagrass species i (g C)

*the unit is converted to standard unit Mg C/ ha

2.4 Estimation of Seagrass Meadows Substrate Carbon Stock

Estimation of seagrass meadows substrate carbon stocks referred to the method of Howard *et al.* (2014) [5] and Walker *et al.* (2012) [15]. Substrates were sampled using a special soil corer (length ±1.5 m, diameter 2.5 cm) (Figure 5). The sample was collected for 1 meter, and separated into five depths (0-15 cm, 15-30 cm, 30-50 cm, 50-70 cm, and 70-100 cm) for organic carbon content analysis to see the differentiation between layers of depth.

Fig. 5. Soil corer.

In determining dry bulk density, substrate samples per depth were taken with a certain volume using a syringe, and oven-dried at 60°C for 24 hours. The dry weight of the substrate was weighed using an electric balance. Substrate carbon content was determined using the Walkley & Black method at the SEAMEO BIOTROP laboratory in Bogor. Substrate composition analysis was added as a supporting data. The following is the equation used in estimating substrate carbon stocks according to Walker *et al.* [15]:

$$\mathrm{Csa} = \Sigma\ \mathrm{DBDi} \times \%\mathrm{CSi} \times \mathrm{Dsi} \times 100$$

Csa = Weight of substrate carbon per unit area (Mg C/ ha)
DBDi = dry bulk density of substrate i (g/cm^3)
%Csi = carbon content of substrate i (in decimals) (%DBD)
Dsi = Substrate depth i (cm)
100 = Conversion factor g C/cm^2 to Mg C/ ha

2.5 Physicochemical water parameters measurement

Physiochemical water parameters measured in this research are listed in Table 1, which are important factors in water quality standards for seagrass ecosystems [16, 17].

Table 1. Physiochemical water parameters measured.

Parameter	Device	Unit
Current Speed	Floating drag device	m/s
Turbidity	Turbidity meter	NTU
Depth	BMKG & AMMAN Data	M
Temperature	Multimeter	ºC
Salinity	Multimeter	$^0/_{00}$
pH	Multimeter	-
DO	Multimeter	Mg/L

Physiochemical parameters were measured twice during the high and low tides. The high-tide time is between 12.00-15.00 Central Indonesia Time (WITA), while the low-tide time is between 15.00-18.00 WITA.

3 Results and Discussions

The seagrass meadows area based on Landsat 8 OLI image analysis was 107.1 ha and their distribution is presented in Figure 6. The seagrass class accuracy obtained was 82.1%, while the total class accuracy obtained was 79.0%. Seagrass spread from ±30 m to ±600 m perpendicular from the shoreline line.

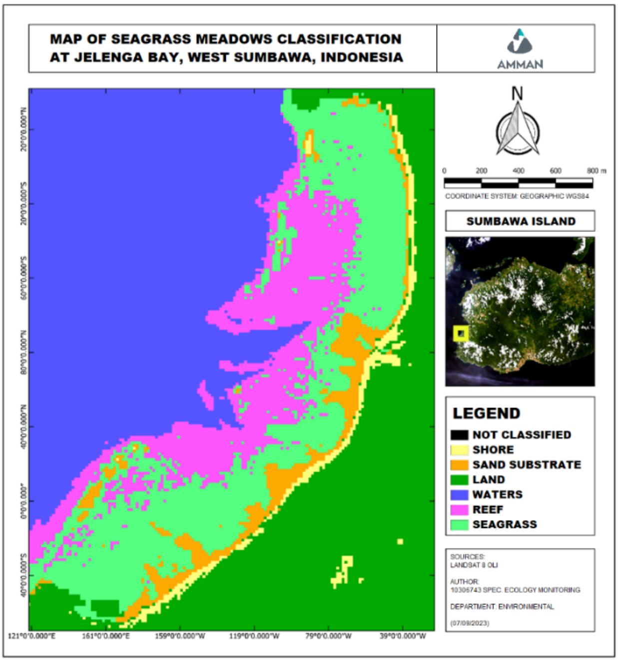

Fig. 6. Seagrass meadows at Jelenga Bay classification map.

The seagrass species found at Jelenga Bay were *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, and *Halodule pinifolia.* Species occurence frequency at 45 observation points from highest to lowest were *Cymodocea rotundata* (62.22%), *Thalassia hemprichii* (55.56%), *Enhalus acoroides* (44.44%), and *Halodule pinifolia* (6.67%) respectively (Figure 7).

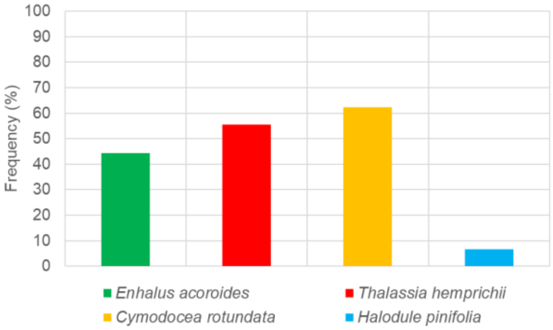

Fig. 7. Seagrass occurence frequency per species at Jelenga Bay

Seagrass density from highest to lowest were *Cymodocea rotundata* (177.96 individuals/m^2), *Thalassia hemprichii* (61.33 individuals/m^2), *Halodule pinifolia* (24.80 individuals/m^2) and *Enhalus acoroides* (14.49 individuals/m^2) respectively (Figure 8). These results indicated that the *Cymodocea rotundata* species dominated Jelenga Bay seagrass meadows. Overall, seagrass meadows density at Jelenga Bay can be categorized as low, namely <300 individuals/m^2 [18].

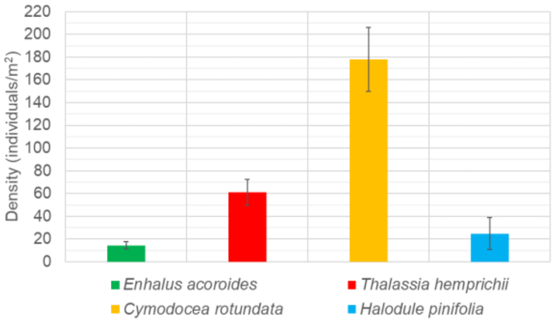

Fig. 8. Seagrass density per species at Jelenga Bay.

Organic carbon content analysis in seagrass aboveground biomass showed that *Cymodocea rotundata* was the highest with 31.150 %DW, followed by *Enhalus acoroides* (30.020 %DW), *Halodule pinifolia* (29.000 %DW), and *Thalassia hemprichii* (24.900 %DW) respectively. Meanwhile, the highest organic carbon content in seagrass belowground biomass was also showed by *Cymodocea rotundata* (35.130 %DW), followed by *Thalassia hemprichii* (29.620 %DW), *Halodule pinifolia* (24.480 %DW), and *Enhalus acoroides* (21.550 %DW) (Table 2).

Table 2. Dry weight and organic carbon content of aboveground and belowground seagrass per individual species at Seagrass Meadows of Jelenga Bay.

Species	Biomass Carbon Pool	Number of individuals	Average	±	Organic Carbon Content (% DW)
Enhalus acoroides	Above ground	13	2.210	0.348	30.020
	Below ground	17	4.205	1.025	21.550
Thalassia hemprichii	Above ground	19	0.401	0.097	24.900
	Below ground	27	0.267	0.103	29.620
Cymodocea rotundata	Above ground	106	0.086	0.049	31.150
	Below ground	127	0.053	0.026	35.130
Halodule pinifolia	Above ground	449	0.008	0.001	29.000
	Below ground	449	0.013	0.003	24.480

The total carbon stock in the seagrass community was 19.15 Mg C (0.18 Mg C/ha) for aboveground and 28.37 Mg (0.26 Mg C/ ha) for belowground. The highest aboveground carbon stock value was contributed by *Enhalus acoroides* species (7.39 Mg C) (Figure 9).

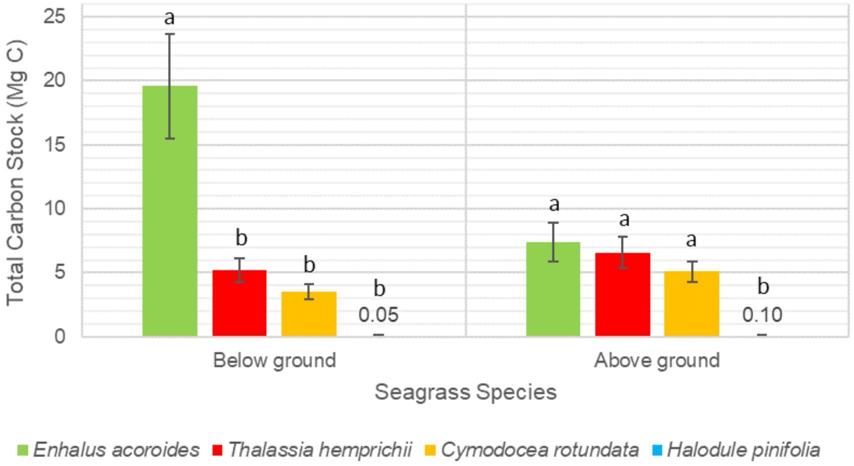

Fig. 9. Above ground and below ground seagrass biomass carbon stocks distribution in each species at Jelenga Bay ($p>0.05$).

This value was significantly different from the aboveground carbon stock value contributed by the *Halodule pinifolia* species (0.09 Mg) but was not significantly different from the other two species, *Thalassia hemprichii* and *Cymodocea rotundata* with respective values of 6.56 Mg C and 5.10 Mg C. The highest belowground carbon stock value was also contributed by *Enhalus acoroides* (19.58 Mg C). This value was significantly different from belowground carbon stocks contributed by other species, namely *Thalassia hemprichii*, *Cymodocea rotundata*, and *Halodule pinifolia*, which respectively contributed carbon stocks of 5.20 Mg C, 3.52 Mg C and 0.05 Mg C .

The significant contribution of carbon stock by *Enhalus acoroides* bed was contrast to the prevalence of *Cymodocea rotundata* within the community. This difference arose primarily from the substantial variance in dry weight, which was directly linked to the carbon stocks of these two species. Both aboveground and belowground dry weights of *Enhalus acoroides* individuals can reach tens to hundreds of times that of other species. Morphologically, *Enhalus acoroides* ranks as the largest among the twelve other species found in Indonesia [19]. Consequently, the presence of *Enhalus acoroides* exerts a profound influence on the magnitude of carbon stock in the seagrass meadows ecosystem.

Organic carbon content analysis in seagrass meadows substrate showed that depth between 15-30 cm was the highest with 0.341 %DBD, followed by depth 70-100 cm (0.301 %DBD), depth 50-70 cm (0.276 %), depth 30-50 cm (0.242 % DBD), and 0-15 (0.185 % DBD) respectively (Table 3).

This varied organic carbon content showed that carbon sequestration in substrate creates layers which varied between depth ranges, and probably caused by different turnover rate affected by season. It is also important to note that the predominant component of the substrate composition at each depth was sand (Table 4). Sand particles are larger than dust and clay, which influences the substrate's organic carbon holding capacity.

The total carbon stock within seagrass meadows substrates (in 1 meter depth) amounted to 4,589.98 Mg C, equating to 42.86 Mg C/ ha. The greatest contribution to substrate carbon stocks at different depths were as follows: at 70-100 cm depth, amounted to 1,494.19 Mg C;

at 50-70 cm, amounted to 948.86 Mg C; at 30-50 cm, amounted to 857.89 Mg C; at 15-30 cm, amounted to 777.90 Mg C; and at 0-15 cm, amounted to 511.19 Mg C (see Figure 10).

Table 3. Dry bulk density, organic carbon content, and seagrass meadows substrate composition at Jelenga Bay Seagrass Meadows.

	Dry bulk density (DBD) (g/cm^3)			**Substrate Composition (%)**				
Substrate Depth (cm)	**Average**	**±**	**Organic carbon content (% DBD)**	**Sand (200µ-2 mm)**	**Fine Sand (100-200µ)**	**Very Fine Sand (50-100µ)**	**Silt (2-50µ)**	**Clay (0.2-2µ)**
0-15	1.720	0.014	0.185	89.20	5.10	2.10	1.20	2.40
15-30	1.420	0.028	0.341	48.50	31.70	12.10	3.80	3.90
30-50	1.655	0.021	0.242	59.20	26.70	8.80	2.70	2.60
50-70	1.605	0.021	0.276	43.40	41.80	9.20	2.80	2.80
70-100	1.545	0.007	0.301	22.70	66.20	6.00	1.20	3.90

Table 4. Physicochemical water parameters measured in Jelenga waters.

	pH	**Salinity ($^0/_{00}$)**	**DO (mg/L)**	**Temperature (°C)**	**Current Speed (m/s)**	**Turbidity (NTU)**	**Depth (m)**
Jelenga Bay Measurement	8.35	29.47	5.73	29.40	0.05	1.73	0-3
±	0.14	1.54	0.87	0.57	0.02	1.10	Semidiurnal
Optimum Range	7.5 – 8.5*	24 – 35*	> 5 *	28 -30 *	0.05 – 1.00 **		Tide
* = Optimum range based on KEPMENLH No. 51 2004							
** = Optimum range based on Koch (2001)							

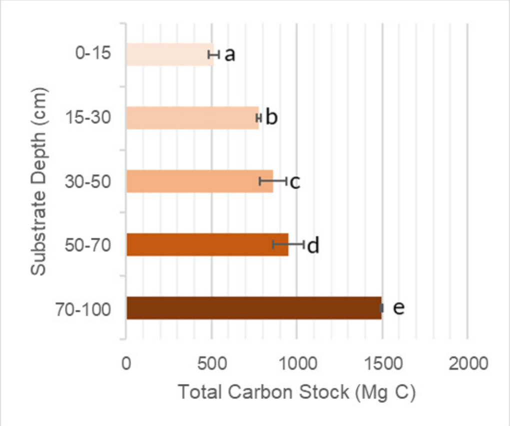

Fig. 10. Seagrass Meadows Substrate Carbon stocks distribution per depth ($p > 0.05$).

The physiochemical conditions of Jelenga Bay waters are shown in Table 4. Overall, the measured physicochemical parameters of the water support the optimal growth of seagrass biomass. Factors such as currents, turbidity, temperature, salinity, pH, and dissolved oxygen (DO) levels were all within the optimal range, contributing to the achievement of optimal biomass and photosynthesis rates by seagrasses at Jelenga Bay [17][21][22]. On the other hand, it is crucial to note that particular attention should be given to the depth and tidal cycles. Jelenga Bay exhibits a depth range of 0-3 meters and experiences semidiurnal tidal cycles, occurring twice within a 24-hour period, indicating a high level of hydrodynamics at this beach. These parameters were considered as limiting factors.

When assessing the potential carbon stock per hectare, the seagrass meadows at Jelenga Bay exhibited reserves of 0.18 Mg C/ ha aboveground, 0.26 Mg C/ ha belowground, and 42.86 Mg C/ ha within the seagrass meadows substrates. When compared to carbon stock values in other locations in Indonesia [22] and the global average [7], these values appear relatively low (refer to Table 5).

Table 5. Carbon stocks estimation comparation at Jelenga Bay, Indonesia [22] and global [7].

Seagrass Carboon Pool	**This research**	Global Data	Java	Southern Celebes	Southern Celebes	Eastern Borneo	Eastern Borneo
	(*C. rotundata* dominant)		(*E. Acoroides* dominant)	(*T. Hemprichii* dominant)	(*E. acoroides* dominant)	*H. Uninervis* dominant)	(*H. Uninervis* dominant)
Above ground (Mg C/ha)	**0.18**	0.75	0.66	0.3	0.27	0.14	0.05
		(0.001-5.548)					
Below ground (Mg C/ha)	**0.26**	1,76	1.75	1.79	0.86	0.23	0.19
		(0.001-17.835)					
Substrate (Mg C/ha)	**42.86**	139.7	62.4	31.3	214	80	121
		(9.1 – 628.1)					

Globally, carbon reserves range from 0.001 to 5.548 Mg C/ ha, with an average of 0.755 Mg C/ ha for aboveground carbon reserves, 0.001 to 17.835 Mg C/ha, averaging 1.756 Mg C/ ha for belowground carbon reserves, and 9.1 to 628.1 Mg C/ ha, with an average of 139.7 Mg C/ ha for seagrass meadows substrate carbon reserves. If compared to recent research in South East Asia, carbon reserves in Jelenga bay was alson within the range [25][26].The carbon stocks within seagrass communities and substrates can be attributed to various factors. The lower carbon stock in the seagrass community in this research was influenced by the dominant seagrass species. *Cymodocea rotundata*, which prevails in the community structure, maintains carbon reserves lower than those of *Enhalus acoroides*, a species with significantly lower density and occurrence frequency. This discrepancy arose from substantial morphological distinctions between the two species. Furthermore, substrate carbon reserves were also relatively low to global data reference [7].

In highlight, the low density of seagrass, composition of substrates with larger particles, high hydrodynamics, and seasonal factors collectively led to the low carbon reserves within the substrate, and considered as the limiting factors. The sparse seagrass bed resulted in suboptimal litter trapping on the seagrass meadows substrate, while the larger particle size diminished the substrate's capacity to store organic carbon. The increased water hydrodynamics contributed to the suboptimal burial of litter within the substrate, possibly leading to litter was being carried out to open sea and was not effectively buried within the seagrass meadows substrate. Seasonal factor also suspected to have an impact to the seagrass turnover rate, and the carbon sequestration in seagrass meadows substrate [23].

4 Conclusion

The total carbon stocks at Jelenga Bay were estimated as follows: 19.1 Mg C (0.18 Mg C/ha) aboveground, 28.4 Mg C (0.26 Mg C/ha) belowground, and 4,590.0 Mg C (42.86 Mg C/ha) within the seagrass meadows substrate. The substrate carbon stock had the most significant influence on the total carbon stock. Factors that affected carbon stocks included physiochemical parameters, seagrass species, density, substrate composition, and water hydrodynamics. It is recommended to use more sophisticated tools and establish permanent plots to conduct comprehensive analysis of the substrate carbon pool.

The authors extend their gratitude and dedicate this research, with special recognition, to the memory of the late Mr. Muhamad Salamudin Yusuf (Ecoline) for his invaluable contributions to the field of conservation in Indonesia, particularly in West Nusa Tenggara. Secondly, a sincere gratitude is extended to Mrs. Dr. Devi Nandita Choesin (ITB) for her massive contribution in this research particularly, and Blue Carbon research in Indonesia generally. Furthermore, heartfelt thanks are also extended to Mrs. Susi Rahmawati, S.Si, M. Sc., and Mr. Drs. Wawan Kiswara from BRIN, Prof. Dr. Ir. Irwan Sukri Banuwa, M.Si from University of Lampung, and Mr. Iwan Tri Cahyo Wibisono, S.Hut from Wetlands International Indonesia for their constructive feedbacks and suggestions during the development of this research methodology.

References

1. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., IPCC, (Cambridge University Press, UK, 2007)
2. S. Fuss, J.G. Canadell, G.P. Peters, M. Tavoni, R.M. Andrew , R. M., Ciais, Philippe. Nature **4**, 10, 850–853, (2014)
3. UNFCCC. Paris Agreement, (2015)
4. C. Nellemann, E. Corcoran, C.M. Duarte, L. Valdés, C. De Young, L. Fonseca, G. Grimsditch, Blue Carbon: A Rapid Response Assessment (United Nations Environment Programme, GRID-Arendal, 2009)
5. J. Howard, S. Hoyt, K. Isensee, M. Telszewski, E. Pidgeon, Coastal blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses. (Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA, 2014)
6. J. Couwenberg, R. Dommain, H. Joosten, Glob Change Biol **16**, 32, (2010)
7. J. W. Fourqurean, C.M. Duarte, H. Kennedy, N. Marbà, M. Holmer, M.A. Mateo, E.T. Apostolaki, G.A. Kendrick, D. KrauseJensen, K.J. McGlathery, O. Serrano, Nature Geosci., **5**, 505–509, (2012)
8. W.D. Larkum, R.J. Orth, C.M. Duarte, Seagrasses: Biology, Ecology, and Conservation (Springer, Netherlands, 2006)
9. R.J. Orth, T.J. Carruthers, W.C. Dennison, C.M. Duarte, J.W. Fourqurean, K.I. Heck, Bioscience, **56**, 987–996 (2006)
10. F.T. Short, W. Carruthers, Dennison, M. Waycott, J. of Experiment. Mar. Biol. and Ecol. **350**, 3-20 (2007)
11. E. Poedjirahajoe, N.P.D. Mahayani, B.R. Sidharta, M. Salamuddin, J. Ilmu dan Tek. Kel. Trop, **5**, 1, (2013)

12. C.C. Wabnitz, S. Andréfouët, D. Torres-Pulliza, F.E. Muller-Karger, P.A. Kramer, Remote Sensing of Environ, **112** (8), 3455-3467, (2008)
13. R. Congalton, Remote Sensing of Environ, **37**, 35–46, (1991)
14. S. Rahmawati, W. Kiswara, Oseanologi dan Limnologi di Indonesia, **38**, 1, 143-150 (2012)
15. S.M. Walker, T.R.H. Pearson, F.M. Casarim, N Harris, S. Petrova, A. Grais, E. Swails, M. Netzer, K.M. Goslee and S. Brown, Standard Operating Procedures for Terrestrial Carbon Measurement (Winrock International, US, 2012)
16. S. English, C. Wilkinson, V. Baker, Survey Manual for Tropical Marine Resources. Townsville (Australian Institute of Marine Science, Townsville, 1997)
17. Kementerian Lingkungan Hidup RI. Keputusan Menteri Lingkungan Hidup Nomor 51 Tahun 2004 (Kementerian Lingkungan Hidup, Jakarta, 2004)
18. F.T. Short, R.G. Coles, Global seagrass research methods, (Elsevier Science, Amsterdam, 2001)
19. S. Rahmawati, A. Irawan, I.H. Supriyadi, M.H. Azkab, Panduan monitoring Padang Lamun, (LIPI, Jakarta, 2014)
20. E.W. Koch, Estuaries, **24**, 1-17, (2001).
21. T. Tomascik, A.J. Mah, A. Nontji, M.K. Moosa, The Ecology of Indonesian seas (The Ecology of Indonesia Series, Indonesia, 1997)
22. D. Alongi, D. Indonesia’s blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. (Wetlands Ecology and Management, Jakarta, 2015)
23. O. Serrano, A.M. Ricart, P.S. Lavery, M. Mateo, A. AriasOrtiz, P. Masque, A. Steven, C.M. Duarte, Key Biogeochemical Factors Affecting Soil Carbon Storage in Posidonia Meadows. (Edith Cowan University, Joondalop, 2016)
24. A. Rustam, N.S. Adi, A. Daulat, W. Kiswara, D.S. Yusup, R. Ambo-Rappe, Pedoman Pengukuran Karbon di Ekosistem Padang Lamun. (ITB Press, Bandung, 2019)
25. S. Rahmawati, B. Prayudha, H. Prayitno, K. Mcmahon, M. Vanderklift, U. Hernawan, A. Wahyudi, Blue Carbon in Seagrass Ecosystem: Guideline for the Assessment of Carbon Stock and Sequestration in Southeast Asia. (UGM Press, Yogyakarta, 2019)
26. M. Stankovic, R. Ambo-Rappe, F. Carly, G. Dangan, F. F.M.D. Floredel., M.S. Hossain, W. Kiswara, C. Van Luong, P. Minh-Thu, A.K. Mishra, T. Noiraksar, N. Nurdin, J. Panyawai, E. Rattanachot, M. Rozaimi, U.S. Htun, A. Prathep, Sci. of The Total Environ, **783**, 146858 (2021)
27. A.J. Wahyudi, S. Rahmawati, A. Irawan, H. Hadiyanto, B. Prayudha, M. Hafizt, A. Afdal, Ocean Sci. J. **55**, 1, 85–97, (2020)