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RESEARCH PAPER

# BIOMASS CARBON STOCKS IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT, SOUTH SULAWESI, INDONESIA

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ABSTRACT. Mangrove forest plays a crucial role in climate change mitigation by storing carbon in its above-belowground pools. However, this forest remains under considerable high exploitation from the expansion of settlement and aquaculture pond that likely results in much $CO_2$ release to the atmosphere. The objective of this research is to estimate biomass carbon stocks of mangrove rehabilitated areas in Sinjai District, South Sulawesi. We used a line transects method for mangrove vegetation survey and determined above-belowground biomass and carbon stock using published allometric equations and a conversion factor, respectively. The results showed that the mean values of carbon stocks in above-belowground biomass were 125.48±93.48 Mg C $ha^{-1}$ and 60.23±44.87 Mg C $ha^{-1}$. The aboveground biomass stored more carbon than the belowground pool. However, low planting distance in mangrove rehabilitation and conversion of mangrove area into settlements and aquaculture ponds in the last three decades have affected forest structure and biomass carbon magnitudes. Therefore, preservation of intact mangrove and restoration of disturbed forests with pay attention to planting distance should consider. Besides, halting the expansion of settlements and aquaculture ponds are worthwhile options to maintain and possibly increase biomass carbon stocks.

KEY WORDS: Mangrove; biomass carbon stocks; mangrove rehabilitation; planting distance

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## INTRODUCTION

Mangrove forests play an important role in climate change mitigation by acting as sinks of carbon (Murdiyarso et al. 2015; Alongi et al. 2015). Mangroves store carbon in their above-belowground biomass through the photosynthesis process and also in soil by sedimentation process (Howard et al. 2014). Despite mangrove areas occupied at less 1% of the world's tropical forest areas (Giri et al. 2011), these forests could store up to 4.19 Pg C in 2012 (Hamilton and Friess 2018).

Mangroves are among the most significant carbon-rich forests in tropical areas (Donato et al. 2011) and contribute about half of the total blue carbon emissions from coastal ecosystems (Pendleton et al. 2012). However, mangroves are currently being degraded and deforested at alarming rates (Murdiyarso et al. 2015). Since 1980, nearly half of the total mangrove covers in the world had lost (FAO 2007). Thomas et al. (2017) reported that the most significant regional mangrove loss was occurred in Southeast Asia during the period 1996–2010 (approximately 50%), corresponding to 18.4% of the global mangrove area. Also, Hamilton and Casey (2016) calculated that the deforestation of worldwide mangroves extent became lower during 2000 – 2012 (from 17.3 million to 16.4 million or approximately 5%) due to increase policy intervention to rehabilitate this ecosystem. However, deforestation and degradation rates at up to 0.39% per year since 2000 had contributed to an annual carbon emission of about 0.21–0.45 Pg $CO_2$ to the atmosphere (Hamilton and Friess 2018). Over-exploitation for many purposes, such as commercial logging, fuelwood, charcoal, and conversion into other land-uses, primary into aquaculture ponds, have trusted as a driver of mangrove losses (Kusmana 2015; Murdiyarso et al. 2015; Malik et al. 2017).

The mangroves of South Sulawesi province are one of the essential areas for carbon storage in Indonesia (Malik et al. 2015a; Suharti et al. 2016). These forests distribute in the coastal area of Makassar City and Districts of Maros, Pangkep, Barru, Pinrang, East Luwu, Luwu, Bone, Sinjai, Takalar, Jeneponto, Bantaeng, and Bulukumba. During the period 1950 – 2005, mangrove covered area in South Sulawesi had declined about 88 thousand hectares, and only 12 thousand hectares were saved (Bakosurtanal 2009). Our previous data showed that the annual deforestation rates of mangrove in South Sulawesi was between 1% and 5 % during the period 1979 – 2012 (Malik et al. 2017). Therefore, it is vital to protect and rehabilitate mangrove areas to sustain their services and mitigate climate change impact. However, studies on mangrove biomass carbon stocks as a part of deforestation management and mitigation factor are still very limited in this region. Meanwhile, it is critical to meet the knowledge gap of policymakers in decision-making for these issues.

The objective of this research is to estimate biomass carbon stocks in mangrove rehabilitated areas of Sinjai District, South Sulawesi Province, especially in Tongke-Tongke and Samataring villages. Mangrove rehabilitation efforts are being implemented since 1984 by an initiative of local communities in these two areas (Amri 2008). Mangroves in these two areas are appropriated to the case study, as we hypothesized, they have a potential of biomass carbon stocks. However, mangroves in Sinjai District are still under high-pressure, primary from the expansion of settlements and aquaculture ponds (Suharti et al. 2016) that causes many potential $CO_2$ releases to the atmosphere.

## MATERIALS AND METHODS

### Study Area

The research was conducted in the area of Sinjai District, South Sulawesi, with a focus on rehabilitated mangroves of Tongke-Tongke and Samataring villages. The study area situated at 5°8′–5°10′ sl. and 120°15′–120°17′ el., bordering with the North Sinjai sub-District in the North, the Bone Bay in the East, the Tellu Limpoe sub-District in the South, and the South Sinjai and Central Sinjai sub-Districts in the West (Fig. 1).

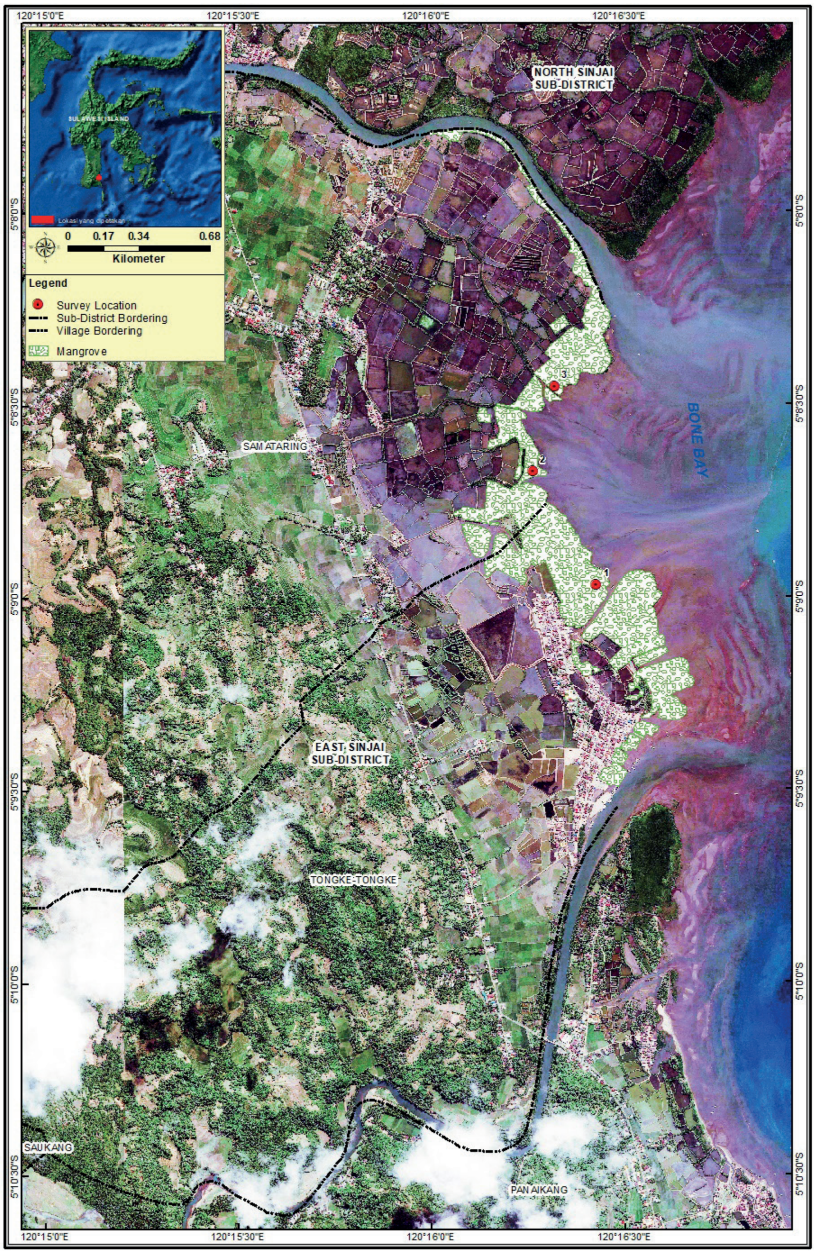

**Fig. 1. Study area: Tongke-Tongke and Samataring Villages in Sinjai District, South Sulawesi Province, Indonesia**

The distance of the study area from Makassar City, the capital of South Sulawesi Province, is about 220 km, and seven kilometers from the Sinjai District Center. Mangroves covered areas were about 688 ha in 2016 (BPS Kabupaten Sinjai 2017) and distributed along the coastal and riverine zones; moreover *Rhizophora* sp. dominates (Suharti et al. 2016). The total population of two villages was 8.370 people in 2016, and most of them were working as fishermen and shrimp farmers (BPS Kabupaten Sinjai 2017).

### Data Collection

We used own methods for data collection (Malik et al. 2015b; Malik et al. 2019):

Mangrove vegetation structure was determined in May 2017 using a line-transect from the seaward edge to the landward margin. Its length depended on the thickness of the mangrove patch. Three transects were installed randomly at the three sites, including one transect in Tongke-Tongke Village and two transects in Samataring Village (Fig. 1).

Three terraced plots with size 10 m x 10 m were established using a measuring tape and plastic ropes in each transect and marked its position using Global Positioning System (GPS) Garmin 64s. The space between plots was about 30 m reliant on the specific vegetation features and the landscape.

Inside each plot, we identified species names of all mangrove trees and noted diameters at breast height (DBH) 1.3 m above the ground surface or 30 cm above the highest prop root for *Rhizophora* sp. using a measuring tape. Besides, we noted the species name and an individual number of each mangrove tree using a tally counter, whereas tree heights were measured using a clinometer and measuring tape.

### Data Analysis

The density of species (Di, tree ha$^{-1}$) and basal area (BA, m$^2$ ha$^{-1}$) of mangrove trees were calculated by equations (1) and (2), correspondingly (Malik et al. 2015b; Malik et al. 2019):

$$Di = \frac{ni}{A} \qquad (1)$$

where ni – number of stand species i; A – total area of the sample observations, ha;

$$BA = \frac{1}{4}\pi DBH^2 \qquad (2)$$

where DBH – diameter at breast height.

Aboveground biomass ($AGB_{(tree)}$, Kg) of *Rhizophora* sp. was calculated by using Kauffman's et al. (2011) allometric equation (3):

$$AGB_{(tree)} = Lb + Wb + PRb \qquad (3)$$

Leaf biomass Lb $=10^{(-1.8571+ (2.1072x(LOG(DBH)))}$
Wood biomass Wb = Wv x ρ x 1000
Wood volume Wv = 0.0000695 x DBH$^{2.64}$
Prop roots biomass (PRb):

- PRb = Wb x 0.101 if DBH <5cm,
- PRb = Wb x 0.204 if DBH >5≤10cm,
- PRb = Wb x 0.356 if DBH >10≤15cm,
- PRb = Wb x 0.273 if DBH >15≤20cm,
- PRb = Wb x 0.210 if DBH >20cm.

Belowground biomass ($BGB_{(root)}$, Kg) of *Rhizophora* sp. was calculated by using Komiyama's et al. (2005) allometric equation (4):

$$BGB_{(root)} = 0.196 \times \rho^{0.899} \times (DBH)^{1.11} \qquad (4)$$

where ρ – wood density, g cm$^{-3}$ (for *Rhizophora mucronata* Lam. ρ = 0.792 and for Rhizophora apiculata Blume ρ = 0.855).

To estimate carbon stocks in above-belowground biomass of a mangrove tree ($AGC_{(tree)}$ and $BGC_{(root)}$), we used conversion factors from Kauffman and Donato (2012):

$$AGC_{(tree)} = AGB_{(tree)} \times 0.48 \qquad (5)$$

$$BGC_{(root)} = BGB_{(root)} \times 0.39 \qquad (6)$$

where $AGC_{(tree)}$ – aboveground carbon content in a mangrove tree (kg C); $BGC_{(root)}$ – belowground carbon content in a mangrove root (kg C); $AGB_{(tree)}$ – aboveground biomass of a mangrove tree (Kg); $BGB_{(root)}$ – belowground biomass of a mangrove root (Kg).

Furthermore, to calculate the $AGC_{(tree)}$ and $BGC_{(root)}$ stocks per hectare, we used equations from Lugina et al. (2011):

$$T-AGC_{(tree)} \text{and } T-BGC_{(root)} = \frac{GB}{1000} \times \frac{10000}{A \text{ plot}} \qquad (7)$$

where T-$AGC_{(tree)}$ and T-$BGC_{(root)}$ – above-belowground carbon of mangrove tree and root per hectare (Mg C ha$^{-1}$); Cb – $AGC_{(tree)}$ and $BGC_{(root)}$ stocks per tree (kg C); A plot – total area of the sample observations (m$^2$).

Moreover, to calculate the relationship between a mangrove tree density and diameter and T-$AGC_{(tree)}$ and T-$BGC_{(root)}$, linear regression analysis was implemented.

## RESULTS

### Mangrove Structure

Five hundred sixty standing live mangrove trees were identified at nine plots into three sites. Two mangrove species – *Rhizophora mucronata* Lam. (Rm) and *Rhizophora apiculata* Blume (Ra) – were recorded.

According to the analysis of vegetation, the largest quantity of trees was found at the plot 3 into the site I (82 trees), and the smallest one was found at the plot 3 into the site II (46 trees) (Table 1). The highest density was marked at the site I plot 3 (911 trees ha$^{-1}$), while the lowest one was recorded at the site III plot 1 (444 trees ha$^{-1}$).

### Mangrove Biomass and carbon stocks

The average $AGB_{(tree)}$ and $BGB_{(root)}$ of mangrove trees for all plots inside three analyzed sites were 1,254.82±934.80 kg and 87.92±37.54 kg, respectively. The highest $AGB_{(tree)}$ and $BGB_{(root)}$ was found at the site I plot 3 (2,672.59 kg and 139.47 kg), whereas the lowest one was recorded at the site III plot 2 (55.87 kg) and plot 3 (24.19 kg) (Table 2).

The mean values of T-$AGC_{(tree)}$ and T-$BGC_{(root)}$ stocks per site were 125.48±93.48 Mg C ha$^{-1}$ and 60.23±44.87 Mg C ha$^{-1}$, respectively. The highest means of T-$AGC_{(tree)}$ and T-$BGC_{(root)}$ were found for Rm at the site I plot 3 (267.26 Mg C ha$^{-1}$ and 128.28 Mg C ha$^{-1}$) (Table 2).

As linear regression analysis showed, T-$AGC_{(tree)}$ and T-$BGC_{(root)}$ stocks strongly depend on DBH (coefficient of determination $R^2$ = 0.7796), whereas the density of trees does not play a significant role in carbon accumulation (Fig. 2).

**Table 1. Species composition and structure of the mangroves**

| Site | Plot | Species | Number of tree | Height (m) | D (tree ha$^{-1}$) | DBH (cm) | BA (m$^2$ ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| I (Tongke-Tongke) | 1 | Rm | 56 | 7.64 | 622 | 7.25 | 4.31 |
| | 2 | Rm | 65 | 8.20 | 722 | 7.73 | 4.83 |
| | 3 | Rm | 82 | 10.86 | 911 | 8.35 | 6.88 |
| II (Samataring) | 1 | Ra | 54 | 11.00 | 600 | 8.89 | 6.90 |
| | 2 | Ra | 54 | 11.00 | 600 | 9.81 | 8.31 |
| | 3 | Ra | 46 | 11.00 | 511 | 9.63 | 8.05 |
| III (Samataring) | 1 | Ra | 76 | 10.00 | 444 | 5.35 | 3.08 |
| | 2 | Ra | 79 | 9.13 | 878 | 2.64 | 0.41 |
| | 3 | Ra | 48 | 10.00 | 533 | 2.64 | 0.62 |
| Total | 9 | - | 560 | - | - | - | - |
| Mean value | | | 62 | 9.87±1.28 | 647±160,63 | 6.92±2.77 | 4.82±2.99 |

*Rm – Rhizophora mucronata Lam.; Ra – Rhizophora apiculata Blum.; D – density of species i; DBH – diameter at breast height; BA – basal area*

**Table 2. The above-belowground biomass and carbon stocks of mangrove trees**

| Site | Plot | Species | AGB$_{(tree)}$ (Kg) | AGC$_{(tree)}$ (Kg) | BGB$_{(root)}$ (Kg) | BGC$_{(root)}$ (Kg) | T-AGC$_{(tree)}$ (Mg C ha$^{-1}$) | T-BGC$_{(root)}$ (Mg C ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| I (Tongke-Tongke) | 1 | Rm | 817.61 | 392.45 | 80.44 | 31.37 | 81.76 | 39.25 |
| | 2 | Rm | 1,068.05 | 512.67 | 98.83 | 38.55 | 106.81 | 51.27 |
| | 3 | Rm | 2,672.59 | 1,282.84 | 139.47 | 54.39 | 267.26 | 128.28 |
| II (Samataring) | 1 | Ra | 1,737.32 | 833.91 | 104.64 | 40.81 | 173.73 | 83.39 |
| | 2 | Ra | 2,268.97 | 1,089.11 | 116.61 | 45.48 | 226.90 | 108.91 |
| | 3 | Ra | 1,863.85 | 894.65 | 97.38 | 37.98 | 186.39 | 89.46 |
| III (Samataring) | 1 | Ra | 750.38 | 360.18 | 97.48 | 38.02 | 75.04 | 36.02 |
| | 2 | Ra | 55.87 | 26.82 | 32.26 | 12.58 | 5.59 | 2.68 |
| | 3 | Ra | 58.75 | 28.20 | 24.19 | 9.43 | 5.87 | 2.82 |
| Total | 9 | - | 11,293.40 | 5,420.83 | 791.31 | 308.61 | 1,129.34 | 542.08 |
| Mean | - | - | 1,254.82±934.80 | 602.31±448.71 | 87.92±37.54 | 34.29±14.64 | 125.48±93.48 | 60.23±44.87 |

*Rm – Rhizophora mucronata Lam.; Ra – Rhizophora apiculata Blum.; AGB$_{(tree)}$ – aboveground biomass of a mangrove tree; BGB$_{(root)}$ – belowground biomass of a mangrove root; AGC$_{(tree)}$ – aboveground carbon of a mangrove tree; BGC$_{(root)}$ – belowground carbon of a mangrove root; T-AGC$_{(tree)}$ – aboveground carbon of mangrove tree per hectare; T-BGC$_{(root)}$ – belowground carbon of mangrove tree per hectare.*

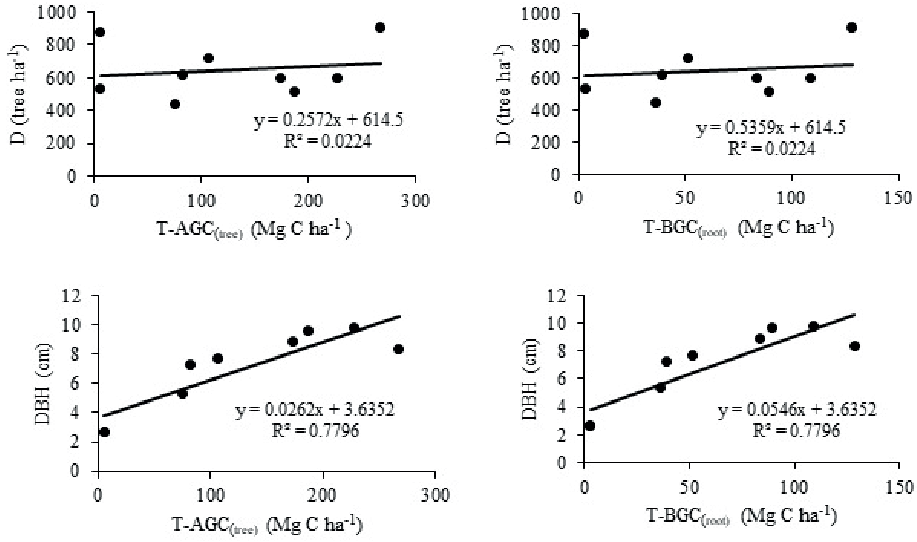

**Fig. 2. The relationships between a mangrove tree density (D) and diameter at breast height (DBH), and T-AGC$_{(tree)}$ and T-BGC$_{(root)}$**

**Fig. 3. Mangroves in Tongke-Tongke Village, Sinjai District. Low planting distance of planted mangrove (A). Deforested mangrove area for expansion of settlement (B) and aquaculture pond (C)**

## DISCUSSION

The mangroves in this area are occupied by two mangrove species, namely Rm and Ra (Table 1). Both Ellison (2000) and Primavera and Esteban (2008) demonstrated that most mangrove rehabilitation programs in Southeast Asian countries mainly focused on planting commonly mangrove species such as *Rhizophora* sp. These species were favored due to their ability to protect the coastal area from erosion, high waves, and storms. They have a higher capability to trap the sediment than other species, and their seedlings are easy to find around this area.

However, generally planting distance of these mangroves was too small (0.5 m x 0.5m). Thus, it can affect a plant growth, especially a tree diameter (Fig. 3a). The mean value of trees diameter (6.92±2.77 cm) in this area was lower than the value in the similar age (33 years) mangrove rehabilitated area in Can Gio Mangrove Biospheres Reserve (CGMBR), Ho Chi Minh City, Mekong Delta (10.5 cm) (Nam et al. 2016).

Ryan and Yoder (1997) demonstrated that the amount of light, nutrients, and water influenced plant growth over time; the larger planting distance can make the higher intensity of light, including the photosynthesis process for carbon sequestration, and more available nutrients for plants. Conversely, the lower planting distance causes the competition for sunlight, also absorption of nutrients and carbon increases strongly (Mawazin and Suhaendi 2008). The decreasing distance under mangrove rehabilitation is used to trap sediment (Fig. 3b) and achieve new lands for settlements or aquaculture ponds faster. After mangroves will reach maturity and much sediment will be trapped in this area, trees will be cut and land will be converted into a settlement or an aquaculture pond (Fig. 3c).

The low mean values of the mangrove tree basal area (4.82±2.99 m$^2$ ha$^{-1}$) indicate that the forest is in disturbed status.

Furthermore, we found that more carbon is saved in AGC$_{(tree)}$ (68%) than in BGC$_{(root)}$ (32%) for all plot sites (Table 2). The higher carbon stocks of AGC$_{(tree)}$ correspond to similar studies in several mangrove forests in Indonesia (Murdiyarso et al. 2015; Alongi et al. 2015). Donato et al. (2011) revealed that the contribution of AGC$_{(tree)}$ to the total carbon storage was higher than BGC$_{(root)}$ in mangrove estuaries and oceanic in the Indo-Pacific region.

Our mean values of T-AGC$_{(tree)}$ and T-BGC$_{(root)}$ stocks were 125.48±93.48 Mg C ha$^{-1}$ and 60.23±44.87 Mg C ha$^{-1}$ (Table 2). It corresponds to the data of other researchers. For example, considering the total mangrove rehabilitation area in Tongke-Tongke and Samataring villages of Sinjai District at the square about 688 ha in 2016 (BPS Kabupaten Sinjai 2017), the T-AGC$_{(tree)}$ and T-BGC$_{(root)}$ stocks are approximately equal to 129,1 Mg C ha$^{-1}$ and 58,5 Mg C ha$^{-1}$, respectively.

The highest values of T-AGC$_{(tree)}$ and T-BGC$_{(root)}$ were found at the site I plot 3 (267.26 Mg C ha$^{-1}$ and 128 Mg C ha$^{-1}$) (Table 2). Although these values were affected by the density of the mangrove tree (Table 1), the values of T-AGC$_{(tree)}$ and T-BGC$_{(root)}$ stocks generally were more affected by tree diameter (Fig. 2). It is higher than stocks of mangrove rehabilitated areas in CGMBR, Mekong Delta region, Vietnam (61.4 Mg C ha$^{-1}$ and 8.7 Mg C ha$^{-1}$) where *Rhizophora* sp. also dominates (Nam et al. 2016). Both Komiyama (2014) and Alavaisha and Mangora (2016) revealed that the mangrove forest structure has a significant effect on carbon stock accumulation, while the root biomass was positively correlated with stem diameter (Perera and Amarasinghe 2013). In addition, any losses or regrowth of mangrove forests is tightly coupled with land-use change (Murdiyarso et al. 2015; Mahasani et al. 2015) and natural disturbance, such as sea-level rise (SLR) (Ward et al. 2016). Alongi (2008) claimed that mangroves in Sulawesi are one of the hotspots vulnerable to SLR due to a lower tidal range. Flooding that triggered by SLR in the mangrove area will drastically reduce productivity and photosynthesis processes, which cause the overall lifespan of mangroves to be short (Shehadi 2015), resulting in loss of potential biomass carbon stocks in this area.

Increasing the planting distance and termination of settlement and aquaculture pond expansion are the most effective methods to maintain and possibly increase biomass carbon stocks for mitigating climate change, preservation of intact forests, and restoration of the mangroves.

## CONCLUSIONS

This study has demonstrated the biomass carbon stocks in mangrove rehabilitated areas in Sinjai District, South Sulawesi. The mean values of T-AGC$_{(tree)}$ and T-BGC$_{(root)}$ of the mangroves were 125.48±93.48 Mg C ha$^{-1}$ and 60.23±44.87 Mg C ha$^{-1}$, respectively. The aboveground pool stores more carbon than belowground biomass. The values of T-AGC$_{(tree)}$ and T-BGC$_{(root)}$ stocks were more affected by diameter than the density of mangrove trees. However, low planting distance under rehabilitation and over-exploitation of the mangrove for settlement and aquaculture expansions has affected forest structure and impacted to mangrove damage resulting in not-maximum carbon sequestration in plant biomass.

It is important to consider changes of planting distance for protection of intact forests and rehabilitation of disturbed mangroves. Moreover, halting the expansion of settlement and aquaculture pond should be considered as the most effective method to increase carbon stocks in plant biomass for climate change mitigation and sustainable mangrove management in this area. ■

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