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Carbon stock in the *Thalassia hemprichii* and *Cymodocea rotundata* predominated seagrass species at coastal waters of Pramuka Island, Indonesia

Isty ANGRELINA[1], Tri PRARTONO[2,*], Dietriech G. BENGEN[2], RASTINA[2]

*1. Graduate student at the Marine Science Study Program, IPB University, Bogor 16680, Indonesia. 2. Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, IPB University, Bogor 16680, Indonesia. *Corresponding author's emails: triprartono@yahoo.com*

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ABSTRACT: Seagrass beds are important carbon sinks that play a potential role in climate mitigation. The amount of carbon stored in seagrass ecosystems is greatly determined by the size of the seagrass species. This study aimed to determine the differences between carbon stocks in large seagrass represented by *Thalassia hemprichii* and smaller seagrass represented by *Cymodocea rotundata* in Pramuka Island, Seribu Islands, DKI Jakarta (Daerah Khusus Ibukota Jakarta). Four stations were selected purposively to represent sites with different densities and predominant species. The parameters measured were characteristics of seagrass (species density, leaf area, biomass, and carbon stock) and environmental parameters (water depth and sediment grain size distribution). Seagrass carbon stock was measured using the Loss on Ignition (LOI) method. The results showed that the seagrass *T. hemprichii* had a higher density, leaf area, biomass, and carbon stock than those *C. rotundata*. The carbon stock of *T. hemprichii* in Pramuka Island was 18.22–443.73 g C m^{-2} while *C. rotundata* was 5.99–25.61 g C m^{-2}. Moreover, large seagrasses have great potential to deposit more carbon in seagrass sediments. The analysis using PCA showed a relationship between the size of seagrass morphology and the amount of carbon stock. This study shows that seagrasses with large morphology strongly support the high value of carbon stocks stored in seagrass ecosystems.

KEY WORDS: Blue carbon stock, climate change, organic carbon, productivity, Seribu Islands.

INTRODUCTION

Since the pre-industrial era, the concentration of CO_2 in the atmosphere has increased dramatically, mainly driven by economic and population growth, leading to the greenhouse effect. Some of the most critical greenhouse effect impacts are global warming, sea-level rise, more intense droughts, devastating floods, wildfires, and storms. Furthermore, the greenhouse effect will affect human systems, such as livelihoods, health, and people's culture (Björk *et al.,* 2008; IPCC, 2014). Therefore, strategic efforts are needed to solve this problem by reducing the concentration of carbon in the atmosphere.

The blue carbon concept is a natural-based solution (NbS) that can overcome these problems by absorbing and storing organic carbon carried out by marine vegetation. In addition, marine ecosystems can efficiently trap carbon and deposit it into the sediments (Kennedy dan Bjork, 2009). Seagrass is one of the marine vegetation with great potential as blue carbon (Fourqurean *et al.*, 2012). Globally, seagrass beds only cover an area of 17.7–60 million ha, which can absorb about 41.4–112 Tg C yr^{-1} and store about 4,200–8,400 Tg C (Fourqurean *et al.,* 2012; Howard *et al.,* 2017; Mcleod *et al.*, 2011). Nevertheless, 58% of the global seagrass areas have been estimated to be degraded at an accelerating rate of 7% per year since 1990 (Short *et al.,* 2011; Waycott *et al.,* 2009). The degradation of seagrass beds will release carbon back into the atmosphere and further contribute to the greenhouse effect.

Research on the potential of seagrass ecosystems as blue carbon has been carried out, and it has shown variations in the spatial potential of carbon storage. The variation can be caused by different conditions of seagrass beds, such as seagrass properties and physical environmental parameters. Each seagrass species has a different potential for absorbing and storing carbon, depending on the morphology, species density, primary production, biomass, carbon content, and canopy cover (Mateo *et al.,* 2006; Rozaimi *et al.,* 2013). The size of seagrass morphology plays an important role in the variation of carbon stocks in seagrass ecosystems. Large seagrasses such as *E. acoroides, P. australis* have higher productivity and longer-lived vegetation parts, so they can accumulate more organic carbon in the biomass than small seagrasses such as *Halophila* sp., *Holodule* sp. (Duarte *et al.,* 1998; Ricart *et al.,* 2015, 2017; Rozaimi *et al.,* 2013). Meanwhile, physical parameters will affect the growth of seagrass. Seagrass species can grow and develop well in suitable conditions that subsequently influence carbon stock in the seagrass ecosystem (Mazarrasa *et al.,* 2018; Samper-Villarreal *et al.,* 2016; Serrano *et al.,* 2018).

Pramuka Island, a part of Seribu Islands, is a small island surrounded by seagrass beds. There were seven seagrass species found on Pramuka Island, i.e., *H. ovalis*, *H. uninervis*, *S. isoetifolium*, *C. serrulata*, *C. rotundata*, *T.*

hemprichii, and *E. acoroides* which dominated by *T. hemprichii* and *C. rotundata* (Feryatun *et al.,* 2012). *T. hemprichii* is a climax seagrass with a large morphology, while *C. rotundata* is a pioneer seagrass that has a small size. Unfortunately, few studies still evaluate seagrass's carbon storage potential with the size of seagrass morphology. Moreover, studies about the potential of seagrass beds on Pramuka Island are rarely disclosed. Therefore, this study was conducted to differentiate the contribution of the large seagrass representative by *T. hemprichii* and those small seagrasses representative by *C. rotundata* in the carbon stock on Pramuka Island. The seagrass characteristics information can be assessed to develop and optimize seagrass beds on Pramuka Island as a blue carbon ecosystem.

MATERIALS AND METHODS

Site Location and Sampling Design

This research was conducted on Pramuka Island of Seribu Islands, DKI Jakarta (Daerah Khusus Ibukota Jakarta) Province (5°44'45.60"S and 106°36'50.40"E) (Figure 1) in January 2021. Sampling was carried out purposively at four stations. Station 1 (S1) was located on the western part of Pramuka Island, close to human and jetty activities. Station 2 (S2) was in the southern part of the island. Seagrass beds at this station coexist with mangroves (*Rhizophora* sp.). Station 3 (S3) in the eastern part of the island, close to community settlements and possible disturbances of anthropogenic waste. Lastly, Station 4 (S4) was in the island's northern part, far from human activities. The vegetation found at this station is not only seagrass but also mangrove (*Rhizophora* sp.) and other natural vegetation.

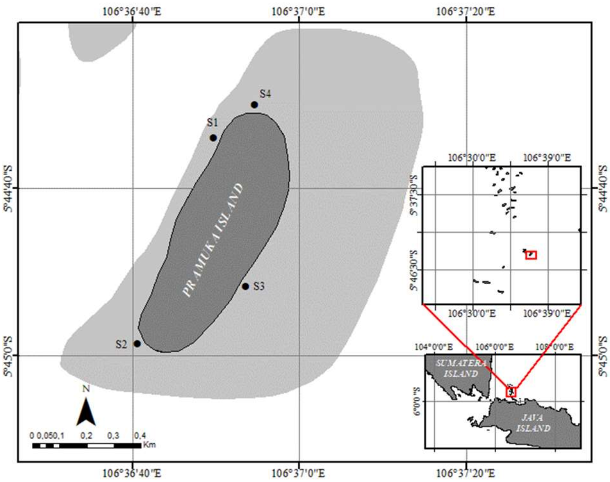

Fig. 1. Locations of study sites in Pramuka Island of Seribu Island, Indonesia.

Three substations with 25 m intervals were applied parallelly to the shoreward edge at each station, also known as depth transects across a meadow (McKenzie *et al.,* 2003) (Figure 2). The initial substation was positioned at the seagrass found firstly from the shoreline.

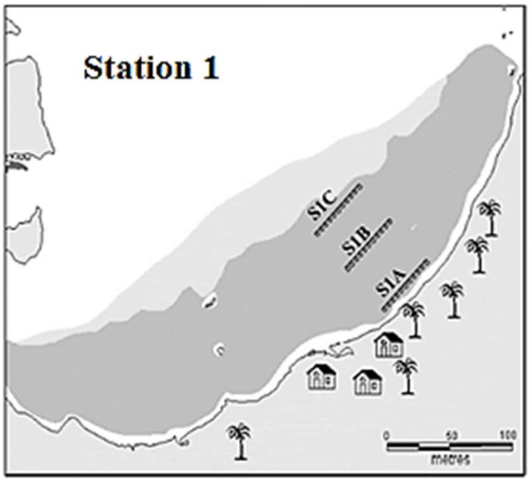

Fig. 2. Schematic of sampling site (McKenzie *et al.,* 2003)

Data collection

Determination of water depth and sediment grain-size distribution

The water depth was measured manually using a scale palm. Then the actual water depth value was calculated by correcting the mean sea level/MSL using Formula (1) (Suhana *et al.,* 2016).

$$\Delta d = d_t - (h_t - MSL) \quad (1)$$

Note:
Δd = corrected water depth (cm)
d_t = water depth measured at time t (cm)
h_t = the height of the tidal water level at time t (cm)
MSL = Mean Sea Level (cm)

Sediment grain-size analysis was carried out using a dry sieving method of the ASTM (C 136 – 01) procedure. Sediment samples taken in the field were dried at 60°C for 48 hours using an oven and then sieved using a sieve shaker. The weight of each sediment fraction was weighed and classified into three categories, i.e., gravel (>2 mm), sand (63 μm–2 mm), and mud (<63 μm) (Blott and Pye, 2001).

Determination of Seagrass Density

The density of seagrass species was performed at each substation based on Kenzie *et al.,* (2003), and the seagrass was observed at 0.5 m × 0.5 m quadrate transect. The density of each seagrass species was determined by counting all the shoots within the quadrate transect (Rahmawati *et al.,* 2014).

Collecting Seagrass Sample

The whole seagrass fragment consisting of leaves, rhizomes, and roots was collected with a spade. The fragment of each species should consist of at least 20 shoots. After collecting the seagrass fragment, they were cleaned and put in a zip-lock plastic, labeled, and stored in a cool box to keep them fresh until analysis (Huang *et al.,* 2015).

Table 1. Physical parameters (water depth and sediment distribution) at the study site on Pramuka Island.

Parameter	S1		S2			S3			S4		
	A	B	A	B	C	A	B	C	A	B	C
Water depth (m)	0.65	1.02	0.69	0.67	0.86	1.09	0.80	0.92	0.40	0.49	0.50
Mud (%)	5.16	2.07	5.03	2.71	0.94	1.74	1.38	0.82	1.08	0.61	0.67
Sand (%)	90.32	94.51	86.92	90.07	86.71	96.57	93.72	95.12	88.41	95.04	94.75
Gravel (%)	4.52	3.42	8.05	7.22	12.35	1.69	4.90	4.06	10.51	4.36	4.58

Measurement of Seagrass Leaf Area

In the laboratory, the leaf area was measured by taking a photo of one side seagrass leaf placed on a size-scale paper and then estimated using ImageJ software (Samper-Villarreal *et al.,* 2016; Vizzini *et al.,* 2019). Ten replications for each seagrass species were performed to estimate the seagrass leaf area.

Estimation of Seagrass Biomass

All seagrass samples were cleaned from epiphytic material and were dried at 60°C using an oven. After reaching the stable weight, samples were weighed as dry weight of seagrass (DW). Seagrass biomass was estimated by multiplying the dry weight per shoot and the density of the seagrass species (Rahmawati *et al.,* 2019).

Calculation of Seagrass Carbon Stock

Carbon stocks were analyzed by the Loss on Ignition (LoI) method. A pre-cleaned porcelain cup was put in a muffle furnace at 500°C for 2–3 hours and then weighed as the initial weight of the porcelain cup (a). Afterward, the dry seagrass sample was placed into the initial cup (b) and put in a muffle furnace at 450°C for 4 hours or until the sample color turned grey. The sample ash was cooled in a desiccator for 30 minutes and then weighed (c). The LoI value, organic carbon, and carbon stocks stored in the seagrass were calculated using equations 2, 3, and 4, respectively (Rahmawati *et al.,* 2019).

$$\mathrm{LoI} = \frac{[(b-a) - (c-a)]}{(b-a)} \times 100 \quad (2)$$

Note:
LoI = total organic matter (%)
a = initial weight of porcelain of cup (g)
b = sample + cup weighed (g)
c = ash + cup weighted (g)

$$C_{org} = 0{,}43 \times \mathrm{LoI} - 0{,}33 \quad (3)$$

Note: C_{org} = seagrass organic carbon (%)

$$\mathrm{OCS} = B \times C_{org} \quad (4)$$

Note: OCS = seagrass carbon stock (g C m^{-2})

Data analysis

Principal Component Analysis (PCA) was performed with the XLSTAT application to examine the spatial characteristics of the research area based on seagrass properties and physical parameters observed in this study.

RESULTS

Water Depth and Sediment Grain-Size Distribution

The results of water depth and sediment grain-size determination indicate that the environmental conditions of seagrass beds at each research location on Pramuka Island tend to have the same conditions (Table 1). The research area can be classified as shallow and flat, with depths ranging from 0.40–1.09 m (Table 1). It was covered by sand-dominated sediments (86.7–96.6%), primarily coral fragments and mollusk shells of origin. Irianto (2007) and Utami *et al.,* (2018) found that sediment composition in Seribu Islands, which includes Pramuka Island, was biogenous carbonate sediments, specifically limestone reefs, composed of 12.8–59.5% coral fragments and 16.6–24.5% mollusk shells.

Seagrass density

The seagrass density calculation showed that seagrass *T. hemprichii* had a higher density than *C. rotundata* (Figure 3A). Seagrass *T. hemprichii* was distributed throughout the study sites with a density ranging from 104.00–984.80 ind m^{-2}. Furthermore, *T. hemprichii* found in S1A and S2B was significantly denser than the other substations, i.e., 765.60 ind m^{-2} and 984.80 ind m^{-2}, respectively. Meanwhile, seagrass *C. rotundata* density ranged from 80.00–580.80 ind m^{-2}, whereas a significantly denser *C. rotundata* was found in S2B with 580.80 ind m^{-2} but was found absent in S3.

Seagrass leaf area

The results of measuring the seagrass leaf area using ImageJ software showed that seagrass *T. hemprichii* had larger leaves than *C. rotundata,* with an average ratio of 3:1 (Figure 4). The leaf area of *T. hemprichii* ranged from 9.08–29.90 cm^2, and the average was 16.41 cm^2 (Figure 3B). The highest *T. hemprichii* leaf area (29.90 cm^2) was found in S3, especially S3A, while S4C (9.08 cm^2) was much smaller than the other stations. The leaf area of *C. rotundata* ranged from 3.09–14.08 cm^2, whereas a considerably higher leaf area of *C. rotundata* (14.08 cm^2) was found in S2A. Seagrass *T. hemprichii* is a type of climax seagrass with a large morphology (large and thick leaves and rhizomes) with a longer turnover. Meanwhile, *C. rotundata* is a pioneer seagrass with a small morphology (small and thin leaves and rhizomes) with rapid turnover (Kilminster *et al.,* 2015).

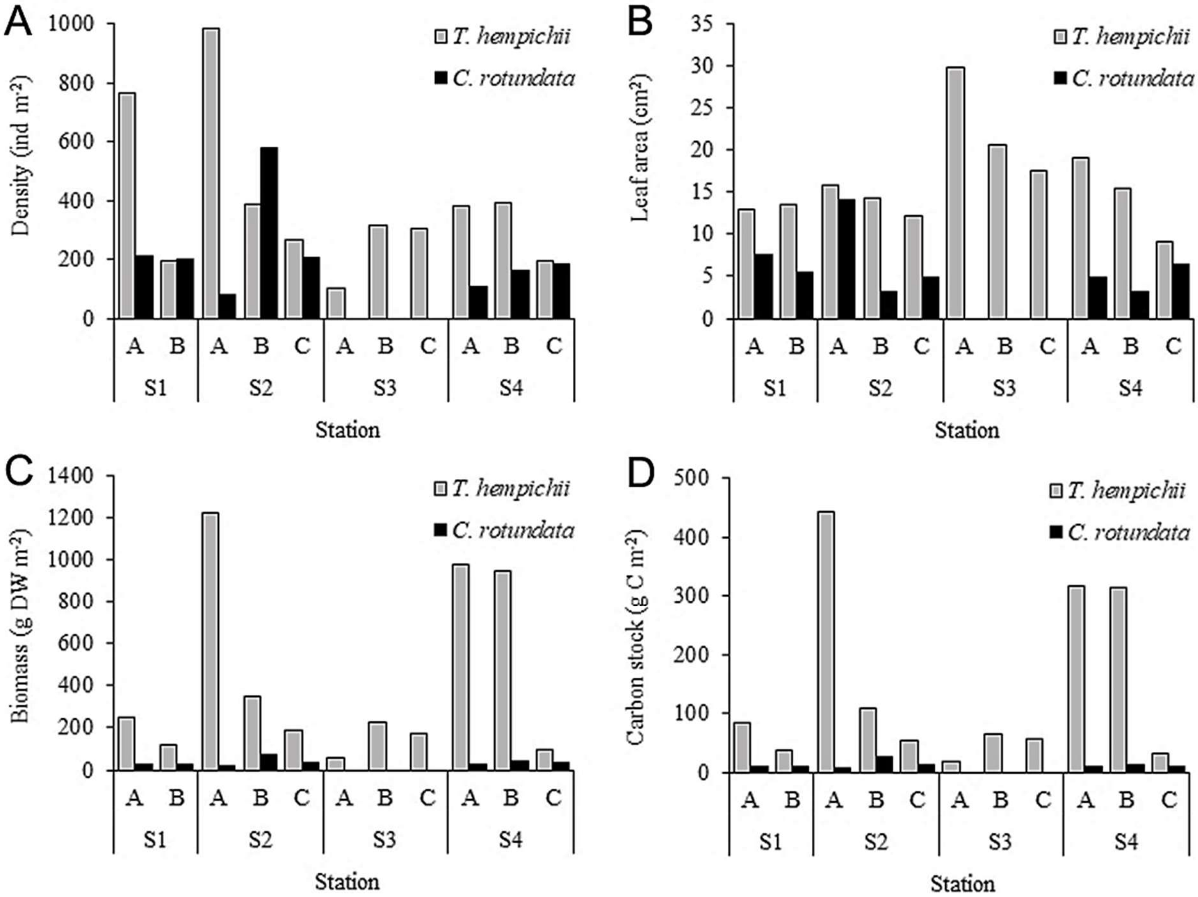

Fig. 3. Seagrass properties (***T. hemprichii* and *C. rotundata***) on the study site of Pramuka Island. **A**. Population density (ind m^{-2}) **B.** Leaf area (cm^2). **C**. Biomass (g DW m^{-2}). **D**. Carbon stock (g C m^{-2}).

Fig. 4. Illustration of seagrass leaf morphology. **A**: ***T. hemprichii***. **B**: ***C. rotundata***.

Seagrass biomass

The total biomass of *T. hemprichii* (60.70–1,225.13 g DW m^{-2}) was significantly higher than that of *C. rotundata* (16.42–71.39 g DW m^{-2}), especially on *T. hemprichii* found in S2A (g DW m^{-2}), S4A (g DW m^{-2}), and S4B (g DW m^{-2}) (Figure 3C). However, it was interesting that *T. hemprichii* in S4 was significant and non-correspondingly to its densities. Meanwhile, the biomass of *C. rotundata* among the sites was relatively similar.

Seagrass carbon stock

It is predicted that the morphology of seagrass will correspond to the carbon stock value. The estimated total carbon stock was higher in *T. hemprichii* (18.22–443.73 g C m^{-2}) compared to those of *C. rotundata* (5.99–25.61) (Figure 3D). Generally, the average carbon stock *T. hemprichii* was 12-fold greater than *C. rotundata*. The carbon stock of *T. hemprichii* was significantly higher in S2A (443.73 g C m^{-2}), S4A (317.49 g C m^{-2}), and S4B (315.21 g C m^{-2}), respectively. Meanwhile, the carbon stock of *C. rotundata* followed similar trends as biomass in all sites.

Spatial conditions of environmental parameters and seagrass properties

Figure 5A showed the results of PCA analysis on seagrass properties (seagrass leaf area, seagrass density, and seagrass carbon stocks of seagrass *T. hemprichii* and *C. rotundata*) in all research locations centered on two axes (F1 and F2) of 80.20%. The PCA results showed that seagrass characteristics in each research station were relatively different. Substation S2B was characterized by having a high density and carbon stock of *C. rotundata*. S2A was characterized as having a high density and carbon

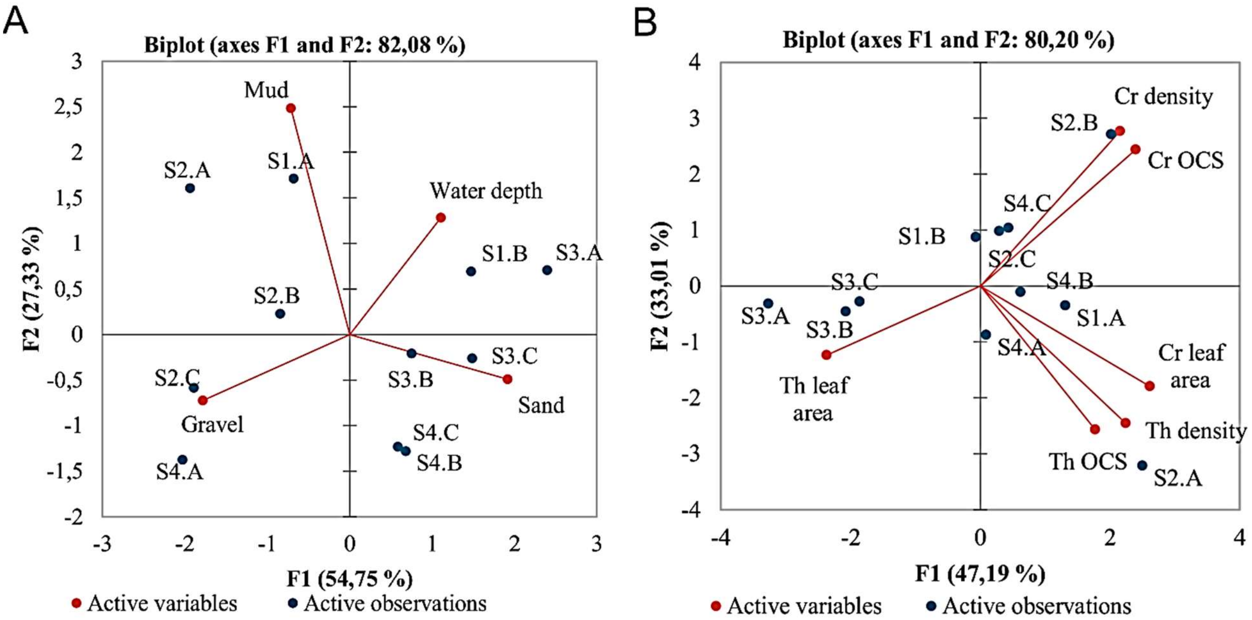

Fig. 5. Principal Component Analysis (PCA) between research stations with (**A**) seagrass properties; (**B**) physical parameters. OCS = organic carbon stock

stock of *T. hemprichii* and bigger *C. rotundata* leaves. Meanwhile, S3A, S3B, and S3C had a larger leaf area of *T. hemprichii*. The PCA results show that the amount of carbon stock stored in the seagrass ecosystem depends on the type of seagrass that dominates the ecosystem. Meanwhile, the leaf area of the same species did not significantly affect the seagrass carbon stocks.

The PCA results on environmental parameters at the study site (water depth, percentage of silt, sand, and gravel) also showed that the data was centered on two main axes (F1 and F2) with a total variance of 82.08% (Figure 5B). Although the environmental conditions in the seagrass ecosystem are relatively unvaried, Figure 5B shows that several seagrass ecosystems on Pramuka Island grown in deeper waters with higher sand percentages as found in S1B, S3A, S3B, and S3C. Some locations were also found in shallow waters, with more gravel, e.g., S2A, S2C, and S4A. Seagrasses were also found on substrates with a higher percentage of mud, such as S1A and S2A.

Based on Figure 5, it can be seen that seagrass properties, especially the seagrass morphology and species density, have influenced the amount of seagrass carbon stock. At the same time, the environmental conditions are not much different on Pramuka Island. The highest seagrass carbon stock was found in S2A, characterized by a very dense *T. hemprichii* and has a higher proportion of mud. The high percentage of mud in this station was suspected of the high density of *T. hemprichii*, which has weakened the current velocity and deposited more fine sediment. Denser seagrass beds will accumulate higher carbon in their biomass and may increase fine sediment and organic matter deposit into the sediment (Greiner *et al.,* 2013; Hansen and Reidenbach, 2012). It was found in S1A and S2A, which had more mud than in other locations. On the other hand, S2B has a high density of *C. rotundata* but does not show the same fate. This is thought cause the meadows not to be able to weaken the current so that it cannot deposit mud in this ecosystem. Seagrass *T. hemprichii* found in S3, which had wider leaves, did not show high carbon stocks because it had a low density. The wider leaves at this station are thought to be due to deeper water depths. Seagrasses that grow in deeper waters have a larger leaf area to help them carry out photosynthesis (Jiang *et al.,* 2019).

DISCUSSION

As described above, seagrass beds on Pramuka Island generally grow in shallow water with a predominantly sandy substrate. Feryatun *et al.,* (2012) found that the current velocity on Pramuka Island was 0.04–0.24 m s^{-1}, but most of the area had very slow currents (<0,1 m s^{-1}). Based on the Hjulström diagram, a current velocity of 0.01–0.10 m s^{-1} will deposit sand. The higher percentage of mud in S1A and S2A was possibly due to the weaker current velocity compared to other locations. Water depth and sediment grain size distribution are necessary environmental parameters because they are closely related to the availability of nutrients and photosynthetic processes that are important for seagrass growth and have a relationship with carbon stocks stored in the seagrass ecosystem. Sandy or coarser substrates may not be easy to accumulate organic matter compared to those muddy because it has a higher porosity which causes organic matter to be released easier (Novak *et al.,* 2020; Röhr *et al.,* 2016; Windusari *et al.,* 2014). Meanwhile, seagrasses that grow in shallower waters have better productivity and could deposit higher carbon stocks than those in deeper waters (Halim *et al.,* 2020; Serrano *et al.,* 2014).

Nevertheless, the report of this study showed that seagrass grows widely in all parts of Pramuka Island, which indicates that the environment of Pramuka Island can support the growth of seagrass, especially the dominant seagrass species, i.e., *T. hemprichii* and *C. rotundata*. Seagrass *T. hemprichii*, a climax seagrass with a large morphology and persistent form, is a cosmopolitan seagrass that can grow on various substrates from coarse sandy to fine sandy sediments (Yunita *et al.,* 2018). This species is also often becoming a dominant species in mixed seagrass beds. *T. hemprichii* is widely distributed throughout the ecoregions of Southeast Asia (Fortes *et al.,* 2018). Meanwhile, Seagrass *C. rotundata*, a small pioneer species also commonly found in Southeast Asia (Fortes *et al.,* 2018), can grow in intertidal areas with sandy substrates. Pioneer species have opposite traits to climax species since these species have a small morphology and low standing-crop (Kilminster *et al.,* 2015).

This study showed that the mean carbon stock of *T. hemprichii* is significantly higher (12-fold) than those observed for *C. rotundata*. This result was, apparently, very commonly found for those larger vegetations. For instance, the study on the Andaman Coast of Thailand found that carbon stocks in living parts of the larger seagrass *E. acoroides* was higher (2.5-fold) than those observed in *T. hemprichii* (Stankovic *et al.,* 2017). Similarly, Rozaimi *et al.,* (2013) found that higher carbon stocks were stored in meadows of the larger seagrass *P. australis*, which was six times higher than those smaller species *H. ovalis*. The difference in the carbon stock between larger and smaller seagrass is probably due to the content of their biomass. The average biomass of *T. hemprichii* was significantly higher than those of *C. rotundata*, i.e., 453.40 g DW m^{-2} and 35.91 g DW m^{-2}, respectively. In addition, Duarte and Chiscano (1999) found that the global average biomass of *T. hemprichii* was significantly higher than that of *C. rotundata*, which was 296.8 g DW m^{-2} and 95.7 g DW m^{-2}, respectively. Therefore, the larger species have an important role in storing more carbon storage in the sediment. This result also suggested that *T. hemprichii* has great potential to store carbon in the Coastal Waters of Pramuka Island.

Seagrass biomass generally reflects the seagrass productivity obtained through carbon absorption from photosynthesis. According to Mateo *et al.,* (2006) seagrass biomass is strongly influenced by seagrass species because different species will have different abilities to absorb and store carbon. Therefore, the biomass of seagrass species is closely related to its density and morphology (Duarte and Chiscano, 1999; Gladstone-Gallagher *et al.,* 2018). A high density of seagrass species will accumulate higher organic carbon (Greiner *et al.,* 2013). Meanwhile, bigger seagrasses with larger leaf surface areas will absorb more carbon because they have greater productivity (Jiang *et al.,* 2019; Macreadie *et al.,* 2014; Tupan *et al.,* 2021). According to Duarte and Chiscano (1999) the maximum production of *T. hemprichii* was 4.2 g DW m^{-2} d^{-1} whereas *C. rotundata* was 0.63 g DW m^{-2} d^{-1}. In addition, the rhizomes and roots of extensive species could penetrate in deeper sediment and tend to have higher biomass, potentially will invest more carbon into below ground, likely to end up buried in situ and will become a source of autochthonous carbon in seagrass sediments (Angrelina *et al.,* 2019; Björk *et al.,* 2008; Kilminster *et al.,* 2015; Mazarrasa *et al.,* 2018). Furthermore, larger seagrasses with higher canopy cover efficiently stabilize the sediment and deposit allochthonous carbon by depositing sediment from outside the beds compared to the smaller seagrasses (Macreadie *et al.,* 2014; Serrano *et al.,* 2018). Therefore, as a natural-based solution to tackle climate change, large seagrasses have to get better management to optimize their role in sequestering and storing carbon.

CONCLUSION

The amount of carbon stock among predominated seagrass species in Pramuka Island (*T. hemprichii* and *C. rotundata*) demonstrated a significant difference. Seagrass *T. hemprichii*, which has a larger morphology, accrues 12-fold more carbon stock than those *C. rotundata*, which has a smaller morphology. The higher carbon stock in *T. hemprichii* was due to this species' higher density, morphology, and biomass. Seagrass species with larger morphology can encourage higher carbon stocks in the seagrass ecosystem.

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LITERATURE CITED

Angrelina, I., A Sartimbul and A.J. Wahyudi 2019. The potential of seagrass beds on the coast of Putri Menjangan as a carbon sequestration ecosystem on Bali Island. IOP Conf. Ser. Earth Environ. Sci. **241(1)**: 012010.

Björk, M., F. Short, E. Mcleod and S. Beer 2008. Managing Seagrasses for Resilience to Climate Change. IUCN.

Blott, S. J and K. Pye 2001. Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surf. Process. Landf. **26(11):** 1237–1248.

Duarte, C. M and C.L. Chiscano 1999. Seagrass biomass and production: a reassessment. Aquat. Bot. **65(1-4):** 159–174.

Duarte, C. M., M. Merino, N.S.R. Agawin, J. Uri, M.D. Fortes, M.E. Gallegos, N. Marbá and M.A. Hemminga 1998. Root production and belowground seagrass biomass. Mar. Ecol. Prog. Ser. **171:** 97–108.

Feryatun, F., B. Hendrarto and N. Widyorini 2012. Kerapatan dan Distribusi Lamun (Seagrass) berdasarkan Zona Kegiatan yang Berbeda di Perairan Pulau Pramuka, Kepulauan Seribu. Management of Aquatic Resources Journal (MAQUARES) **1(1)**: 44–50. (In Bahasa).

Fortes, M.D., J.L.S. Ooi, Y.M. Tan, A. Prathep, J.S. Bujang and S.M. Yaakub 2018. Seagrass in Southeast Asia: a review of status and knowledge gaps, and a road map for conservation. Bot. Mar. **61(3):** 269–288.

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

Gladstone-Gallagher, R.V., R.W. Hughes, E.J. Douglas and C.A. Pilditch 2018. Biomass-dependent seagrass resilience to sediment eutrophication. J. Exp. Mar. Biol. Ecol. **501:** 54–64.

Greiner, J.T., K.J. McGlathery, J. Gunnell and B.A. McKee 2013. Seagrass Restoration Enhances "Blue Carbon" Sequestration in Coastal Waters. PLoS ONE. **8(8):** 1–8.

Halim, M., D.G. Bengen and T. Prartono 2020. Influence of turbidity and water depth on carbon storage in seagrasses, Enhalus acoroides and Halophila ovalis. AACL Bioflux. **13(1):** 309–317.

Hansen, J.C.R. and M.A. Reidenbach 2012. Wave and tidally driven flows in eelgrass beds and their effect on sediment suspension. Mar. Ecol. Prog. Ser. **448**: 271–287.

Howard, J., A. Sutton-Grier, D. Herr, J. Kleypas, E. Landis, E. Mcleod, E. Pidgeon and S. Simpson 2017. Clarifying the role of coastal and marine systems in climate mitigation. Front. Ecol. Environ. **15(1):** 42–50.

Huang, Y.H., C.L. Lee, C.Y. Chung, S.C. Hsiao and H.J. Lin 2015. Carbon budgets of multispecies seagrass beds at Dongsha Island in the South China Sea. Mar. Environ. Res. **106:** 92–102.

IPCC (Intergovernmental Panel on Climate Change) 2014. Climate Change 2014: Synthesis Report. In: R.K. Pachauri & L. A. Meyer (eds.) Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC.

Irianto, S. 2007. Sedimen Permukaan Dasar Laut Teluk Jakarta, Kepulauan Seribu dan Pantai Lampung Timur. J. Teknol. **2:** 22–35. (In Bahasa).

Jiang, Z., C. Zhao, S. Yu, S. Liu, L. Cui, Y. Wu, Y. Fang and X. Huang 2019. Contrasting root length, nutrient content and carbon sequestration of seagrass growing in offshore carbonate and onshore terrigenous sediments in the South China Sea. Sci. Total Environ. **662:** 151–159.

Kennedy, H and M. Björk 2009. Seagrass Meadows. In D.d'. Laffoley & G. Grimsditch (Ed.) The Management of Natural Coastal Carbon Sinks, Gland, Switzerland: IUCN, pp. 23–29.

Kilminster, K., K. McMahon, M. Waycott, G.A. Kendrick, P. Scanes, L. McKenzie, K.R. O'Brien, M. Lyons, A. Ferguson, P. Maxwell, T. Glasby and J. Udy 2015. Unravelling complexity in seagrass systems for management: Australia as a microcosm. Sci. Total Environ. **534:** 97–109.

Macreadie, P.I., M.E. Baird, S.M. Trevathan-Tackett, A.W.D. Larkum and P.J. Ralph 2014. Quantifying and modelling the carbon sequestration capacity of seagrass meadows - A critical assessment. Mar. Pollut. Bull. **83(2):** 430–439.

Mateo, M.A., J. Cebrian, K. Dunton and T. Mutchler 2006. Carbon Flux in Seagrass Ecosystems. In A. W. D. Larkum, R. J. Orth, & C. Duarte (Eds.) Seagrasses: Biology, Ecology and Conservation. 159–192 pp. Springer-Verlag.

Mazarrasa, I., J. Samper-Villarreal, O. Serrano, P.S. Lavery, C.E. Lovelock, N. Marbà, C.M. Duarte and J. Cortés 2018. Habitat characteristics provide insights of carbon storage in seagrass meadows. Mar. Pollut. Bull. **134:** 106–117

McKenzie, L.J., S.J. Campbell and C.A. Roder 2003. Seagrasswatch: Manual for mapping & monitoring seagrass resources by community (citizen) volunteers 2sd edition. In The state of Queensland, Department of Primary Industries, CRC Reef. Queensland. Marine Plant Ecology Group, QDPI.

Mcleod, E., G.L. Chmura, S. Bouillon, R. Salm, M. Björk, C.M. Duarte, C.E. Lovelock, W.H. Schlesinger and B.R. Silliman 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2 In a nutshell: Front. Ecol. Environ. **9(10):** 552–560.

Novak, A.B., M.C. Pelletier, P. Colarusso, J. Simpson, M.N. Gutierrez, A. Arias-Ortiz, M. Charpentier, P. Masque and P. Vella 2020. Factors Influencing Carbon Stocks and Accumulation Rates in Eelgrass Meadows Across New England, USA. Estuaries Coast **43(8):** 432076–2091.

Rahmawati, S., E.U. Hernawan, K. McMahon, B. Prayudha, H.B. Prayitno, A.J Wahyudi and M. Vanderklift 2019. Blue Carbon in Seagrass Ecosystem: Guideline for the Assessment of Carbon Stock and Sequestration in Southeast Asia. Gadjah Mada University Press.

Rahmawati, S., A. Irawan, I.H. Supriyadi and M.H. Azkab 2014. Panduan Monitoring Padang Lamun (M. Hutomo & A. Nontji (eds.)). COREMAP CTI LIPI. (In Bahasa).

Ricart, A.M., M. Pérez and J. Romero 2017. Landscape configuration modulates carbon storage in seagrass sediments. Estuar. Coast. Shelf Sci. **185:** 69–76.

Ricart, A.M., P.H. York, M.A. Rasheed, M. Pérez, J. Romero, C.V. Bryant and P.I. Macreadie 2015. Variability of sedimentary organic carbon in patchy seagrass landscapes. Mar. Pollut. Bull. **100(1):** 476–482.

Röhr, M.E., C. Boström, P. Canal-Vergés and M. Holmer 2016. Blue carbon stocks in Baltic Sea eelgrass (Zostera marina) meadows. Biogeosciences **13(22):** 6139–6153.

Rozaimi, M., O. Serrano and P.S. Lavery 2013. Comparison of carbon stores by two morphologically different seagrasses. J. R. Soc. West. Aust. **96(2):** 81–83.

Samper-Villarreal, J., C.E. Lovelock, M.I. Saunders, C. Roelfsema and P.J. Mumby 2016. Organic carbon in seagrass sediments is influenced by seagrass canopy complexity, turbidity, wave height, and water depth. Limnol. Oceanogr. **61(3):** 938–952.

Serrano, O., H. Almahasheer, C.M. Duarte and X. Irigoien 2018. Carbon stocks and accumulation rates in Red Sea seagrass meadows. Sci. Rep. **8(1):** 1–13.

Serrano, O., P.S. Lavery, M. Rozaimi and M. Mateo 2014. Influence of water depth on the carbon sequestration capacity of seagrasses. Glob. Biogeochem. Cycles **28(9):** 950–961.

Short, F.T., B. Polidoro, S.R. Livingstone, K.E. Carpenter, S. Bandeira, J.S. Bujang, H.P. Calumpong, T.J.B. Carruthers, R.G. Coles, W.C. Dennison, P.L.A. Erftemeijer, M. D. Fortes, A. S. Freeman, T. G. Jagtap, A.H.M. Kamal, G.A. Kendrick, W. Judson Kenworthy, Y.A. La Nafie, I. M. Nasution, R.J. Orth, A. Prathep, J.C. Sanciangco, B. van Tussenbroek, S.G. Vergara, M. Waycott, C. Zieman 2011. Extinction risk assessment of the world's seagrass species. Biol. Conserv. **144(7):** 1961–1971.

Stankovic, M., J. Panyawai, K. Jansanit, T. Upanoi and A. Prathep 2017. Carbon content in different seagrass species in Andaman Coast of Thailand. Sains Malays. **46(9)**: 1441–1447.

Suhana, M.P., I.W. Nurjaya and N.M. Natih 2016. Coastal Vulnerability Analysis of East Coast Bintan Island Using Digital Shoreline Analysis and Coastal Vulnerability Index. Jurnal Teknologi Perikanan Dan Kelautan **7(1):** 21–38. (In Bahasa).

Tupan, C.I., F. Sangur and G.W. Lailossa 2021. Carbon Potential on Seagrass Thalassia hemprichii and Enhalus acoroides in Waai Coastal Waters Ambon Island. J. Sumberd. Akuatik Indopasifik **5(3)**: 293–302. (In Bahasa).

Utami, D.A., L. Reuning and S.Y. Cahyarini 2018. Satellite- and field-based facies mapping of isolated carbonate platforms from the Kepulauan Seribu Complex, Indonesia. J. Int. Assoc. Sedimentol. **4(2):** 255–273.

Vizzini, S., E.T. Apostolaki, E. Ricevuto, P. Polymenakou and A. Mazzola 2019. Plant and sediment properties in seagrass meadows from two Mediterranean CO_2 vents: Implications for carbon storage capacity of acidified oceans. Mar. Environ. Res.**146:** 101–108.

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

Windusari, Y., S. Sarno, E. Saleh and L. Hanum 2014. Substrate characteristics and its Impact on distribution of mangrove species: A case study in Sungai Barong Kecil in The Sembillang National Park at Banyuasin, South Sumatra. J. Biol. Res. **20(1):** 82–86.

Yunita, I.D., N. Widyorini and Supriharyono 2018. Influence of Seagrass *Thalassia hemprichii* Density on the Abundance of Heterotrophic Bacteria at Prawean Beach, Jepara. Journal of Maquares. **7(4):** 415–422. (In Bahasa).