Jurnal Natur Indonesia
22(2), October 2024: 114-121

p-ISSN 1410-9379
e-ISSN 2503-0345

Carbon Storage Potential in Seagrass in the Water of Poncan Gadang Island, Sibolga City, North Sumatra Province

Potensi Penyimpanan Karbon pada Lamun di Perairan Pulau Poncan Gadang, Kota Sibolga, Provinsi Sumatera Utara

Sahrul Ramadhan[1], Zulkifli[1*], Bintal Amin[1]
[1]Department of Marine Science, Faculty of Fisheries and Marine, Universitas Riau, Pekanbaru 28293 Indonesia
*Correspondent Author: zulkifli@lecturer.unri.ac.id

ABSTRACT

This research was conducted in February - March 2023 in Poncan Gadang Island, Sibolga City, North Sumatra Province. This study aimed to analyze the density of seagrass at each station in the research location, analyze the differences in biomass and carbon stocks in the above-ground biomass (Agb) and below-ground biomass (Bgb) parts between stations, the relationship between seagrass density and seagrass biomass and carbon stocks, and the carbon storage potential of seagrass in the waters of Poncan Gadang Island, Sibolga City, North Sumatra Province. The method used in this research was a survey method, which involved direct observations and measurements of samples in the field. The samples were then analyzed in the laboratory, and the results were described descriptively. The calculation results of carbon storage using the Loss on Ignition method for *E. acoroides* in Poncan Gadang Island are as follows: 14,836.07 gC/m^2 at station I, 3,975.09 gC/m^2 at station II, and 65,073.32 gC/m^2 at station III, with a total carbon storage for *E. acoroides* species of 83,884.48 gC/m^2. On the other hand, *C. rotundata* shows relatively lower results compared to *E. acoroides*, with 8,353.20 gC/m^2 at station I, 12,056.76 gC/m^2 at station II, and 7,235.53 gC/m^2 at station III, with a total of 27,645.49 gC/m^2. It can be concluded that the seagrass species *E. acoroides* has a larger biomass and carbon content compared to *C.rotundata*, thus making a significant contribution as a carbon sink in the study area.

Keywords: Poncan Gadang Island, Density, Biomass, Carbon stock, Seagrass

ABSTRAK

Penelitian dilaksanakan pada bulan Februari – Maret 2023, yang berlokasi di perairan Pulau Poncan Gadang Kota Sibolga, Provinsi Sumatera Utara. Penelitian bertujuan untuk menganalisis kerapatan lamun setiap stasiun di lokasi penelitian, menganalisis perbedaan biomassa dan simpanan karbon pada bagian *Agb* dan *Bgb*, antar stasiun, menganalisis hubungan kerapatan lamun dengan biomassa dan simpanan karbon lamun serta menganalisis berapa potensi penyimpanan karbon pada lamun di perairan Pulau Poncan Gadang Kota Sibolga Provinsi Sumatera Utara. Metode yang digunakan pada penelitian ini adalah metode *survey*, yaitu dengan melakukan pengamatan serta pengukuran sampel secara langsung di lapangan kemudian sampel dianalisis di Laboratorium dan hasilnya dijabarkan secara deskriptif. Hasil perhitungan simpanan karbon menggunakan metode *Loss on Ignition* pada *E. acoroides* di Pulau Poncan Gadang pada stasiun I sebesar 14.836,07 gC/m^2, stasiun II sebesar 3.975,09 gC/m^2 dan pada stasiun III sebesar 65.073,32 gC/m^2 dengan total simpanan karbon pada jenis *E. acoroides* sebesar 83.884,48 gC/m^2. Sementara pada *C. rotundata* menunjukkan hasil yang cukup rendah jika dibandingkan dengan *E. acoroides* yaitu 8.353,20 gC/m^2 pada stasiun I, 12.056,76 gC/m^2 pada stasiun II dan 7.235,53 gC/m^2 pada stasiun III dengan total sebesar 27.645,49 gC/m^2. Dapat disimpulkan bahwa lamun jenis *E. acoroides* memiliki nilai biomassa dan kandungan karbon cenderung lebih besar dibandingkan dengan *C. rotundata*, sehingga *E. acoroides* memiliki kontribusi besar sebagai penyimpan karbon pada lokasi penelitian.

Kata Kunci: Pulau Poncan Gadang, Kerapatan, Biomassa, Simpanan karbon, Lamun

Received: 12 September 2024
Accepted: 29 October 2024

INTRODUCTION

Seagrass is a flowering plant (Angiospermae) that belongs to the monocotyledonous group of plants, characterized by roots, rhizomes, leaves, sheaths, flowers, and fruits (Rahmawati et al., 2014). Seagrass meadows are one of the critical ecosystems in coastal areas, alongside mangroves and coral reefs. Seagrass meadows can absorb and sequester carbon dioxide (CO_2) through photosynthesis, known as blue carbon (Graha et al., 2016). Blue carbon refers to plants that can photosynthesize using carbon dioxide and store it in biomass (Sirait et al., 2021).

Seagrasses utilize some absorbed carbon as energy, while the remaining carbon is stored as biomass in seagrass tissues (Khairunnisa et al., 2018). The potential carbon storage below the substrate is preserved and locked in sediments, even if the seagrass dies, whereas carbon in the above-ground substrate is stored only while the seagrass is alive (Negara et al., 2020). The mechanism of carbon uptake in seagrasses involves synthesizing carbon into biomass and food reserves. The carbon stored in this biomass remains as long as the seagrass is alive. Seagrass biomass is influenced by age, composition, structure, and vegetation development. Seagrass biomass is divided into two components: Above-ground biomass (Agb), which includes leaves, leaf sheaths, and stems, and Below-ground biomass (Bgb), which provides for roots and rhizomes.

Many studies have been conducted on the carbon storage potential of seagrasses. Campbell et al. (2015) studied carbon stocks in seagrass meadows in Abu Dhabi, United Arab Emirates. Githaiga et al. (2017) assessed carbon stocks in seagrass meadows in Gazi Bay, Kenya. Fourqurean et al. (2012) examined seagrass ecosystems as global carbon sinks. In Indonesia, Irawan (2017) found that seagrasses can absorb carbon ranging from 133.24 to 133.71 gC/m^2 in above-ground and below-ground substrates on Bintang Island. Oktari (2022) researched *C. rotundata* seagrass species in Dusun Jati Mentawai, with average carbon stocks ranging from 2.08 to 13.11 gC/m^2 in above-ground and below-ground biomass. Putra et al. (2017) studied *C. serrulata* seagrass species on Poncan Island, Sibolga City, and found carbon stocks ranging from 0.06 to 0.24 gC/m^2 in each seagrass component per station. Previous studies mainly focused on carbon storage in *C. serrulata* seagrass. This study aims to analyze and compare the carbon storage of *E. acoroides* and *C. rotundata* seagrass species, which have not been previously investigated in the waters of Poncan Gadang Island. Considering the significant potential of seagrasses in reducing atmospheric CO_2 concentration and mitigating the impacts of global warming, it is crucial to estimate the carbon storage potential in both above-ground and below-ground substrates of seagrasses in the waters of Poncan Gadang Island, Sibolga City, North Sumatra Province.

MATERIALS AND METHOD

Time and place of research

This research was conducted from February to March 2023. The sampling was conducted in Pulau Poncan Gadang, Sibolga City, North Sumatra Province (Figure 1). Sample analysis was performed at the Marine Biology Laboratory, Physical Oceanography Laboratory, Chemical Oceanography Laboratory, Department of Marine Sciences, Faculty of Fisheries and Marine Sciences, Universitas Riau.

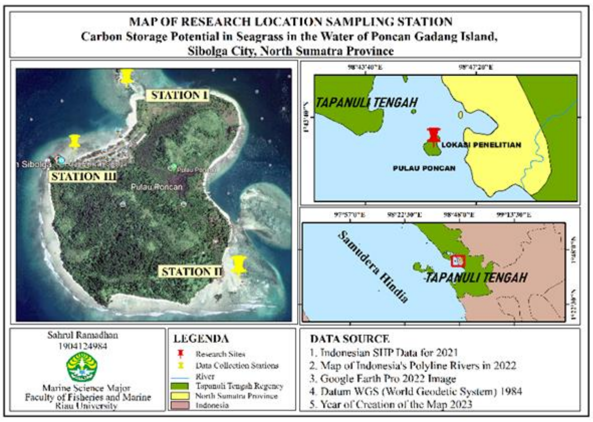


Figure 1. Research location

Determining the location of the sampling

The determination of observation stations is based on a purposive sampling approach, where the objects are selected based on specific characteristics that represent the seagrass meadow conditions in the research area. This approach considers various activities in the area, such as shipping routes, proximity to mangrove ecosystems, and areas near tourist docks (Table 1).

Table 1. Characteristics of the research station

Station	Coordinate Points	Description
I	1°42'56.48" N and 98°45'48.67" E	It is an area near Bangke Island influenced by shipping activities and fishing.
II	1°42'35.34" N and 98°46'5.36" E	It is a mangrove area, and human activities do not influence that particular area.
III	1°42'48.02" N and 98°45'41.14" E	It is a dock area that is influenced by shipping activities and fishing.

Sampling was conducted at 3 (three) research stations using 3 (three) transect lines perpendicular to the coastline. Each transect line consisted of 3 (three) quadrats measuring 1 x 1 m^2. The sampling locations were situated at a distance of 30 m seaward from the shoreline (starting from the initial encounter of seagrass). The transect scheme can be seen in Figure 2.

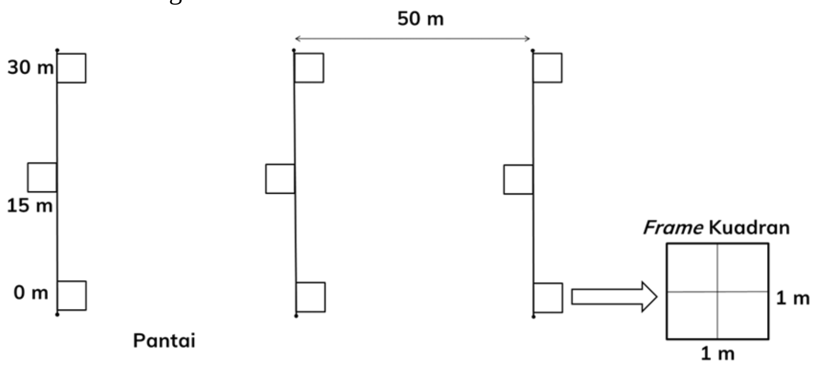


Figure 2. Ransect scheme and quadrat layout of the study

Seagrass density

Sampling is conducted based on the transect line method to determine seagrass density. Seagrass density is calculated as the number of individuals per unit area, expressed in m^2, using the formula proposed by Ira et al. (2013).

$$Di = \frac{Ni}{A}$$

Description:

Di : Species density (ind/m^2)
Ni : The number of individuals within the transect
A : The sampled area's size (m^2)

Measurement of seagrass biomass

Once the samples have been collected, they are analyzed in the laboratory. The dry weight of an individual shoot is multiplied by the number of shoots (density) of seagrass within an m^2 area. The formula used for this calculation refers to Graha et al. (2016):

$$B = W \times D$$

Description:

B : Seagrass biomass (g/m^2)
W : The dry weight of seagrass shoot (g/individual)
D : Species density (individual/m^2)

The calculation of dry weight, according to Prasetya et al. (2018) is:

$$W = Wd - We$$

Description:

W : The dry weight of seagrass shoot (g)
Wd : The weight of the sample and the cup after drying (g)
We : The weight of the empty cup (g)

Measurement of carbon storage in seagrass

The analysis of carbon in seagrass leaves, sheaths, stems, rhizomes, and roots uses the loss on ignition method. This method involves the removal of organic matter through the process of combustion in a furnace. The carbon content is calculated using the loss on ignition method according to Siagian et al. (2017) with the following formula:

$$\text{Total organic matter (TOM \%)}=\frac{\{(b\text{-}a)-(c\text{-}a)\}}{(b\text{-}a)} \times 100\%$$

Description:

a : The weight of the empty cup
b : The weight of the cup + the weight of the sample
c : The weight of the cup + the weight of the ash

After determining the organic matter content in seagrass, the next step is to calculate the organic carbon content in seagrass using the loss on ignition method based on Indriani et al. (2017) with the following formula:

$$C_{org}=\frac{TOM}{K}$$

Description:

C_{org} : The organic carbon content (%)
TOM : The organic matter content (%)
K : The constant value of organic matter **(1,724)**

According to Fourqurean et al. (2014), it can be done by multiplying biomass with carbon content to determine carbon storage.

$$\text{Carbon storage (gC/m}^2\text{)=Biomass (gbk/m}^2\text{)}\times\text{The content } C_{org}(\%/100\%)$$

RESULT AND DISCUSSION

Conditions of the research area

The waters of Poncan Gadang Island are located in the city of Sibolga, North Sumatra Province. Geographically, Poncan Gadang Island is situated at coordinates between 1°42'37"-1°42'40" N and between 98°45'28"-98°45'55" E. There is still some debate regarding the administrative position of Poncan Gadang Island, as it is located on the border between Tapanuli Tengah and the city of Sibolga. Poncan Gadang Island has a gently sloping coastline with predominantly white sandy substrates, producing clear seawater. The marine conditions in Poncan Gadang Island are excellent, and the biological resources are abundant. Coral reefs, mangroves, and seagrass ecosystems thrive there. The growth of seagrass in the waters of Poncan Gadang Island is generally good, and it is evenly distributed along the coast. According to Siagian et al. (2017), seagrass found in the waters of Poncan Gadang Island consists of four species: *Enhalus acoroides, Cymodocea rotundata, C.serrulata,* and *Halodule uninervis*. Other vegetation in the research area includes coconut trees and several species of mangroves.

Water quality parameters

Water quality measurements were conducted at each sampling point and performed in situ during low tide. Water quality parameters were measured with three replicates. The results of the water quality parameter measurements in Poncan Gadang Island can be seen in Table 2.

Table 2. The water quality parameters at the research station

No	Parameter	Quality Standards *	Station I	Station II	Station III
1.	Current speed (m/s)	-	0,08	0,06	0,03
2.	Brightness (cm)	-	79	76	48
3.	Depth (cm)	-	102,22	93,89	48,11
4.	Temperature (℃)	28 – 30	29,7	29,4	26,3
5.	Salinity (ppt)	33 – 34	28	33	30
6.	pH level	7 – 8,5	6,21	6,38	6,94

* Sea Water Quality Standards (Government Regulation of the Republic of Indonesia Number 22 of 2021)

Table 2 shows that the current velocity ranges from 0,03-0,08 m/s, clarity ranges from 48-79 cm, depth ranges from 48,11-102,22 cm, temperature ranges from 26,3-29,7℃, salinity ranges from 28-33 ppt and pH level ranges from 6,21-6,94. These parameters indicate that the water quality is still categorized as suitable for seagrass growth.

Seagrass density

The following results were obtained from the measurements conducted at the research site: the seagrass density at Station I is 67.00 individuals/m², at Station II is 50.56 individuals/m², and at Station III is 88.67 individuals/m². The seagrass density at the research site is presented in Figure 3.

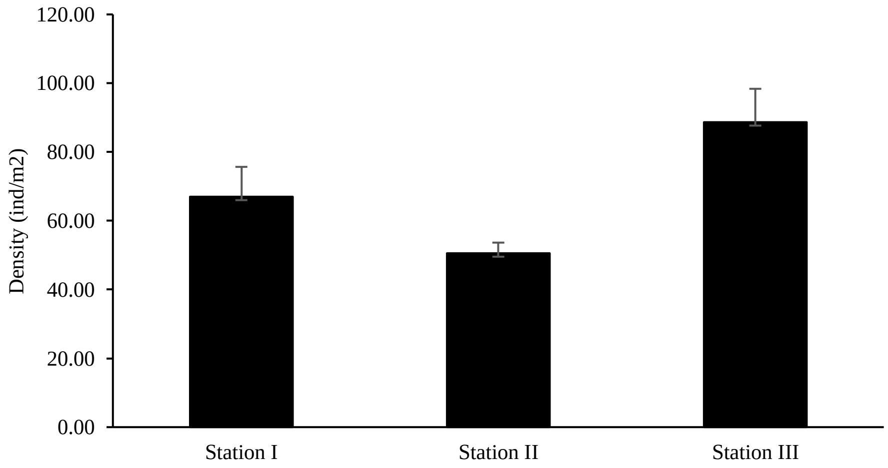


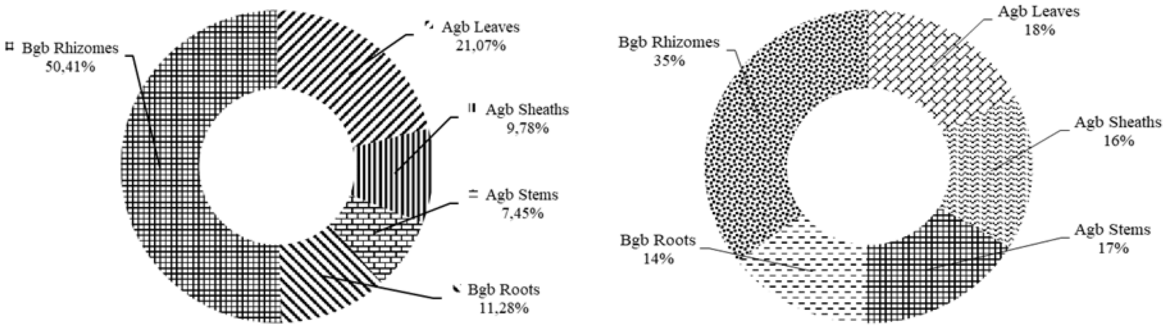
Figure 3. Graph of seagrass density at each research station.

The differences in seagrass composition at each research station are related to their different adaptation abilities at each station. The variation in density at each station is believed to be caused by differences in human activities, as well as other factors such as substrate type and nutrient content at each research station. Based on field observations, Station I is located near Pulau Bangke and is influenced by maritime activities and fishing. Station II is in a mangrove area without human activities, while Station III is located at a pier for ship stops, influenced by maritime activities and fishing. Station III has the highest seagrass density. The research site's water quality parameters also affect the seagrass density variation. This statement aligns with the findings of Oktari (2022), who stated that the surrounding water quality influences seagrass density, and density will increase in natural conditions. According to Putra (2017), high seagrass density is closely related to the number of seagrass species found and is likely influenced by habitat characteristics such as depth and substrate type, which support the growth and presence of seagrass due to their light penetration requirements for photosynthesis.

Seagrass biomass

The biomass of seagrass is divided into above-ground (leaves, sheaths, and stems) and below-ground (roots and rhizomes) (Bagu et al., 2020). The total seagrass biomass of all seagrass species found is 2,386.17 g dry weight per square meter (gdw/m^2), with above-ground tissue biomass of 989.50 gdw/m^2 and below-ground tissue biomass of 1,396.67 gdw/m^2. *E. acoroides* has the highest biomass value among the seagrass species in the waters of Poncan Gadang Island, with a value of 1,761.08 gdw/m^2, while *C. rotundata* has the lowest biomass value of 625.09 gdw/m^2. Based on Figure 3, the average biomass is higher in the lower substrate (rhizome) compared to the above substrate. This is because the lower substrate's biomass material, such as leaves, is denser than the biomass above the substrate (Wahyudi et al., 2016). According to Tasabaramo et al. (2015), the biomass below the substrate comes from nutrients absorbed by the roots in the sediment, as well as organic material resulting from photosynthesis that is mainly stored in seagrass rhizomes.

The high biomass value of *E. acoroides* seagrass in the rhizome area is likely due to its larger size compared to other parts, and the rhizome typically contains 60-80% of the seagrass biomass (Imiliyana et al., 2012). The highest total biomass is found at station III. The higher biomass of *E. acoroides* seagrass in the area with more litter compared to the tourist and mangrove areas is likely due to the higher density of seagrass at that station. As the seagrass density increases, so does its biomass content (Azkab, 2007). The high biomass content in the area with more litter suggests that this area is suitable and preferred by *E. acoroides* seagrass despite the anthropogenic activities (tourist boat docks). However, the impacts of these activities do not seem to affect the biomass of *E. acoroides* seagrass. This is in contrast to the tourist and mangrove areas, where, although there is less anthropogenic activity, these areas are not favored by *E. acoroides* seagrass.



(a) Biomass *E. acoroides* (b) Biomass *C. rotundata*

Figure 3. Biomass *E.acoroides* and *C. rotundata*

Organic c-content of seagrass

The average organic C-content of *E. acoroides* seagrass shows that station III has higher values than other stations, ranging from 40.24 to 51.29%. The station has values ranging from 18.02 to 23.69%, while the lowest values are found at station II, ranging from 4.05 to 6.02%. As for the average percentage of organic C content in different parts of *E. acoroides* seagrass, the highest value is found in the rhizome of station III, which is 51.29%, while the lowest value is found in the leaves of station II, which is 4.05%. Meanwhile, the average organic C-content of *C. rotundata* seagrass shows that station II has higher values than other stations, ranging from 35.72 to 47.91%. Station values range from 34.66 to 41.28%, while the lowest values are found at station III, ranging from 25.19 to 36.78%. The highest percentage of organic C-content in *C. rotundata* seagrass is found in the Bgb part, while the lowest is in the Agb part (Table 3).

Table 3. Calculation results of organic C-content of seagrass in the research station

Station	C-organic *E. acoroides* (%)					C-organic *C. rotundata* (%)				
	Agb			*Bgb*		*Agb*			*Bgb*	
	leaves	sheaths	stems	roots	rhizomes	leaves	sheaths	stems	roots	rhizomes
I	20,57	21,61	21,21	18,02	23,69	36,90	34,66	41,17	36,36	41,28
II	4,05	4,64	4,17	5,05	6,02	41,53	40,41	42,68	35,72	47,91
III	42,80	42,28	46,72	40,25	51,29	29,06	25,19	32,63	36,78	33,21
Average	22,47	22,84	24,03	21,11	27,00	35,83	33,42	38,83	36,29	40,80

Seagrass carbon storage

The carbon storage of *E. acoroides* seagrass in the research location has an average total leaf component of 5,425.43 gC/m^2, the sheath component of 2,506.72 gC/m^2, the stem component of 2,026.89 gC/m^2, the root component of 2,693.70 gC/m^2, and the rhizome component of 15,308.75 gC/m^2. The highest carbon storage is found in the rhizome component, which is 15,308.75 gC/m^2. Meanwhile, the carbon storage of *C. rotundata* seagrass in the research location has an average total leaf component of 1,586.34 gC/m^2, the sheath component of 1,318.66 gC/m^2, the stem component of 1,590.19 gC/m^2, the root component of 1,271.47 gC/m^2, and the rhizome component of 3,448.50 gC/m^2. The highest carbon storage is found in the rhizome component, which is 3,448.50 gC/m^2 (Table 4).

The calculations show that higher biomass leads to higher carbon storage. It can be observed that areas with a higher amount of waste have the most extensive total carbon storage compared to tourist areas and mangrove surroundings. The lower total carbon storage in tourist areas and mangrove surroundings is likely due to the high wave action leading to more litter fall, the seagrass being more exposed during low tides, and the activities of fishermen and tourists near the seagrass. The seagrass part with the highest total carbon storage is found in the rhizome of the area with a high amount of waste, while the lowest is found in the root part of the mangrove surroundings. This is likely due to the rhizome constituting 60-80% of the seagrass biomass, increasing carbon stock percentage and biomass increase (Imiliyana et al., 2012).

Table 4. Calculation results of carbon storage content of seagrass

Station	Transect	Agb			Bgb		Total
		leaves	sheaths	stems	roots	rhizomes	
1	1	-	-	-	-	-	-
	2	1.040,60	917,38	4.93.47	622,33	2.094,29	5.168,08
	3	13.494,94	4.837,86	1.683,49	2.862,21	16.461,63	39.340,13
Average		4.845,18	1.918,41	725,65	1.161,52	6.185,31	14.836,07
2	1	-	-	-	-	-	-
	2	2.316,76	624,26	338,14	1.575,89	7.070,23	11.925,28
	3	-	-	-	-	-	-
Average		772,25	208,09	112,71	525,30	2.356,74	3.975,09
3	1	7.324,97	2.986,01	4.295,25	2.362,88	26.087,77	43.056,87
	2	11.348,12	5.831,88	6.039,94	9.906,35	48.157,10	81.283,38
	3	13.303,49	7.363,13	5.391,79	6.913,57	37.907,73	70.879,70
Average		10.658,86	5.393,67	5.242,32	6.394,27	37.384,20	65.073,32
The average total		5.425,43	2.506,72	2.026,89	2.693,70	15.308,75	27.961,49
Carbon storage *C. rotundata* ($gC/m^{2)}$)							
1	1	2.398,32	1.891,93	2.335,87	1.805,67	3.567,19	11.998,98
	2	2.678,43	1.901,91	1.789,51	1.732,79	2.969,20	11.071,84
	3	195,95	307,83	350,81	334,77	799,41	1.988,78
Average		1.757,56	1.367,22	1.492,06	1.291,08	2.445,27	8.353,20
2	1	1.608,88	1.719,53	1.483,85	1.269,20	2.583,93	8.665,40
	2	1.258,89	1.127,41	1.136,56	924,74	2.326,52	6.774,11
	3	2.376,31	2.049,88	3.174,27	1.360,11	11.770,20	20.730,77
Average		1.748,03	1.632,27	1.931,56	1.184,69	5.560,21	12.056,76
3	1	710,95	565,80	764,80	762,37	1.601,13	4.405,06
	2	1.903,66	1.377,41	2.234,18	1.515,46	3.976,19	11.006,90
	3	1.145,69	926,26	1.041,82	1.738,12	1.442,74	6.294,64
Average		1.253,43	956,49	1.346,94	1.338,65	2.340,02	7.235,53
The average total		1.586,34	1.318,66	1.590,19	1.271,47	3.448,50	9.215,16

*The (-) symbol indicates that seagrass was not found at that location

CONCLUSION

The density of seagrass in the waters of Pulau Poncan Gadang falls under the rare category, dominated by *E. acoroides* seagrass, and there are differences in seagrass density among research stations. The biomass and carbon storage of *E. acoroides* seagrass differ significantly between the Agb and Bgb sections and among research stations. On the other hand, there are no differences in biomass and carbon storage of *C. rotundata* seagrass between the Agb and Bgb sections or among research stations. There is a strong correlation between seagrass density and the biomass and carbon storage of *E. acoroides* seagrass, while *C. rotundata* seagrass exhibits a strong relationship. The carbon storage potential of *E. acoroides* seagrass in the waters of Pulau Poncan Gadang is estimated at 83,884.48 gC/m^2, whereas for *C. rotundata* seagrass, it is 27,645.49 gC/m^2.

In conclusion, the *E. acoroides* seagrass species has a higher biomass and carbon content than *C. rotundata* seagrass, indicating that *E. acoroides* contributes significantly as a carbon sink. Not all seagrass meadows have the same potential for carbon storage. The morphology of seagrass species and habitat characteristics significantly influence the potential for carbon storage in seagrass.

REFERENCES

Azkab, M.H., 2007. *Status sumberdaya padang lamun di Teluk Gilimanuk, Taman Nasional Bali Barat. Status sumberdaya laut Teluk Gilimanuk, Taman Nasional Bali Barat*. Pusat Penelitian Oseanografi-LIPI. Jakarta

Bagu, I.A., Hamidun, M.S., Baderan, D.W.K., 2020. Estimasi simpanan karbon lamun *Enhalus acoroides* di Kawasan Pantai Langala Dulupi Kabupaten Boalemo. *Jambura Edu Biosfer J.*, 2(1): 13-21.

Campbell, J.E., Lacey, E.A., Decker, R.A., Ceooks, S., Fourqurean, J.W., 2015. Carbon storage in seagrass beds of Abu Dhabi, United Arab Emirates. *Estuaries and Coasts*, 38(1): 242-251.

Fourqurean, J.W., Duarte, C.M., Kennedy, H., Marba, N., Holmer, M., Mateo, M.A., Apostolaki, E.T., Kendrick, G.A., Jensen, D.K., McGlathery, K.J., Serrano, O., 2012. Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience*, 5(7): 505–509.

Fourqurean, J.W., Johnson, B., Kauffman, J.B., Kennedy, H., Lovelock, C., Megonigal, J.P., Rahman, A.F., Saintilan, N., Simard, S., 2014. *Coastal blue carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows.* Conservation International, Intergovernmental Oceanographic Commission of UNESCO, USA.

Githaiga, M.N., Kairo, J.G., Gilpin, L., Huxham, M., 2017. Carbon storage in the seagrass meadows of Gazi

Bay, Kenya. *Journal of Plos One*, 12(5): 1–13.

Graha, Y.I., Arthana, I.W., Karang, I.W.G.A., 2016. Simpanan karbon padang lamun di Kawasan Pantai Sanur, Kota Denpasar. *ECOTROPHIC: Jurnal Ilmu Lingkungan (Journal of Environmental Science)*, 10(1): 46–53.

Imiliyana, A., Muryono, M., Purnobasuki, H., 2012. *Estimasi stok karbon pada tegakan pohon Rhizophora stylosa di Pantai Camplong, Sampang-Madura.* Surabaya: Institut Teknologi Sepuluh November.

Indriani, A.J., Wahyudi, W., Yona, D., 2017. Cadangan karbon di area padang lamun pesisir Pulau Bintan Kepulauan Riau. *Oseanologi dan Limnologi di Indonesia*, 3(2): 1-11.

Ira, I., Oetama, D., Julianti, J., 2013. Kerapatan dan penutupan lamun pada daerah tanggul pemecah ombak di Perairan Desa Terebino Provinsi Sulawesi Tengah. *Jurnal Ilmu Perikanan dan Sumberdaya Perairan*, 3(1): 90-97.

Irawan, A., 2017. Potensi cadangan dan serapan karbon oleh padang lamun di bagian utara dan timur Pulau Bintan. Oseanografi dan *limnologi di Indonesia*, 2(3): 35-48.

Khairunnisa, K., Setyobudiandi, I., Boer, M., 2018. Estimasi cadangan karbon pada lamun di Pesisir Timur Kabupaten Bintan. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 10(3): 639-650.

Negara, I.K.S., Karang, I.W.G.A., Putra, I.N.G., 2020. Simpanan karbon padang lamun di Perairan Pantai Nusa Lembongan, Klungkung, Bali. *Journal of Marine Research and Technology*, 3(2): 82-89.

Oktari, M., 2022. *Analisis stok karbon tersimpan pada lamun Cymodocea rotundata di Perairan Tuapejat Kabupaten Kepulauan Mentawai.* Universitas Riau.

Prasetya, D., Yoswaty, D., Ghalib, M., Samiaji, J., Elizal, E., 2018. Analisis biomassa dan karbon pada lamun (*Enhalus acoroides*) di Perairan Timur Laut Pulau Penyengat Kota Tanjungpinang Provinsi Kepulauan Riau. *Journal Online Mahasiswa*, 1(1): 1–13

Putra, I.A., Thamrin, T., Zulkifli, Z., 2017. Potensi penyimpanan karbon pada lamun (*Cymodocea serrulata*) di Perairan Pulau Poncan Sibolga Provinsi Sumatera Utara. *Journal Online Mahasiswa*, 1(1): 1–12

Rahmawati, S., Irawan, A., Supriyadi, I.H., 2014. *Panduan monitoring padang lamun*. Pusat Penelitian Oseanografi Lembaga Ilmu Pengetahuan Indonesia. Jakarta: COREMAP CTI LIPI.

Siagian, Y., Zulkifli, Z., Efriyeldi, E., 2017. Kandungan c-organik di daun lamun pada jenis lamun yang berbeda di Pulau Poncan Sibolga Provinsi Sumatera Utara. *Journal Online Mahasiswa*, 1(1): 1–12.

Sirait, W.K., Hartati, R., Widianingsih, W., 2021. Simpanan karbon pada padang lamun di Perairan Pulau Poteran Madura Jawa Timur. *Journal of Tropical Marine Science*, 5(1): 1–8.

Tasabaramo, I.A., Kawaroe, M., Rappe, R.A., 2015. Laju pertumbuhan, penutupan dan tingkat kelangsungan hidup *Enhalus acoroides* pada yang ditransplantasi secara monospesies dan multispesies. *Jurnal Ilmiah Platax*. 5(21): 210–220.

Wahyudin, Y., Kusumastanto, T., Adrianto, L., Wardiatno, Y., 2017. Jasa ekosistem lamun bagi kesejahteraan manusia. *Omni-Akuatika*, 12(3): 29-46.