Decline in seagrass carbon uptake on Bonebatang Island, Spermonde Archipelago, Indonesia during the period of 2001-2017

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Abstract. The activities of coastal and small islands communities can have an impact on the condition of the adjacent aquatic ecosystems. The magnitude of the impact depends on the type and intensity of the activities carried out. One ecosystem that is prone to be affected is the seagrass ecosystem due to its presence in shallow waters and proximity to the coast. The study was conducted to examine changes in seagrass carbon uptake on Bonebatang Island over a period of 16 years from 2001 to 2017. Estimation of carbon uptake of seven species of seagrasses, i.e., Enhalus acoroides, Thalassia hemprichii, Cymodocea rotundata, Halodule uninervis, Halophila ovalis, Halophila minor, and Syringodium isoetifolium were carried out using the oxygen change method that utilized clear bottles. The percentage of seagrass coverage was calculated using a 50cm x 50cm plot. The average composition of seagrass species from all plots and the capability of each seagrass species to uptake carbon was used as a basis to estimate the capability of seagrass to uptake the carbon per unit area. Changes in carbon uptake were determined using an approach that estimates changes in the seagrass bed areas. Landsat image analysis was used to estimate the area of seagrass in 2001, 2009, and 2017. The results showed that the area of seagrass beds in the period of 2001-2017 decreased by 8.62 ha, from 37.08 ha in 2001 to 28.46 ha in 2017 or decreased by approximately 1.54% per year. As a result of this diminishing in the area, carbon uptake by seagrasses was estimated to decrease by 19.67 MgCO₂ per year from 79.62 MgCO₂ per year in 2001 to 59.95 MgCO₂ per year in 2017. The average decrease in a year reached 1.23 MgCO₂.

1. Introduction
Seagrass ecosystems are coastal ecosystems with a high level of productivity with a variety of ecological roles [1,2]. As the first level in the food chain, seagrass is an important primary producer that can efficiently convert carbon dioxide into the organic matter [3]. Absorption of carbon dioxide for photosynthesis is one of the seagrass vegetation roles as part of a system to reduce carbon emissions in the atmosphere. The absorbed carbon is then stored in the form of carbon reserves in living tissue, both on the sediments in the form of leaves and under the sediments as roots and rhizomes, which are often termed as carbon stocks. The role of seagrass ecosystems as carbon storage is increasingly important, considering that more biomass is stored under the sediments. In addition, decomposition of dead seagrass tissue is more deposited into the sediments, thereby increasing the importance of the role of seagrass as a Carbon sinker.

The need to map the potential of seagrass to uptake the carbon is required to support data collection on a broad scale with a brief time. To date, the estimation of seagrass carbon stocks has
been conducted by direct sampling and measurement in the field [4,5,6]. Likewise, the estimation of carbon sequestration that has been carried out so far has been based on direct measurements in the field. Although this method is more accurate in estimating carbon absorption, the estimation can only be done on a limited basis in a sampling area with prolonged time and high cost.

One of the methods that can be used to simplify the estimation of carbon uptake by seagrasses is by utilizing satellite imagery technology. The use of satellite imagery has often been accomplished to map the extent and coverage of seagrass beds [7,8,9]. This method is considered easier and can access wider seagrass beds. Based on the capability of satellite imagery to map seagrass cover conditions, the satellite imagery is then used to map seagrass carbon uptake potential. However, an empirical model of the relationship between seagrass coverage and carbon uptake must be developed before. This model can be developed by conducting direct sampling and measurement in the field. This research was conducted to determine changes in the capability of seagrass meadows to uptake the carbon in a period of 16 years, by scrutinizing the changing area of seagrass beds using satellite imagery.

2. Materials and methods

The study was conducted on Bonebatang Island, one of the islands in the Spermonde Islands, South Sulawesi Province, which is about 14 km from Makassar City (Figure 1a). Bonebatang Island is uninhabited but is a place for people who live in the surrounding islands to catch fish and collect sand for building materials. Thus the condition of the island, which used to still have wooden buildings as a fisherman stopover for rest, now submerges during high tides (Figure 1b).

![Figure 1. Study area. (a) Map of Bonebatang Island, and (b) Bonebatang Island’s situation in 2001 and 2017.](image)

2.1. Seagrass coverage mapping

Mapping of seagrass coverage was performed using Landsat satellite imagery in three recording periods, i.e., 2001, 2009, and 2017. The procedure used refers to the research that has been carried out [8].
2.2. Carbon Uptake
The oxygen change method was applied to determine the carbon uptake method to determine primary productivity using a clear bottle modified from [10,11]. Seven species of seagrass on Bonebatang Island, i.e. *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule uninervis*, *Halophila ovalis*, *Halophila minor* and *Syringodium isoetifolium* were collected from the subtidal area on the west side of the island. The collection was carried out carefully so that the roots, rhizomes and leaves were collected as a whole stand. Seagrass leaves were cleaned from the epiphytes and attached sediments. Seagrass leaves were put into each of the 270 ml clear bottles by clamping the stem using a perforated rubber cap, while rhizomes and seagrass roots were allowed to appear outside the bottles. Each bottle was filled with one seagrass stand.

Before closing the lid, the bottle was filled with seawater. Seawater filling was carried out carefully into the seawater column by avoiding air bubbles to occur that could affect oxygen concentration before the bottle was incubated. Before the seagrass-filled bottles were incubated, oxygen measurements were carried out in situ using the Winkler titration method [12]. The measurement of these parameters was conducted with five replications. The measured oxygen level was considered as the initial oxygen level.

Next, the incubation of the clear bottle was carried out for three hours [10] from 09.00-12.00 WITA, at a depth of 1 m below the surface of the water with five replications each. In addition, the other five bottles containing seawater (containing plankton) in this depth were also incubated and acted as control and correction factors. At the end of the incubation, the measurement of dissolved oxygen was measured again, which was determined as the final oxygen level value. The values of dissolved oxygen and primary productivity were obtained by using the formula [13]. Every 1 gram of carbon produced is assumed to use 3.67 grams of CO$_2$ to convert the value of primary productivity into the form of CO$_2$ uptake.

2.3. Relationship between seagrass coverage and carbon uptake
The coverage percentage of each type of seagrass was measured using a 50cm x 50cm plot with the procedure referred to [14]. As much as 61 plots spread over seagrass meadows were used in the study and considered to represent the distribution of seagrass in Bonebatang Island. When measuring the percentage of seagrass coverage in the study area, seagrass density was also measured in the same plot. Then the density value of each type of seagrass in the plot was multiplied by the carbon uptake value per shoot. Furthermore, the total carbon uptake value of each type of seagrass in a plot was paired with the percentage of seagrass coverage value so that several data pairs are obtained. The data was then processed using linear regression.

2.4. Estimation of change in carbon absorption
Average values of the seagrass coverage percentage and carbon absorption from 61 plots were calculated to obtain the capability of carbon absorption per unit area. The data was then multiplied by the area of the seagrass meadows on Bonebatang Island. Thus, the estimation of changes in carbon uptake by seagrasses was based on changes in the seagrass beds for 16 years (2001-2017).

3. Results and discussion
3.1. The area and structure of the seagrass community
In 2001, the area of seagrass beds in Bonebatang Island reached 37.08 ha, but the area of seagrasses had decreased for 16 years by 8.62 ha or 23.25% in 2017. The average rate of decline in seagrass areas reached 1.45% per year. The rate of decline in the beds has been accelerating with time, during the first eight years (2001-2009), a decline occurred by 10.68%, but the following eight years (2009-2017) the decline reached 14.07% (Table 1). Seagrass areas were lost mainly on the western and northern sides of the island. However, on the south and northeast sides of the island, new seagrass growth areas were discovered (Figure 2). Several seagrasses *Halophila ovalis* and *H. minor* were found to begin to
grow on the sand substrate in former landmass, but have already submerged when the high tide in
2017.

Changes in seagrass area in the Spermonde Islands using satellite imagery have also been carried
out by [15], where Barranglompo Island adjacent to Bonebatang Island (about 3.3 km) has decreased
in seagrass area at a rate that was higher than that on Bonebatang Island, i.e., 1.95% per year. The
extreme difference between the two islands is the existence of the population. Barranglompo Island
has a very dense population, while Bonebatang Island is uninhabited. Household waste were
discharged into the sea and could reduce the area of seagrasses, especially on the beachside of
Barranglompo Island, but did not occur on Bonebatang Island. In addition to the two islands, other
studies have found that some islands experienced extensive declines, but a number of other islands
experienced large increases in the Spermonde Islands [8,9]. Globally, the rate of decline in worldwide
seagrass reached 7% per year [16]. This rate of decline was much higher than the rate of decline of the
seagrass area on Bonebatang Island.

Table 1. Coverage area and composition of seagrass species.

| Year | Seagrass meadow area (ha) | The decrease compared to 2001 (%) | The average decrease compared to the previous 8 years (%) per year |
|------|--------------------------|---------------------------------|-------------------------------------------------------------|
| 2001 | 37.08                    |                                 |                                                             |
| 2009 | 33.12                    | 10.68                           | 1.33                                                        |
| 2017 | 28.46                    | 23.25                           | 1.76                                                        |

Figure 2. Map of seagrass distribution on Bonebatang Island.

Some activities that can reduce the area of seagrass beds on Bonebatang Island for 16 years
include sand mining and anchoring of ships. Every day about 2-4 ships are used to collect sand, with
an average frequency of 3 times per ship. Sand mining resulted in unstable of the surrounding substrate, thus affecting the growing seagrass. In fact, sometimes sand mining has been carried out on substrate overgrown with seagrass *H. ovalis* and *H. uninervis*, especially in shallow water sections. Meanwhile, the anchor used was usually tethered to the seagrass area so that it would pull seagrass from the substrate each time the anchor was lifted.

In general, the percentage of seagrass coverage on Bonebatang Island varied between sides of the island. High percentages of seagrass coverage were found on the western and northern sides of the island. The average percent of seagrass cover was 59.2%. Based on the categories made [14], the seagrass condition was categorized as solid. *C. rotundata* seagrasses contributed more than half of the total coverage percentage, while *H. ovalis*, *H. minor*, and *H. uninervis* contributed less than 1% (Table 2). Despite having a high density, all three seagrasses generally had a low coverage percentage because of the small stand size.

**Table 2. Coverage and composition of seagrass species.**

| No | Species       | Average seagrass coverage (%) | Species composition (%) |
|----|---------------|-------------------------------|------------------------|
| 1  | *E. acoroides*| 5.8                           | 9.9                    |
| 2  | *T. hemprichii*| 17.7                          | 29.9                   |
| 3  | *H. uninervis*| 0.8                           | 1.3                    |
| 4  | *C. rotundata*| 30.8                          | 51.9                   |
| 5  | *H. ovalis*   | 0.5                           | 0.9                    |
| 6  | *H. minor*    | 0.2                           | 0.3                    |
| 7  | *S. isoetifolium*| 3.4                         | 5.8                    |
|    | **Total**     | 59.2                          | **100.0**              |

3.2. Carbon uptake of seagrass

There were differences in the ability of carbon uptake between seagrass species in three categories. Type *E. acoroides* had the highest carbon uptake in the category per shoot. However, it was relatively low in the category per biomass and leaf area. This differs from *H. ovalis*, *H. minor*, and *H. uninervis* seagrass species, which had lower carbon uptake in the per shoot category but were high in the biomass and leaf area categories (Table 3). *H. uninervis* had the highest ability to uptake carbon per biomass and leaf area. The ability of this type of seagrass was around 4-12 times compared to other types for the category per leaf biomass and 2-3 times for the category per leaf area.

Morphologically, the type of *E. acoroides* had a size that was much larger than other types so that the capability to absorb carbon per shoot was greater, in contrast to the types of *H. ovalis*, *H. minor*, and *H. uninervis*, which were small. However, the last three types of seagrass belong to the pioneer seagrass group with a small shoot size. One of the characteristics of pioneer plants is the ability to grow and expand rapidly [17]. Rapid growth requires a fast rate of photosynthesis so that carbon uptake per biomass and leaf area is higher than other types.

**Table 3. Seagrass carbon uptake based on shoots, dry leaf biomass, and leaf area.**

| No | Species   | Carbon uptake |          |          |          |
|----|-----------|---------------|----------|----------|----------|
|    |           | Per shoot     | Per leaf biomass | Per leaf area |
|    |           | (mgCO₂ shoot⁻¹ h⁻¹) | (mgCO₂ gdw⁻¹ h⁻¹) | (mgCO₂ cm⁻² h⁻¹) |
| 1  | *E. acoroides* | 3.68          | 2.91     | 0.010    |
| 2  | *T. hemprichii* | 0.56          | 5.05     | 0.009    |
| 3  | *H. uninervis* | 1.17          | 35.57    | 0.024    |
| 4  | *C. rotundata* | 0.27          | 5.66     | 0.010    |
| 5  | *H. ovalis*    | 0.07          | 8.41     | 0.012    |
| 6  | *H. minor*     | 0.07          | 9.69     | 0.011    |
3.3. Relationship of seagrass coverage percentage and carbon uptake

The relationship between the percentage of seagrass coverage and carbon absorption capability showed variations between species. Besides, it was due to different biomass in the same coverage area between one type and another. It was also affected by carbon absorption capacity between different species. Although the percentage of seagrass coverage that was obtained could reach 90%, but the highest percentage of seagrass coverage per species found was only 70% in E. acoroides and T. hemprichii species. Seagrass coverage percentage was above 70% in mixed seagrass. Based on the model obtained, in the type of E. acoroides, 70% coverage was able to absorb as much as 233.3 mgCO$_2$.m$^{-2}$.hours$^{-1}$, whereas in the T. hemprichii type, the same amount of coverage could only absorb as much as 36.1 mgCO$_2$.m$^{-2}$.hour$^{-1}$ (Figure 3).

The obtained linear regression model showed the relationship between seagrass coverage percentage and carbon uptake was quite high ($r = 0.796-0.976$; $r^2 = 0.633-0.952$). The determination index of E. acoroides was the lowest among seagrass species due to remarkably large shoot size morphology variations, in contrast to H. minor and H. ovalis, which had more uniform morphological measurements. In all seagrass species, it was likely that the regression slope value at the high cover percent would be higher than the regression slope value at the low cover percent. In the case of biomass, research [18] found that in the T. hemprichii seagrass that had high coverage percentage value also had higher slope values due to overlap of the leaf canopies, which resulted in the high biomass value although the addition of coverage value was small.

![Linear regression between seagrass coverage (%) and carbon uptake of seven species of seagrass (mgCO$_2$.hr$^{-1}$).](image-url)
3.4. Decreased of seagrass carbon uptake

The analysis of the capability of carbon uptake of seagrass, which considering the composition of species and coverage percentage of each species, showed that the average seagrass carbon uptake on Bonebatang Island was 5.77 kgCO$_2$.ha$^{-1}$.hr$^{-1}$ or 2.11 MgCO$_2$.ha$^{-1}$.yr$^{-1}$. Thus, the total carbon uptake capability of the seagrass area of 37.08 ha in 2001 was 79.62 MgCO$_2$.yr$^{-1}$, decreasing to 69.76 MgCO$_2$.yr$^{-1}$ in 2009 and becoming 59.95 MgCO$_2$.yr$^{-1}$ in 2017 (Table 4). The decrease in carbon uptake reached 19.67 MgCO$_2$ over 16 years, or the average reduction per year reached 1.23 MgCO$_2$ (a decrease of 1.54% per year). The rate of decline in the seagrass beds was faster in the second eight years (2009-2017) compared to the first eight years (2001-2009), causing a pattern of decreasing carbon sequestration ability on the seagrass on Bonebatang Island was also the same. In the 2001-2009 period, there was a decrease in carbon uptake by 1.55% per year, and the decline was even greater in the 2009-2017 period to 1.76% per year. This showed that the environmental pressure is getting higher and higher towards the total carbon sequestration ability of seagrass on Bonebatang Island.

### Table 4. Total carbon uptake by seagrass on Bonebatang Island.

| Year | Total carbon uptake (MgCO$_2$) | The decrease compared to 2001 (%) | The average decrease compared to the previous 8 years (%/year) |
|------|-------------------------------|----------------------------------|---------------------------------------------------|
| 2001 | 79.62                         | -                                | -                                                |
| 2009 | 69.76                         | 12.38                            | 1.55                                             |
| 2017 | 59.95                         | 24.70                            | 1.76                                             |

Although it can be used as one of the basic considerations for seagrass ecosystem management efforts in general in the Spermonde Islands, the results of this study also has some weaknesses, especially from the assumptions used, namely: (1) the estimated decrease in carbon sequestration was only based on the decrease in seagrass area and the ability of each seagrass species to uptake carbon in 2017, without considering changes in seagrass coverage percentage and carbon sequestration capacity of each species that might occur due to several factors, such as an increase in water temperature. Each type of seagrass has an optimum temperature for photosynthesis [19], so that temperature changes within a period of 16 years, although small, it still had the potential to affect seagrass physiologically; (2) species composition was considered unchanged from 2001 to 2017, which might occur due to physiological responses of each species of seagrass that are different from environmental changes.

4. Conclusions

Over the past 16 years, there has been a significant decrease in total carbon uptake by seagrass beds on Bonebatang Island. The rate of decline was getting higher and higher due to increasing environmental pressures, especially the anthropogenic influence of community activities carrying out activities on Bonebatang Island. One of the efforts that can be performed to reduce the rate of decline in the ability of seagrass to uptake carbon is to produce a regulation prohibiting sand mining on Bonebatang Island by the Makassar City Government and strengthening control. In addition, efforts to rehabilitate seagrass are also considered to be able to reduce the rate of carbon absorption.

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