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Changes in seagrass carbon stock: implications of decreasing area and percentage cover of seagrass beds in Barranglompo Island, Spermonde archipelago, South Sulawesi, Indonesia

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Abstract. Seagrass ecosystems in shallow waters, including in highly dense small islands, are vulnerable to anthropogenic activities and may lead to a decreasing in seagrass area and percentage cover. As a result, it will negatively affect climate change mitigation, i.e. a decrease in seagrass carbon stock. This research was conducted to evaluate seagrass carbon stock changes in Barranglompo Island, Spermonde archipelago, in 2001 and 2017. Carbon stock estimation was carried out by collecting seagrass biomass based on the category of a sparse, medium, and dense seagrass coverage (each with 20 replications) and analysing their carbon concentrations. Changes in carbon sequestration were analysed using an estimated approach to the changes in the seagrass bed areas. Landsat and Worldview-2 image analysis were utilized to estimate the area of seagrass beds in 2001 and 2017, respectively. Results showed a decrease in seagrass beds by 9.9 ha, from 66.8 ha in 2001 to 56.9 ha in 2017, or an average of 0.62 ha per year. Based on that, it was estimated that seagrass carbon stocks had declined from 74.19 tons in 2001 to 65.21 tons in 2017 or decreased by an average of 0.75% per year. Anthropogenic activities, such as boat anchors as well as household waste disposal in the seagrass area, are considered having the potential in causing a decrease in seagrass area and the percentage coverage.

1. Introduction

Seagrass beds are known as one of the coastal and marine ecosystems that have important roles for the surrounding environment, including high primary productivity [1,2] hence the absorption of carbon dioxide for photosynthesis is also high. This process is very important considering the potential role of seagrass in mitigating climate change together with other coastal and marine vegetation such as mangroves and saltmarsh [3–6]. Most of the carbon dioxide uptake by seagrass is stored as biomass in the seagrass tissues. It is well known that the largest part of seagrass biomass is stored below-ground (roots and rhizomes), making the role of seagrass as a carbon storage even more important. The roots and rhizomes are located a few centimetres below the sediments and become confined carbon in the sediment. Also, seagrass can store carbon in the sediment at a high rate due to several reasons, including (1) the seagrass tissues have low concentrations of nitrogen and phosphorus, therefore the litter which is a substrate for microbes does not support the growth of microbes, which impact the low decomposition rate of seagrass (2) the oxygen concentration in seagrass sediments is often found to be relatively low, or even in the state of anaerobic conditions. This condition results in an inefficiency of microbial metabolism thereby can increase the amount of carbon buried [4,7].



Although seagrasses have important roles in the coastal and marine areas, yet seagrass beds have been degraded at a fairly high rate from time to time. The global decline in seagrass area between 1990 and early 2000, which was estimated at more than 7% per year [8,9] is somewhat alarming. This damage causes the degradation of the seagrass ecosystem services, including its potential services in the context of climate change mitigation. Decreasing in the seagrass beds area will reduce the number of carbon stocks, which in turn will reduce the amount of carbon dioxide absorbed. Damage to the seagrass beds also reduces the ability of the seagrass to capture and deposit non-seagrass organic carbon suspended in the water column through its ability to absorb currents [10]. Furthermore, damaged seagrass beds have a further impact which will create new problems. Seagrass damage that has occurred since the mid-20th century has been shown to trigger carbon dioxide emissions from carbon stocks below the sediments [6].

Damage to seagrass beds can be caused by natural disasters or as a result of anthropogenic activities. However, the latter is the main cause of seagrass degradation in almost all areas. Anthropogenic activities can cause damages to seagrass directly or indirectly [11,12]. Seagrass damage due to sand dredging, ship anchors moorings, infrastructure development are examples of direct impacts of human activities. Meanwhile, eutrophication can indirectly lead to seagrass damage because it will cause rapid algae growth, which can interfere with seagrass growth. In the end, seagrass damage can occur at a slow or rapid rate depending on the level of eutrophication. Among others, human activities that can damage the seagrass ecosystem, are triggered by rapid population growth.

One of the islands in the Spermonde Archipelago, South Sulawesi, Indonesia which has a very dense population is Barranglompo Island. Apart from the dense population, the high economic growth has caused the number of fishing vessels to also increase quite significantly. The obvious impact of the dense population on the island is the high production of household waste which is generally directly disposed into the sea. Meanwhile, the large number of fishing boats that anchor in the seagrass area, may cause damage to the seagrass. Besides potentially reducing the area of the seagrass, the effect of this anchor can reduce seagrass cover. When the anchor is lifted, several types of seagrass are uprooted from the substrate but often some seagrass species, especially *E. acoroides*, can survive depending on the size and model of anchor used by the boat. Changes in the seagrass area and coverage can cause changes in seagrass carbon stock. Therefore, this study was conducted to estimate changes in carbon stock due to changes in the area and coverage of seagrass in Barranglompo Island.

2. Materials and Methods

This study was conducted in Barranglompo Island, South Sulawesi Province, which is approximately 11 km from Makassar City (Figure 1). Barranglompo Island is one of the densely populated islands in the Spermonde Archipelago. It has an area of 20.64 ha [13] with a population of 4697 people (in 2019) or with a density of 228 people per ha.

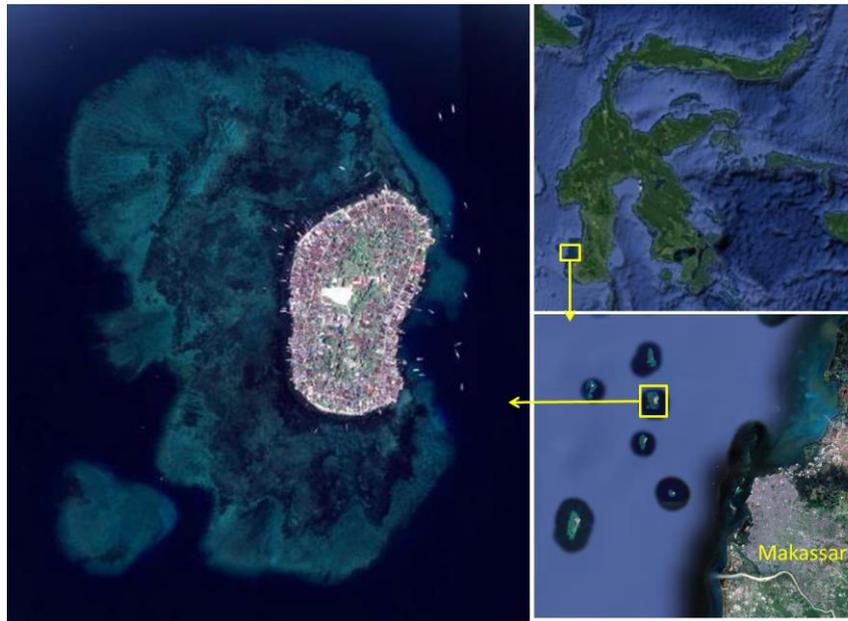


Figure 1. Map of study area on Barranglompo Island

2.1. Seagrass coverage mapping

The mapping of seagrass coverage was generated using Landsat 6 satellite imagery for 2001 and Worldview 2 for 2017. To manage the different spatial resolution between the two satellite images, an alignment was carried out before it was applied to compare the area of the seagrass beds in 2001 and 2017. Seagrass coverage was divided into three categories, i.e. sparse, medium, and dense [14]. The procedure used referred to the previous research [15]. As much as 40 plots (size: 50cm x 50cm) for each category of seagrass coverage were used to validate seagrass coverage data in the field.

2.2. Carbon Stock

Carbon stock values were determined by multiplying the value of the biomass and carbon concentrations. Seagrass biomass was collected using a special crowbar in a 20cm x 20cm plot with a depth where seagrass roots penetrated. For each percentage coverage category, seagrass biomass was extracted from one in every two plots observed, resulting in 20 plots for biomass extraction for each category. The biomass samples were then separated by the above-ground (leaves) and below-ground (roots and rhizomes) biomass. The samples were oven-dried (60°C) until a constant weight was obtained [16]. Then, it was weighed using a digital scale with an accuracy of 0.01 grams. The total seagrass biomass was then converted into dry weight per square meter for each category of seagrass coverage.

The values of carbon concentrations of six seagrass species used in this study are the secondary data from previous studies at the same location [13], but by averaging the carbon concentration values in rhizomes and roots to obtain the below-ground carbon concentration (in the referred previous study, the rhizome and root carbon concentrations were separated).

The total carbon stock of each seagrass coverage category was calculated using the formula of [13]:

$$C_t = \sum (L_i \times c_i)$$

where C_t = total carbon stock (tonnes), L_i = area of seagrass coverage category i (m^2) and c_i = average carbon stock of seagrass coverage category i (ton / m^2)

The area of each seagrass coverage category in 2001 and 2017 obtained from the results of satellite image analysis was the basis for estimating the total carbon stock of seagrass beds using the formula above. The change in the total carbon stock for 16 years was determined from the differences in the total value of seagrass carbon stock during the two image recording periods.

3. Results and Discussion

3.1. Area and structure of seagrass community

The area of seagrass beds in Barranglompo Island in 2001 was 66.8 ha, however, it decreased to 56.9 ha in 2017. During 16 years, the area decreased by 9.9 ha or an average of 0.62 ha per year (0.93% per year). The sparse and dense categories of seagrass contributed to the decline in the seagrass area. However, the medium category of seagrass was experiencing an increase in the area of 26.6 ha for 16 years or an average of 9.4% per year. This was due to the change of the dense seagrass coverage category to the sparse category (Table 1).

Table 1. The coverage area of seagrass bed in Barranglompo Island

Year	Category	Seagrass meadow area (ha)	Change of seagrass area compared to 2001	
			(ha)	(%)
2001	Sparse	14.1		
	Medium	17.7		
	Dense	35.0		
	Total	66.8		
2017	Sparse	2.9	11.2 (decrease)	79.4 (decrease)
	Medium	44.3	26.6 (increase)	150.3 (increase)
	Dense	9.7	25.3 (decrease)	72.3 (decrease)
	Total	56.9	9.9 (decrease)	

Although changes in the area of seagrass beds occurred on all sides of the island, it showed that higher changes were in the southwest and south of Barranglompo Island. Also, in several areas of seagrass beds, there was a decrease in the condition of seagrass coverage from dense to sparse category, or from medium to sparse category (Figure 2). This declining condition of seagrass coverage which was only one level below the previous category indicated that the declined condition was not occurring massively, but was occurring slowly. It was believed that the rate of decline in the seagrass area in the last 10 years was higher than in the previous years. This assumption is supported by a study conducted by [17] who found that the decline in seagrass area for 19 years from 1993 to 2012 was only 3.57 ha or an average of 0.19 ha per year. This study, however, resulted in three times higher. It may be due to the wastes that were disposed directly into the sea where partially settled in the seagrass area, especially near the coastline, so that it had the potential to decrease seagrass coverage.

The decline in area and changes in seagrass coverage which was becoming higher lately is thought to be the implication of the increasing population and greater intensity of anthropogenic activities. The higher population caused higher household waste production. On the south side of the island around the coastline, there had been a fairly large area of changes in seagrass coverage from the medium category to the sparse category. Meanwhile, on the north side, some areas had changed from the dense category to the medium category, although on the west side there was an increase from the medium category to the dense category in the narrow area near the coastline (Figure 2). Even though the presence of garbage was not the only cause of changes in seagrass coverage around the coastline, the contribution of garbage was significant enough to cause changes in seagrass coverage.

Although it was uncertain, it was also suspected that the rapid algae growth that occurred at certain times could affect the composition based on seagrass coverage. The algae attach on the

seagrass leaves, thus inhibits the photosynthesis process. This is especially true for small seagrass species.

Unlike the garbage which causes more changes in seagrass coverage, anthropogenic activities such as boat moorings in the seagrass area have the potential to cause a decrease in seagrass area and coverages. Generally, boats that were moored used two anchors. If the anchor was pulled some of the seagrasses would be uprooted from the substrate. This happened repeatedly so that several areas of the seagrass bed became quite large holes and had the potential to reduce the area of the seagrass bed. Large boats were generally moored in the outer seagrass area and around the deeper coral reefs. Generally, the reduction of the seagrass area occurred around coral reefs (Figure 2). Apart from boat anchors, damage to coral reefs also had the potential to cause a reduction in the area of seagrass beds. Corals that were damaged resulting coral fragments and would cover part of the substrate where the seagrass grew. In Barranglombo Island, there was a significant addition of the areas of coral rubble and sand [17].

Several studies that used satellite imagery had been carried out in the Spermonde Islands, and they also proved that in general, the area of seagrass in this area had decreased. Research conducted by [18] in Bonebatang Island showed a decrease in the seagrass area by 0.54 ha per year (1.45% per year). For 44 years, Balanglombo Island had also experienced a decrease in seagrass area by 5.95 ha or an average of 0.14 ha per year (1.26% per year) [19]. In general, the decline in the seagrass area in the Spermonde Islands was still smaller than the global decline, which reached 7% per year [8,9].

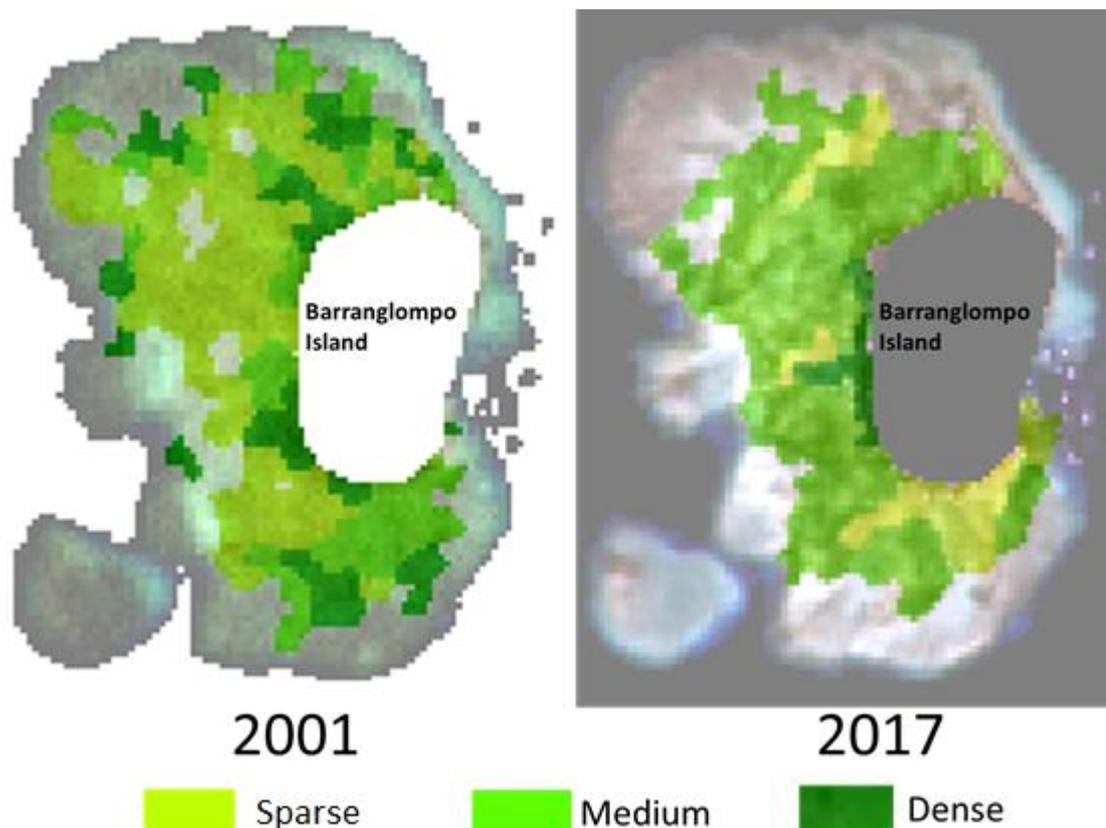


Figure 2. Map of seagrass distribution on Barranglombo Island

In general, three types of seagrass had a high contribution to the seagrass coverage area on Barranglompo Island, i.e. *Thalassia hemprichii*, *Enhalus acoroides*, and *Cymodocea rotundata*. Among the three categories of seagrass coverage, the highest contribution of *T. hemprichii* was found in the medium coverage category, while *E. acoroides* and *C. rotundata* were found in the dense coverage category. Other types of seagrass did not have a significant contribution to the seagrass coverage (Table 2). Based on the category of seagrass coverage, the average coverages in the sparse, medium, and dense categories were 23.9%, 45.5%, and 78.3%, respectively. Although in general the seagrass in Barranglompo Island was in the form of mixed seagrass, in several areas, the mentioned three types of seagrass with a high contribution to seagrass coverage could be found growing monospecies. Also, morphologically these three species of seagrass had a larger size than the others.

Table 2. Seagrass coverage (average \pm SE) and species composition

No	Species	Category of seagrass coverage					
		Sparse		Medium		Dense	
		Seagrass Coverage (%)	Species Composition (%)	Seagrass Coverage (%)	Species Composition (%)	Seagrass Coverage (%)	Species Composition (%)
1	<i>E. acoroides</i>	0.7 \pm 0.3	2.9	8.8 \pm 1.2	19.4	19.3 \pm 3.0	24.6
2	<i>T. hemprichii</i>	16.5 \pm 2.3	69.0	36.0 \pm 2.4	79.2	47.3 \pm 4.5	60.4
3	<i>C. rotundata</i>	5.0 \pm 1.3	20.9	0.0 \pm 0.0	0.0	11.8 \pm 3.3	15.0
4	<i>H. uninervis</i>	0.0 \pm 0.0	0.0	0.4 \pm 0.3	0.9	0.0 \pm 0.0	0.0
5	<i>H. ovalis</i>	1.2 \pm 0.5	5.0	0.3 \pm 0.2	0.6	0.0 \pm 0.0	0.0
6	<i>S. isoetifolium</i>	0.5 \pm 0.3	2.1	0.0 \pm 0.0	0.0	0.0 \pm 0.0	0.0
	Total	23.9 \pm 2.4	100.0	45.5 \pm 2.3	100.0	78.3 \pm 1.9	100.0

3.2. Carbon stock of seagrass species

Sampling conducted during field data validation showed that the average carbon stock in the sparse seagrass cover category was 44.1 ± 6.2 gC.m⁻², while in the medium and dense coverage category were 108.8 ± 12.7 gC.m⁻² and 162.2 ± 16.3 gC.m⁻², respectively. More than 90% of seagrass carbon stock was contributed by two species of seagrass, i.e. *T. hemprichii* and *E. acoroides*, although both had different contributions levels to each category of seagrass coverage. In the sparse seagrass coverage category, the contribution of *T. hemprichii* was more than ten times that of *E. acoroides* (Table 3), although the seagrass coverage differed by more than twenty times (Table 2). The non-linear difference between the carbon stock and cover of the two species of seagrass was due to the difference in biomass per shoot. The biomass per shoot of *E. acoroides* can reach 4-6 times than that of *T. hemprichii*. In the medium seagrass coverage category, the carbon stock of *T. hemprichii* was only about twice than that of *E. acoroides*, even in the dense seagrass coverage category, the two species contributed similarly.

In contrast to other seagrass species, these two species of seagrass contributed high carbon stock due to their wide distribution in Barranglompo Island [13]. Both species of seagrass are a climax type group and have high adaptability to environmental conditions. Also, morphologically, these two species had a large size compared to other types of seagrass. Leaf width and length of *E. acoroides* and *T. hemprichii* ranged from 1.2–2.0 cm, 30–200 cm [20], 0.261-0.720 cm, and 3.5-9.1 cm [21], respectively.

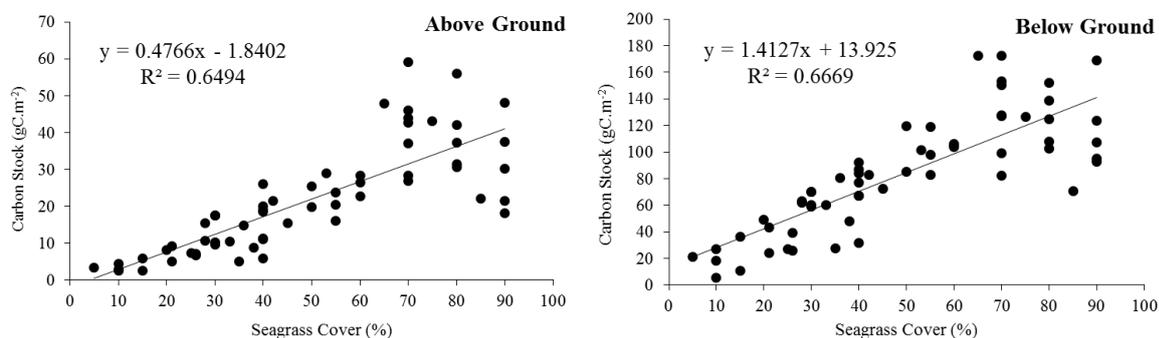
Table 3. Carbon stock of seagrass species (average \pm SE) during field validation in 2017

No	Species	Carbon stock					
		Sparse		Medium		Dense	
		(gC.m ⁻²)	%	(gC.m ⁻²)	%	(gC.m ⁻²)	%
1	<i>E. acoroides</i>	3.1 \pm 1.2	7.1	32.2 \pm 3.6	29.6	83.1 \pm 13.9	51.2
2	<i>T. hemprichii</i>	38.4 \pm 5.1	87.1	76.1 \pm 4.2	69.9	73.6 \pm 6.9	45.4
3	<i>C. rotundata</i>	2.0 \pm 0.6	4.5	0.0 \pm 0.0	0.0	5.5 \pm 2.0	3.4
4	<i>H. uninervis</i>	0.0 \pm 0.0	0.0	0.5 \pm 0.3	0.4	0.0 \pm 0.0	0.0
5	<i>H. ovalis</i>	0.4 \pm 0.2	1.0	0.1 \pm 0.0	0.4	0.0 \pm 0.0	0.0
6	<i>S. isoetifolium</i>	0.1 \pm 0.1	0.3	0.0 \pm 0.0	0.0	0.0 \pm 0.0	0.0
Total		44.1 \pm 6.2	100.0	108.8 \pm 12.7	100.0	162.2 \pm 16.3	100.0

3.3. Relationship of seagrass coverage percentage and carbon stock

There was a linear relationship between the seagrass coverage and the carbon stock, for both the below-ground carbon stock, above-ground, or total. The resulting linear regression model showed a fairly close relationship ($r_2 = 0.649$ - 0.676 ; $r = 0.796$ - 0.976). The variation of carbon stock in the dense seagrass coverage category was higher than that in the sparse and medium seagrass cover category (Figure 3). The high variation in carbon stock in the dense coverage category was due to the various species composition. Several plots showed that *T. hemprichii* dominated the seagrass area, but some other plots were dominated by *E. acoroides*. Morphologically, these two seagrass species had different sizes, so that in the same coverage, the carbon stock values were different. In the sparse and medium seagrass coverage categories, *T. hemprichii* dominated consistently (Table 3).

Also, in the dense seagrass coverage category, there could be quite a lot of overlap between seagrass leaves, especially in *T. hemprichii* species. Therefore, in some plots, a small increase in the value of seagrass cover could cause a substantial increase in the value of carbon stock, but in other plots, the addition of the same value of seagrass coverage could only add a little value to the carbon stock. This differs in the sparse and medium seagrass coverage categories, where the overlap between leaves was less to occur than that in the dense seagrass coverage category. In the case of biomass, a study conducted by [22] found that at high coverage percentage of *T. hemprichii* seagrass, the slope value of the regression equation was also higher due to overlapping of leaf canopies, which led to a high increase in biomass value despite the small increase of the coverage value.



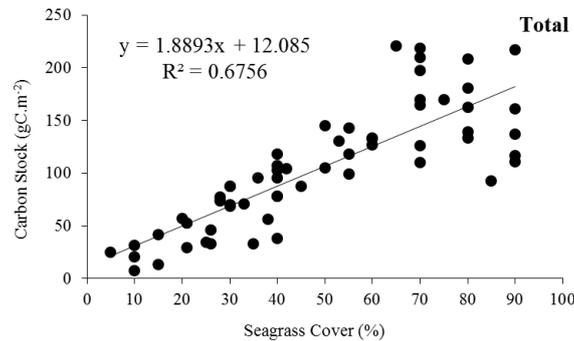


Figure 3. Linear regression between seagrass coverage (%) and carbon stock (gC.m^{-2})

3.4. Change of seagrass carbon stock

The total carbon stock of seagrass in 2001 reached 82.25 tons and in 2017 decreased to 65.21 tons (Table 4). Therefore, there was a decline in carbon stock by 17.05 tonnes over 16 years or an average decline of 1.07 tonnes per year (1.30% per year). When it was related to the area of seagrass beds, the average carbon stock reached 1.23 tonnes/ha in 2001 and was about 1.15 tonnes/ha in 2017. The decline in carbon stock in the category of sparse and dense seagrass coverage was 4.94 tons and 41.04 tons, respectively, while in the medium seagrass coverage category there was an increase in carbon stocks by 28.94 tons.

In 2001, the largest contribution of carbon stock was in the category of dense seagrass coverage, which reached around 69.0%. However, in 2017, the largest contribution was in the category of medium seagrass coverage, which reached 73.9%. This change occurred due to the alteration of several seagrass areas from the dense coverage category in 2001 to the medium coverage category in 2017. Thus, the decline in seagrass carbon stock was an implication of decreasing the seagrass area and changes in seagrass coverage. With the decline in seagrass carbon stocks, one of the important roles of seagrass beds in the context of mitigating climate change as carbon sinks and stores had decreased significantly.

Table 4. Total seagrass carbon stock on Barranglompo Island

Year	Category	Carbon stock		
		Above Ground (tons)	Below Ground (tons)	Total (tons)
2001	Sparse	0.97	5.25	6.22
	Medium	3.62	15.63	19.26
	Dense	13.12	43.66	56.78
	Total	17.71	64.54	82.25
2017	Sparse	0.20	1.08	1.28
	Medium	0.07	39.13	48.19
	Dense	3.64	12.10	15.74
	Total	12.90	52.31	65.21

4. Conclusions

The decline in carbon stock in Barranglompo Island for 16 years was very significant, thus reducing one of its important roles in the context of mitigating climate change. The decline in the value of carbon stocks was directly related to a decrease in the area of seagrass beds and changes in seagrass coverage. This was due to the increasingly high intensity of anthropogenic activities, especially boat moorings and disposal of household waste, which had an impact on the seagrass ecosystem.

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