Role of the Seagrass Bed at Kemujan Island, Karimunjawa Islands, Indonesia, as a Carbon Sink Area

by Anindya Wirasatriya

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Role of the Seagrass Bed at Kemujan Island, Karimunjawa Islands, Indonesia, as a Carbon Sink Area

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Abstract: The Java Sea acts as a carbon source that contributes to the release of carbon dioxide into the atmosphere. The blue carbon ecosystems in the Karimunjawa Islands may absorb and store the carbon released from the Java Sea. The carbon stock in Kemujan Island (Karimunjawa Islands), one of these blue carbon ecosystems, was previously estimated using a remote sensing approach. In the present study, we investigated the carbon stock in the seagrass bed at Kemujan Island by conducting field observations and laboratory analysis. The result shows that there are only two seagrass species in the study area—'Enhalus acoroides' and 'Thalassia hemprichii'—which are categorized as nearly dense and very dense, respectively. Regarding the carbon biomass, the carbon stock below the substrate is more than that above the substrate. However, the carbon stock in the seagrass biomass is less than in the sediment. The average carbon stock in the seagrass bed at Kemujan Island is 4901.91 g C/m², which is much more than the amount estimated by means of remote sensing. Furthermore, this amount is much larger compared with the average carbon stock of other areas in the Karimunjawa Islands. The large amount of carbon stock stored in the seagrass bed at Kemujan Island denotes the role of this seagrass bed as a carbon sink area.

Keywords: Seagrass Bed, Carbon Stock, Kemujan Island, Karimunjawa Islands

Introduction

The recent increase in the global mean surface temperature reached 0.87°C between 2006 to 2015 relative to that of the preindustrial period between 1850 to 1900), causing climate change (Hoegh-Guldberg et al. 2018). This surface warming is majorly contributed by the increase of carbon dioxide (CO_2) in the atmosphere due to the rapid increase of fossil fuel use and cement manufacture, as we as land-use changes over the last decade (Friedlingstein et al. 2010). Jackson et al. (2018) reported that observations from the National Oceanic and Atmospheric Administration Earth System Research Laboratories show that the CO_2 concentration in the atmosphere in 2000, 2010, and 2018 was 369.55, 389.90, and 409.68 ppm, respectively. Thus, the emissions of anthropogenic CO_2 have become the main contributor for the climate change.

On the other hand, oceans play an important role in carbon storage. About one-quarter of the anthropogenic carbon emission is thought to be sequestered in the ocean annually (Le Quéré et al. 2009). The annual global ocean uptake of anthropogenic CO_2 is estimated to be 1.4–2.5 Pg C yr-1 (e.g., Takahashi et al. 2002, 2009; McKinley et al. 2011), whereas the cumulative uptake since the preindustrial period is about 120–140 Pg C (Sabine et al. 2004; Khatiwala, Primeau, and Hall 2009). However, oceans can act as the source or sink of CO_2 being influenced by a number of biological and physical processes such as wind speed, sea surface temperature, salinity, photosynthesis, and respiration rate (Chester 2000; Botkin and Keller 2000).

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By collecting and conducting measurements of sea surface pCO_2 from 1984 to 2013 within Indonesian Seas, mainly during the summer monsoon, Kartadikaria et al. (2015) showed that these seas predominantly act as a carbon source. Focusing on an area in the Java Sea, Wirasatriya et al. (2020) estimated the CO_2 flux by using satellite data and found that the Java Sea becomes a CO_2 source, which reached a maximum during the summer. Only small areas along the southern Borneo Island between May 2015 and August 2016 became CO_2 sink areas. Due to the limitation of spatial resolution of the satellite data used by Wirasatriya et al. (2020), the Karimunjawa waters were left blank in their analysis. Later on, Latifah et al. (2020) conducted a field survey and managed to calculate the carbon flux in the Karimunjawa waters during the summer monsoon. They found that the Karimunjawa waters also act as a carbon source. Thus, generally, the Java Sea acts as a carbon source, contributing to the release of CO_2 into the atmosphere.

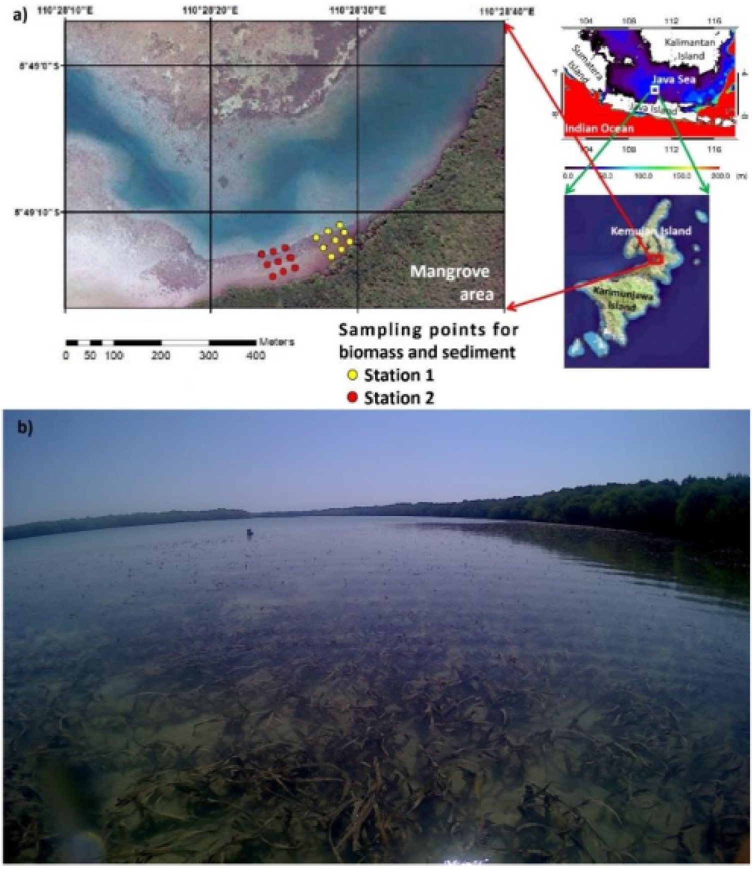

Figure 1: (a) Study Area in Kemujan Island with the Sampling Points;
(b) Seagrass Bed Condition in the Study Area
Source: Wirasatriya et al.

As an ocean ecosystem entity, coastal ecosystems play an important role in the carbon sequester, and are known as blue carbon ecosystems. In the tropics, mangrove and seagrass ecosystems are the major blue carbon ecosystems (Siikamäki et al. 2013). Seagrass beds have an important role as a natural carbon sink that can sequester and store large amounts of carbon in a millennium timescale (Duarte, Middelburg, and Caraco 2005; Kennedy et al. 2010; Fourqurean et al. 2012). Furthermore, Fourqurean et al. (2012) reported that seagrass ecosystems can globally store up to 19.8 Pg carbon. This amount is comparable to that of mangrove ecosystems, can store up to 20 Pg carbon (Donato et al. 2011).

The Karimunjawa Islands, located at the center of the Java Sea (Figure 1a), enclose the blue carbon ecosystems that may balance the role of the Java Sea as a carbon source. In the present study, we investigated the carbon stock of the seagrass ecosystems in Kemujan Island, one of the two main islands in the Karimunjawa Islands. Figure 1b shows the high seagrass bed density in the study area. The carbon stock in the mangrove ecosystem in Kemujan Island was estimated by Hartoko et al. (2014) using a remote sensing approach. The researchers found that about 91.2 tons of carbon was stored in the aboveground mangrove biomass. With respect to seagrass ecosystems, Hafizt and Danoedoro (2013) mapped the distribution of carbon stock in the seagrass bed from the northern to the southern part of Kemujan Island using a remote sensing approach. They found that the approximate carbon storage was about 6.66 tons of carbon. In the present study, we investigated, using field observations and laboratory analysis, the carbon stock in the seagrass ecosystems inside the bay at the southern part of Kemujan Island (Figure 1a), an aspect that was missing in the analysis by Hafizt and Danoedoro (2013).

Materials and Methods

Sampling Site, Design, and Method

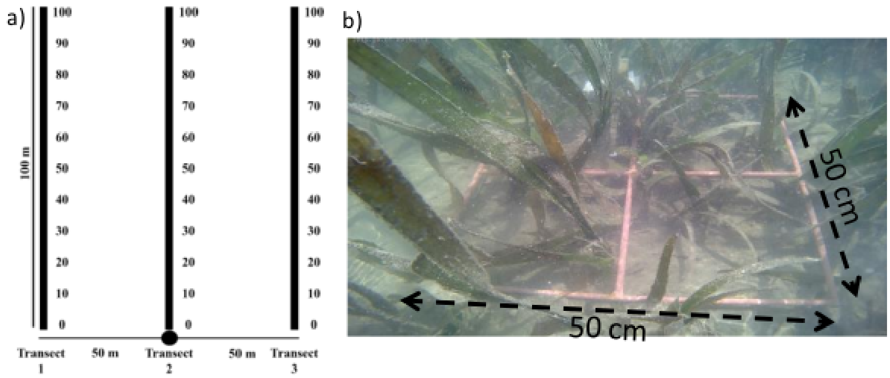

Figure 2: (a) Transect Design in Each Station for Density and Species of Seagrass;
(b) Quadrant Transect of 50 × 50 cm
Source: Wirasatriya et al.

Field sampling was conducted in August 2019. The sampling location was selected inside the bay at the southern part of Kemujan Island, where the seagrass bed is located in front of the mangrove area (Figure 1a). We divided the area into two stations, which represented the different characteristics of the seagrass and the sediment. Station 1 was located at 110°28′ 23.2″ E—110°28′ 25.7″ E; 5°49′ 12.9″ S—5°49′ 13.8″ S, while Station 2 was at 110°28′ 28.7″ E—110°28′ 28.2″ E; 5°49′ 10.9″ S—5°49′ 13.1″ S. Each station consisted of three line transects. The seagrass species and density sample in each line were each taken at 10 m (Figure 2a) with 50 × 50 cm quadrant transect (Figure 2b). The seagrass biomass and sediment were each taken at 50 m in each line transect, which made each line transect consist of three sampling points for the biomass and the sediment. Thus, the total sampling points for the biomass and the sediment were 18 sampling points for 2 stations (Figure 1a). The biomass and sediment samples were taken using seagrass core from the surface bed to about 25 cm depth, following the approach of Rustam et al. (2019). The density of seagrass was calculated following Tuwo's approach (2011).

$$K_{ji} = \frac{N_i}{A} \qquad (1)$$

where K_{ji} is the ith seagrass species density (ind/m^2), N_i is the total number of individual species from the ith species (ind), and A is the size of the sampling transect (m^2).

Laboratory Analysis

A laboratory analysis was conducted to obtain the carbon stock in the seagrass biomass and the sediment. To calculate the carbon stock in the seagrass biomass, we used the loss on ignition method, following the approach of Rustam et al. (2019). By using this method we obtained the percentage of organic matter as well as of carbon organic (C). The seagrass biomass and carbon weight biomass were calculated using Duarte's formula (1990).

$$B = W \times K \qquad (2)$$

$$BC = B \times \%C \qquad (3)$$

where B is the seagrass biomass (g/m^2), W is the dry weight of the seagrass (g/ind), K is the seagrass density (ind/m^2), C is the percentage of carbon organic (%), and BC is the carbon biomass of the seagrass (g C/m^2).

Carbon in the sediment was analyzed following the approach of Kauffman and Donato (2012), that is, by calculating the dry bulk density and the carbon biomass. We also analyzed the grain size of the sediment by using the granulometry method. The classification of the grain size of the sediment follows Shepard's approach (1954).

Results

Carbon Stock in the Seagrass Biomass

We found only two seagrass species in the study area: *Enhalus acoroides* and *Thalassia hemprichii*. The density of each species is presented in Figure 3. In Station 1, the densities of *Thalassia hempricii* and *Enhalus acoroides* were 341 and 92 ind/m^2, respectively, while in Station 2, they were 372 and 53 ind/m^2, respectively. Thus, the density of *Thalassia hemprichii* was higher than that of *Enhalus acoroides* in both the stations. On the basis of the classification by Braun-Blanquet (1965), the densities of *Thalassia hemprichii* and *Enhalus acoroides*) were categorized as very dense and nearly dense, respectively.

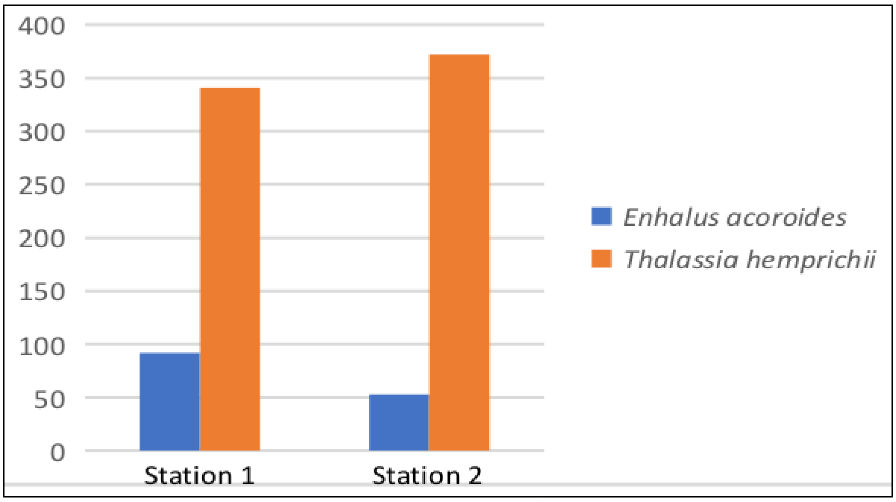

Figure 3: Density of the Seagrass (ind/m^2) in Stations 1 and 2
Note: The Position of Stations Is Depicted in Figure 1a.
Source: Wirasatriya et al.

We divided the analysis of the seagrass biomass into biomass above and below the substrate. In addition, we analyzed the seagrass biomass by organ. The results are listed in Tables 1–3.

Table 1: Biomass of *Enhalus acoroides* (g/m²)

Station	*Transect*	*Biomass by Organ*			*Biomass by Position*		
		Root	*Rhizome*	*Leaf*	*Below the Substrate*	*Above the Substrate*	*Total*
1	1	6.26	16.45	9.41	22.71	9.41	32.12
	2	6.14	20.73	6.36	26.87	6.36	33.23
	3	11.55	24.16	9.31	35.71	9.31	45.02
Total					85.29	25.08	110.37
2	1	2.11	3.73	2.18	5.84	2.18	8.03
	2	2.11	3.73	2.18	5.84	2.18	8.03
	3	1.49	5.09	2.19	6.58	2.19	8.77
Total					18.27	6.56	24.83

Source: Wirasatriya et al.

Table 2: Biomass of *Thalassia hemprichii* (g/m²)

Station	*Transect*	*Biomass by Organ*			*Biomass by Position*		
		Root	*Rhizome*	*Leaf*	*Below the Substrate*	*Above the Substrate*	*Total*
1	1	10.12	1.64	2.15	11.76	2.15	13.91
	2	0.29	2.34	2.09	2.63	2.09	4.71
	3	0.97	2.95	2.02	3.92	2.02	5.94
Total					18.30	6.26	24.56
2	1	0.75	0.98	0.53	1.73	0.53	2.26
	2	0.19	0.43	1.25	0.62	1.25	1.87
	3	0.44	0.11	0.47	0.55	0.47	1.02
Total					2.90	2.25	5.15

Source: Wirasatriya et al.

Table 3: Total Seagrass Biomass (g/m²)

Station	*Total Biomass*		
	Below the Substrate	*Above the Substrate*	*Total*
1	103.59	31.34	134.93
2	21.17	8.80	29.97

Source: Wirasatriya et al.

Root and rhizome are the components of the below the substrate biomass. Tables 1 and 2 show that the biomass below the substrate is higher than that above the substrate for both the species and both the stations. This result is consistent with the findings of Hemminga and Duarte (2000). Furthermore, Erftemeijer, Osinga, and Mars (1993) stated that since rhizome stores more organic matter as produced by photosynthesis, the rhizome biomass is higher than the above the substrate biomass. Table 3 summarizes the seagrass biomass below and above the substrate in the study area. The seagrass biomass in Station 1 was found to be higher than in Station 2. The seagrass biomass data was then converted into carbon biomass data, as shown in Tables 4–6.

As also derived from the seagrass biomass, as shown in Tables 1 to 3, the carbon biomass is higher below the substrate than above the substrate (see Tables 4 to 6). Supriadi (2012) stated that the higher carbon stock below the substrate is due to the lesser physical disturbance than above the substrate. Furthermore, Kennedy and Bjork (2009) reported that the carbon stock below the substrate remained stored despite the shoot being dead. In contrast, the carbon biomass above the substrate was stored only if the shoot was alive.

Table 4: Carbon Stock of *Enhalus acoroides* (g C/m^2)

Station	Transect	Biomass by Organ			Biomass by Position		
		Root	Rhizome	Leaf	Below the Substrate	Above the Substrate	Total
1	1	190.98	562.03	297.57	753.01	297.57	1050.59
	2	400.10	847.70	304.05	1247.80	304.05	1551.85
	3	223.83	485.41	119.80	709.24	119.80	829.04
Total					2710.05	721.43	3431.48
2	1	71.49	124.74	71.62	196.23	71.62	267.85
	2	87.88	140.65	77.12	228.54	77.12	305.66
	3	158.55	102.88	88.02	261.43	88.02	349.45
Total					686.20	236.76	922.95

Source: Wirasatriya et al.

Table 5: Carbon Stock of *Thalassia hemprichii* (g C/m^2)

Station	Transect	Biomass by Organ			Biomass by Position		
		Root	Rhizome	Leaf	Below the Substrate	Above the Substrate	Total
1	1	17.41	57.25	69.07	74.65	69.07	143.72
	2	10.38	43.72	63.84	54.11	63.84	117.95
	3	6.10	41.50	55.47	47.60	55.47	103.06
Total					176.36	188.37	364.73
2	1	23.12	29.97	15.70	53.09	15.70	68.80
	2	23.12	29.97	15.70	53.09	15.70	68.80
	3	25.26	25.24	6.69	50.50	6.69	57.19
Total					156.68	38.10	194.78

Source: Wirasatriya et al.

Table 6: Total Carbon Biomass (g C /m^2)

Station	Total Carbon Biomass		
	Below Substrate	Above Substrate	Total
1	2886.41	909.80	3796.21
2	842.88	274.86	1117.74

Source: Wirasatriya et al.

The analysis by species shows that *Enhalus acoroides* has a higher carbon biomass than *Thalassia hemprichii*, since the biomass of the former is higher than that of the latter. As stated by Graha (2015), the variation in carbon biomass is influenced by biomass differences among species and organs. The increase of carbon stock is parallel with the increase of biomass.

Carbon Stock in the Sediment

With regard to sediment classification, both stations were dominated by sand. However, at Station 1 the sand color was darker than at Station 2, since the sands in Station 1 contained more silt than the sands in Station 2. The substrate type in Station 1, which was silty sand, was more favorable for seagrass growth. This caused the seagrass biomass in Station 1 to be higher than in Station 2. Carbon stock in sediments is listed in Table 7.

Table 7: Carbon Stock in Sediments (g C/m^2)

Station	Transect	Measurement	
		Dry Bulk Density (g/mL)	Carbon in Sediment (g C/m^2)
1	1	6.14	722.87
	2	6.26	910.27
	3	7.42	955.69
Total		19.81	2588.83
2	1	7.85	851.60
	2	7.11	728.90
	3	7.13	720.54
Total		22.09	2301.03

Source: Wirasatriya et al.

Similar to the carbon biomass, the carbon stock in the sediment in Station 1 was also higher than in Station 2. This was caused by the denser seagrass in Station 1 than in Station 2. Madjid (2007) stated that the main organic source of the sediment is derived from plant organic tissues, such as leaf, branch, fruit, root, and rhizome. The weathering process of the falling leaves and also the dead organisms associated with the seagrass increases the organic content of the sediment. Furthermore, total organic carbon is also higher in the finer grain size than in the coarser grain size of the sediment (Dewanti, Muslim, and Prihatiningsih 2016).

Total Carbon Storage in the Seagrass Bed

The total carbon storage in the seagrass bed in Kemujan Island was calculated by summing the carbon biomass with the carbon in the sediment, as shown in Table 8. Furthermore, to obtain the spatial distribution of total carbon stock, we interpolated nine sampling points in each station, as presented in Figure 4. Station 1 had twice the amount of total carbon stock than Station 2. The total carbon stocks at Stations 1 and 2 were 6385.04 g and 3418.77 g C/m^2, respectively. Thus, the average carbon stock in both areas was 4901.91 g C/m^2, which was much higher than the amount obtained by Hafizt and Danoedoro (2015), who estimated it by the remote sensing approach.

The total carbon stock in the study area was also much higher than in the other areas the Karimunjawa Islands as reported by previous studies. For example, the total carbon stocks in the seagrass bed at Menjangan Kecil Island and Sintok Island were only 301.80 and 29.72 g C/m^2, respectively (Hartati, Pratikto, and Pratiwi 2017). Ganefiani, Suryanti, and Latifah (2019) found that the total carbon stocks around the harbor area of the Karimunjawa Islands and the Pancur Beach were only 97.06 and 127.82 g C/m^2, respectively. The much higher total carbon stock in the study area may correspond to the location of the study area, which was in a semi-enclosed bay. This area is protected from high waves and strong currents, enabling organic matter to settle and be sequestered by the seagrass ecosystem. In addition, this area is close to the mangrove area, which may be the source of the organic matter transported to the seagrass area.

Table 8: Total Carbon Stock (g C/m^2)

Station	*Carbon Stock*			
	Below the Substrate	*Above the Substrate*	*Sediment*	*Total*
1	2886.41	909.8	2588.83	6385.04
2	842.88	274.86	2301.03	3418.77

Source: Wirasatriya et al.

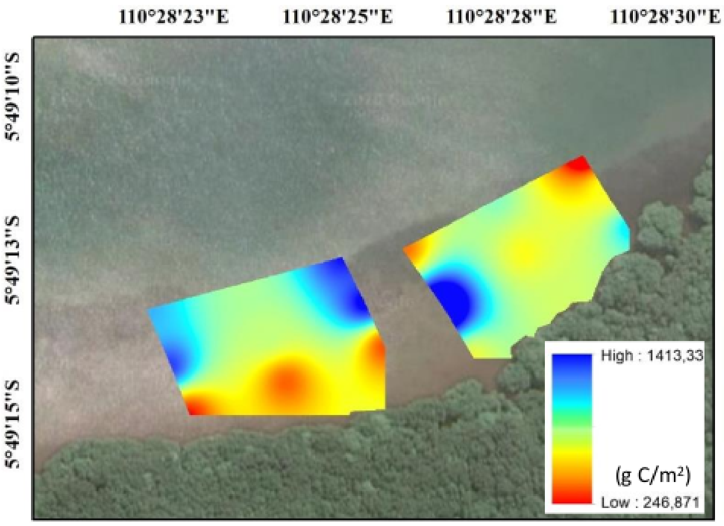

Figure 4: Spatial Distribution of the Carbon Stock in Kemujan Island
Source: Wirasatriya et al.

Conclusion

The carbon stock in the seagrass beds at Kemujan Island, Karimunjawa Islands, Indonesia, was been investigated by means of field observations and laboratory analysis. The conclusions are summarized as follows:

1. Only two seagrass species were found in the study area: *Enhalus acoroides* and *Thalassia hemprichii*. The densities of *Enhalus acoroides* and *Thalassia hemprichii* were categorized as nearly dense and very dense, respectively.
2. Regarding the carbon biomass, the carbon stock below the substrate was more than that above the substrate. However, the carbon stock in the seagrass biomass was less than in the sediment.
3. The average carbon stock in the seagrass bed at Kemujan Island, Karimunjawa Islands, Indonesia, was 4901.91 g C/m^2. This amount was much more than the amount that was found in the other areas of the Karimunjawa Islands. The ability of the seagrass bed at Kemujan Island to store high carbon stocks denotes its importance as a carbon sink area.

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