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Abdul Malik <abdulmalik@unm.ac.id>

GES Journal Registration

1 message

no-reply@elpub.science <no-reply@elpub.science> Thu, Oct 17, 2019 at 5:32 PM
Reply-To: "Sergey R. Chalov" <ges-journal@geogr.msu.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>

Abdul Malik

You have now been registered as a user with GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY. We have included your username and password in this email, which are needed for all work with this journal through its website. At any point, you can ask to be removed from the journal's list of users by contacting me.

Username: malikgeounm
Password: oceanor95

Thank you,
Sergey R. Chalov

____

Sergey R. Chalov,
Secretary-General of
Geography, Environment, Sustainability jounal
http://ges.rgo.ru/

UNM

Abdul Malik <abdulmalik@unm.ac.id>

GES Submission Acknowledgement

1 message

Sergey R. Chalov <no-reply@ojs0x00.elpub.science> Thu, Oct 17, 2019 at 6:31 PM
Reply-To: "Sergey R. Chalov" <ges-journal@geogr.msu.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik:

Thank you for submitting the manuscript, "BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT SOUTH SULAWESI INDONESIA" to GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Manuscript URL: https://ges.rgo.ru/jour/author/submission/840
Username: malikgeounm

If you have any questions, please contact me.

____

Sergey R. Chalov,
Secretary-General of
Geography, Environment, Sustainability jounal
http://ges.rgo.ru/

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Abdul Malik <abdulmalik@unm.ac.id>

Re: GES BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT SOUTH SULAWESI INDONESIA

1 message

Нина Алексеева <nalex01@mail.ru> Tue, Jan 28, 2020 at 4:01 AM
Reply-To: Нина Алексеева <nalex01@mail.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>
Cc: GES Journal <ges-journal@geogr.msu.ru>

Dear Abdul Malik,
Thank you for your letter.
Yes, I think you should consider two reviewer's opinions and submit the revised paper taking into account the comments and remarks, if necessary.

Regards,
Nina Alekseeva,
GES Editor

> Понедельник, 27 января 2020, 12:00 +03:00 от Abdul Malik <no-reply@ojs0x00.elpub.science>:
>
> Dear Nina Alexeeva
> (Editor of GES)
>
> We found two reviews from Reviewer A and C for the manuscript in our account.
> Could we start to give feedback to the reviewers what they comments and suggestions to the manuscript or need to wait other reviewers?
>
> Best Regards,
> Abdul Malik
> (Corresponding author)
>
> ____
> Sergey R. Chalov,
> Secretary-General of
> Geography, Environment, Sustainability jounal
> http://ges.rgo.ru/

--
Н.Н. Алексеева
(495)939-21-40, 38-42

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Abdul Malik <abdulmalik@unm.ac.id>

GES Editor Decision

1 message

GES Editor <no-reply@ojs0x00.elpub.science> Wed, Apr 1, 2020 at 9:37 PM
Reply-To: GES Editor <ges-journal@geogr.msu.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!

We have reached a decision regarding your submission to GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY, "BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT SOUTH SULAWESI INDONESIA".

Our decision is revisions required. We kindly ask you to log in to the website and find the reviews either embedded as text or attached in separate files. Please revise your manuscript and re-upload it to the website within 3 weeks. You need to compile the answers to the reviewer's questions. Please send them within single word/pdf file to our email address: ges-journal@geogr.msu.ru

GES Editor
Editorial Board of Geography, Environment, Sustainability journal
Russian Geographical Society
ges-journal@geogr.msu.ru

____

Sergey R. Chalov,
Secretary-General of
Geography, Environment, Sustainability jounal
http://ges.rgo.ru/

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Abdul Malik <abdulmalik@unm.ac.id>

GES Editor Decision

5 messages

GES Editor <no-reply@ojs0x00.elpub.science> Sun, Apr 26, 2020 at 9:13 PM
Reply-To: GES Editor <ges-journal@geogr.msu.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!

Three weeks after the notification on your manuscript review "BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT SOUTH SULAWESI INDONESIA" has passed 5 days ago. When should we expect the revised manuscript?

GES Editor
Editorial Board of Geography, Environment, Sustainability journal
Russian Geographical Society
ges-journal@geogr.msu.ru

____
Editorial Office
http://ges.rgo.ru/

Abdul Malik <abdulmalik@unm.ac.id> Mon, Apr 27, 2020 at 12:04 AM
To: GES Editor <ges-journal@geogr.msu.ru>

Dear GES Editor

We apologize for the delay in sending the revised version of the manuscript. If possible we would like to ask a time extension for 7-10 days to finish and send back the revised manuscript.

Best regards,
Abdul Malik
(Corresponding author)

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--
Abdul Malik, Ph.D.

Department of Geography
Faculty of Mathematics and Natural Sciences

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South Sulawesi - INDONESIA
Phone: +62-853 9859 2785 Fax: +62-411-880568
E-mail: abdulmalik@unm.ac.id

GES Journal <ges-journal@geogr.msu.ru> Mon, Apr 27, 2020 at 12:45 AM
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!
We will be waiting for the manuscript in 7-10 days.

--
Best regards,
Alexey Maslakov,
Geography, Environment, Sustainability
Editorial Office.
Website: http://ges.rgo.ru/jour

26.04.2020, 19:04, "Abdul Malik" <abdulmalik@unm.ac.id>:
[Quoted text hidden]

Abdul Malik <abdulmalik@unm.ac.id> Mon, May 4, 2020 at 12:24 AM
To: GES Journal <ges-journal@geogr.msu.ru>

Dear Editor of GES

We have sending the revised of the manuscript with title " "BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT SOUTH SULAWESI INDONESIA" with two versions (with track changes and no track changes), and the response to comments and suggestions of the reviewers in separate file.

Best Regards,
Abdul Malik
(Corresponding author)

.

[Quoted text hidden]

GES Journal <ges-journal@geogr.msu.ru> Mon, May 4, 2020 at 7:25 PM
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!
Thank you for the email. We have received all the files!

--
Best regards,
Dr. Alexey Maslakov,
Geography, Environment, Sustainability
Editorial Office.
Website: http://ges.rgo.ru/jour

03.05.2020, 19:25, "Abdul Malik" <abdulmalik@unm.ac.id>:
[Quoted text hidden]

Abdul Malik[1*], Abd. Rasyid ~~Djalil[2]~~Jalil[2], Ahsin Arifuddin[1], Ainun Syahmuddin[1]
[1]Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar (UNM), Jl. Malengkeri Raya, Kampus UNM Parangtambung, Makassar 90224, Indonesia.
[2]Department of Marine Science, Faculty of Marine Science and Fisheries, Universitas Hasanuddin, Jl. Perintis Kemerdekaan Km. 10, Makassar, 90245, Indonesia.

***Corresponding author**: E-mail: abdulmalik@unm.ac.id

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

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 for 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.

KEYWORDS: Mangrove; biomass carbon stocks; climate change mitigation; South Sulawesi.

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). Mangrove 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

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Commented [OC7]: Either "…stores carbon in its…" Or "…store carbon in their…"
Commented [AM8R7]: Thanks for the suggestion. We have edited: "…store carbon in their…"

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 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~~; Murdiyarso et al. 2015~~).

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 ~~Regencies~~ 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 mangrove forest 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 object 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 focused on rehabilitated mangroves of Tongke-Tongke and Samataring villages. The study area situated at 5°8' - 5°10' ~~nl~~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). ~~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 a fishermen and a shrimp farmers (BPS Kabupaten Sinjai 2017).~~

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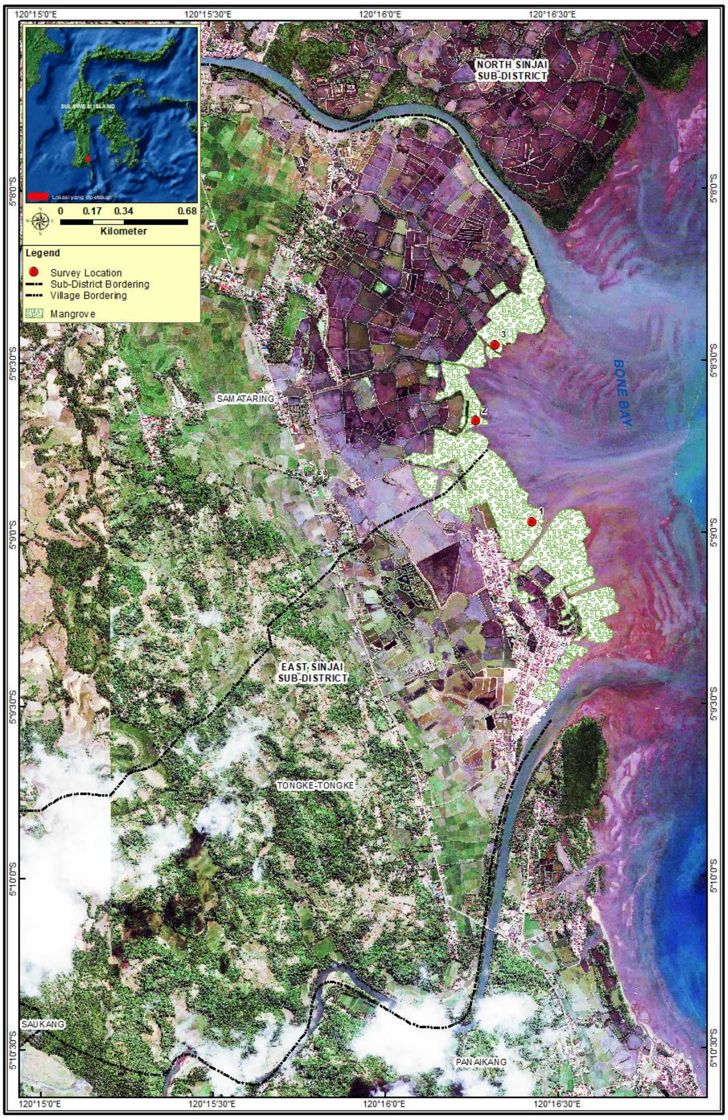

Fig. 1. Study area: Tongke-Tongke and Samataring Villages in Sinjai District, South Sulawesi Province, Indonesia

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 a fishermen and a shrimp farmers (BPS Kabupaten Sinjai 2017).

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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 ~~(Malik et al. 2015b; Malik et al. 2019)~~.

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):

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

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

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

~~where Di (tree ha^{-1}); BA (m^2 ha^{-1}); ni: number of stand species i; A: total area of the sample observations (ha); and~~ where DBH – diameter at breast height.

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

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

Leaf biomass $Lb = 10^{(-1.8571+(2.1072\times(LOG(DBH)))}$

Wood biomass $Wb = Wv \times \rho \times 1000$

Wood volume $Wv = 0.0000695 \times DBH^{2.64}$

Prop roots biomass (PRb):

- $PRb = Wb\times 0.101$ if $DBH< 5cm$,;
- $PRb = Wb\times 0.204$ if $DBH>5\leq 10cm$,;
- $PRb = Wb\times 0.356$ if $DBH>10\leq 15cm$,;
- $PRb = Wb\times 0.273$ if $DBH>15\leq 20cm$,;
- $PRb= Wb \times 0.210$ if $DBH>20cm$.

Below-ground biomass ($BGB_{(root)}$) 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 ~~root carbon stocks~~ ($AGC_{(tree)}$ and $BGC_{(root)}$), we used conversion factors from Kauffman and Donato (2012):

Commented [OC19]: You use the same papers four times!!!

Commented [AM20R19]: Thanks, we have accepted to delete it

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Commented [OC21]: What symbols are there?

Commented [AM22R21]: Thanks for the correction.

Commented [OC23]: What about units of measurements? Tones, kilograms?

Commented [AM24R23]: Kilograms. We have added it.

Commented [OC25]: It is very difficult to read. I offer to do a list

Commented [AM26R25]: Thanks for the correction. We have accepted it.

Commented [OC27]: What is difference between root and belowground biomass? If there are two different pools, where is the third equation?
If there are the same parts, you must withdraw one of they

Commented [AM28R27]: Thanks for the correction. It is the same part. so we have deleted one.

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

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

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

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

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

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

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

RESULTS

Mangrove Structure

560 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 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}).

Table 1. Species composition and structure of mangrove.

Site	Plot	Species	Number of tree	Height (m)	D (tree ha^{-1})	DBH (cm)	BA (m^2 ha[illegible])
I (Tongke-Tongke)	1	Rm	56	7.64	622	7.25	[illegible]
	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.~~95~~92±2.77	4.[illegible]

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

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

Commented [OC29]: Kg C? Mg C? per tree? Or per hectare?
Commented [AM30R29]: Thanks for the comment. It is in Kg
Commented [OC31]: What about units of measurements? Kg?
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Commented [OC33]: Insert another symbol for new parameter. These abbreviatures you used earlier
Commented [OC34]: Copy this and past in other formulas! Or past only "Mg C" if it needs
Commented [OC35]: Kg C per tree? Meter?
Commented [AM36R35]: Thanks for the comment. It is in Kg per tree
Commented [OC37]: What symbols are there?
Commented [OC38]: Is it one number? Upper you write about two parameters - density and diameter at breast height
Commented [AM39R38]: No. it is two numbers, density and diameter at breast height. We have edited it.
Commented [OC40]: A reader may see it in the table
Commented [AM41R40]: Thanks for the correction. We have accepted to delete it.
Commented [OC42]: Passive voice
Commented [AM43R42]: Thanks for the correction. We have accepted to revise it.
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Commented [OC44]: Insert standard deviations! ±
Commented [AM45R44]: Thanks for the suggestion, we have inserted it.
Commented [OC46]: Total? For what? It may be interesting only if you want to calculate the total biomass of all trees in the forest. But it isn't useful to know the biomass inside a few sites
Commented [AM47R46]: Thanks for the correction. We accepted to delete it.

$BGB_{(root)}$ 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 $AGC_{(tree)}$ and $BGC_{(root)}$ 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 $AGC_{(tree)}$ and $BGC_{(root)}$ 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).

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

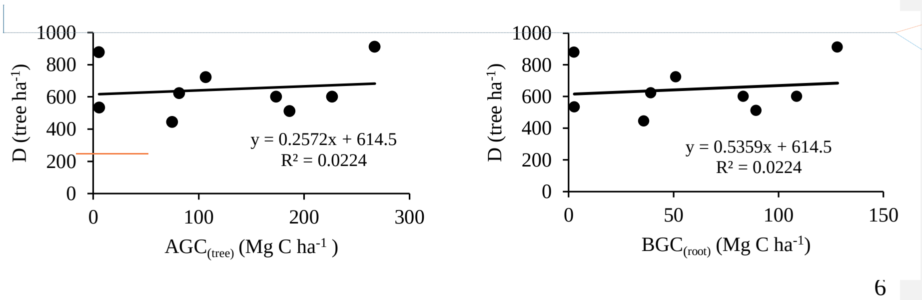
Site	Plot	Species	$AGB_{(tree)}$ (Kg)	$AGC_{(tree)}$ (Kg)	$BGB_{(root)}$ (Kg)	$BGC_{(root)}$ (Kg)	T-$AGC_{(tree)}$ (Mg C ha^{-1})	T-BGC(r… (Mg C ha…
I (Tongke-Tongke)	1	Rm	817.61	392.45	80.44	31.37	81.76	39…
	2	Rm	1,068.05	512.67	98.83	38.55	106.81	51…
	3	Rm	2,672.59	1,282.84	139.47	54.39	267.26	128…
II (Samataring)	1	Ra	1,737.32	833.91	104.64	40.81	173.73	83…
	2	Ra	2,268.97	1,089.11	116.61	45.48	226.90	108…
	3	Ra	1,863.85	894.65	97.38	37.98	186.39	89…
III (Samataring)	1	Ra	750.38	360.18	97.48	38.02	75.04	36…
	2	Ra	55.87	26.82	32.26	12.58	5.59	2…
	3	Ra	58.75	28.20	24.19	9.43	5.87	2…
Total	9	-	11,293.40	5,420.83	791.31	308.61	1,129.34	542…
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…

Rm – *Rhizophora mucronata Lam.*; Ra – *Rhizophora apiculata Blum.*; $AGB_{(tree)}$ – aboveground biomass of a mangrove tree; $BGB_{(root)}$ – belowground biomass of a mangrove roots; $AGC_{(tree)}$ – aboveground carbon of a mangrove tree; $BGC_{(root)}$ – belowground carbon of a mangrove roots.

. The mean values of $AGC_{(tree)}$ and $BGC_{(root)}$ stocks per site were 125.48±?? Mg C ha^{-1} and 60.23±?? Mg C ha^{-1}, respectively. The highest means of $AGC_{(tree)}$ and $BGC_{(root)}$ 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).

Furthermore, linear regression analysis showed that $AGC_{(tree)}$ and $BGC_{(root)}$ stocks of the mangrove increase with the increase of mangrove trees density and diameter. However, the accumulation of $AGC_{(tree)}$ and $BGC_{(root)}$ were larger influenced by the size of DBH than the density of trees (coefficient of determination R2 = 0.7796,) (Fig. 2).

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



Commented [OC48]: Passive voice

Commented [AM49R48]: Thanks for the correction. We have accepted to revise it.

Commented [OC50]: It is a local result for three sites; you can't extrapolate it for the forest. The average values are more useful and interesting

Commented [AM51R50]: Thanks, you right, we have deleted it

Commented [OC52]: Create another symbol For example, T-AGC, total AGC

Commented [AM53R52]: We have edited to T-AGC and T-BGC

Commented [OC54]: Create another symbol It is not clear what is difference between the sixth and the ninth columns

Commented [AM55R54]: We have edited to T-BGC. The sixth column viewed the Belowground Biomass (root) in Kg, while the ninth column showed the Belowground carbon (root) in Mg C/ha-1

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Commented [OC56]: Insert standard deviations

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Commented [OC58]: It is a local result for three sites; you can't extrapolate it for the forest. The average values are more useful and interesting

Commented [AM59R58]: Thanks, you right, we have deleted it

Commented [OC60]: NO! R2 < 0,3 for D

Commented [AM61R60]: Thanks for the correction. We have accepted it.

Commented [OC62]: Incorrect term. It isn't correlation. It is determination or approximation

Commented [AM63R62]: Thanks, you right, we have accepted to delete it

Commented [OC64]: There are bad coefficients. Your regression doesn't predict the real data well.

Commented [AM65R64]: Thanks for the comment.

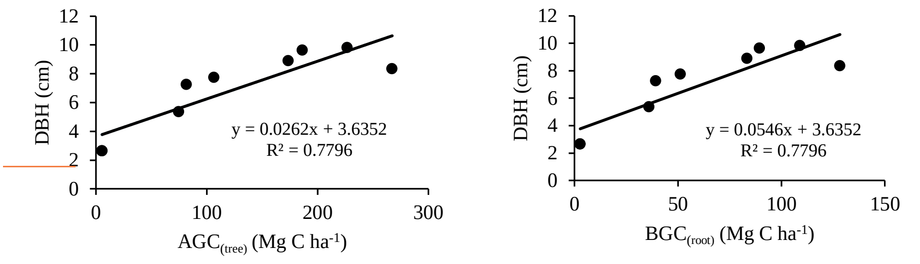

Fig. 2. The relationships between a mangrove tree density (D) and diameter at breast height (DBH), and $AGC_{(tree)}$ and $BGC_{(root)}$

DISCUSSION

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 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 × 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 on plant growth over time, the larger planting distance can make 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). There is an indication that.

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}), indicates that the forest is in disturbed status.

Commented [OC66]: These equations are very good

Commented [AM67R66]: Thanks for the comments.

Commented [OC68]: ± standard deviation

Commented [AM69R68]: Thanks for the correction. We have inserted it.

Commented [OC70]: Where is it? In a book, in a paper, or in a document?
See the correction below

Commented [AM71R70]: Thanks for the correction.

Commented [OC72]: Insert standard deviations! ±

Commented [AM73R72]: Thanks for the suggestion, we have inserted it.

Commented [OC74]: ± standard deviation

Commented [AM75R74]: Thanks for the correction. We have inserted it

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).

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 $AGC_{(tree)}$ and $BGC_{(root)}$ stocks were 125.48±93.48 Mg C ha^{-1} and 60.23±44.87 Mg C ha^{-1} (Table 2). 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 $AGC_{(tree)}$ and $BGC_{(root)}$ stocks are approximately equal to ~~88,822.12 Mg C and 40,234.62 Mg C,.~~ 129,1 Mg C ha^{-1} and 58,5 Mg C ha^{-1}~~.~~, respectively.

The highest values of $AGC_{(tree)}$ and $BGC_{(root)}$ 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 $AGC_{(tree)}$ and $BGC_{(root)}$ stocks generally were more affected by trees 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. dominates also (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 (~~Howard~~ Murdiyarso et al. ~~2014~~2015; Mahasani et al. 2016~~;~~) 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.

~~. Expansions of settlements and aquaculture ponds have disrupted the growth and caused mangrove deforestation, resulting in the loss of potential biomass carbon stocks in this area.~~

Thus, availability to maintain and possibly increase biomass carbon stocks for mitigating climate change, preservation of intact mangrove and restoration for mangrove was observed in framework of the planting distance and expansion of settlement and aquaculture pond.

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 mangrove.

CONCLUSIONS

This study has demonstrated the biomass carbon stocks in mangrove rehabilitated area in Sinjai District, South Sulawesi. The mean values of $AGC_{(tree)}$ and $BGC_{(root)}$ of mangrove were 125.48±~~??~~93.48 Mg C ha^{-1} and 60.23±~~??~~44.87 Mg C ha^{-1}, respectively. The

Commented [OC76]: You tell about amount, not about concentration

Commented [AM77R76]: Thanks, you right, we have accepted to delete it

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Commented [OC78]: There is a value per hectare. Create new symbols

Commented [AM79R78]: Thanks for the suggestion. We have implementation by using "Mg C ha^{-1}"

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Commented [OC80]: But there is the total value

Commented [AM81R80]: Thanks for the correction. We have deleted the total value.

Commented [OC82]: There is a value per hectare

Commented [AM83R82]: You right. thanks for the correction.

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Commented [AM85R84]: Thanks for the correction. We agreed, the value per hectare is more useful than the total.

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Commented [OC86]: chronology

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Commented [AM89R88]: Thanks for the correction. We have accepted it.

aboveground pool stores more carbon than belowground biomass. The values of $AGC_{(tree)}$ and $BGC_{(root)}$ stocks were more affected by diameter than the density of mangrove trees. However, low planting distance under rehabilitation and over-exploitation of 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 expected that the protection of intact forests and rehabilitation of disturbed mangrove might consider the planting distance. It is important to consider changing planting distance for protection of intact forests and rehabilitation of disturbed mangrove. Moreover, halting the expansion of settlement and aquaculture pond should be considered as the most effective methods to increase carbon stocks in plant biomass for climate change mitigation and sustainable mangrove management in this area.

Commented [OC90]: It is not clear

Commented [AM91R90]: Thanks for the correction. We have accepted it.

ACKNOWLEDGMENTS

We thank the Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP) for funding this research with a contract project number: 069.5/PSRP/SC/SPK-PNLT/IV/2017, dated 10 April 2017. We are grateful to the Department of Geography Faculty of Mathematics and Natural Sciences Universitas Negeri Makassar, Government of South Sulawesi, and Sinjai District for supporting this work. We are also grateful to the two anonymous reviewers for excellent comments and suggestions to this paper.

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To the Reviewers,

We would like to sincerely thank and appreciate the highly constructive critics of this manuscript. We have implemented all these suggestions in the revised version.

Here is the detail of the revisions in the manuscript and our responses to the reviewers' comments and suggestions:

REVIEWER A:

Review of the article

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

The general opinion on the article is:

The article seems to be quite topical and of current interest. The article is relevant and consistent with the subject of the magazine.

The article is mainly based on the field survey research in the mangrove areas in Sinjai District, South Sulawesi. There are some questions on the materials and data collection methods to be clarified by the authors.

1. It is not clear how the three line-transects were delineated in the study. Was the choice of the line-transects random or the authors had significant reasons to put line-transects in the study within their actual location.

   Response: Thanks for the comment. The three line-transects was installed randomly in this study. We have added it in the text (see line 101 of the revised version of manuscript)

2. Are the mangroves within the transects semi-natural or planted?

   Response: Thanks for the comments. Mangroves within the transects are planted. They are planted since 1984 by an initiative of local communities in these areas (see lines 73-74 of the revised version of manuscript).

3. The authors are addressing the properties of vegetation as the tree density and diameter of the mangrove trees. Are there any other features of vegetation cover (for example, the age of the trees) and landscape location that could affect the mangrove biomass and carbon stocks? Or there is no field evidence of such influence?

   Response: Thanks for the comments. Mangroves in these two areas (Tongke-tongke and Samataring villages) were planted since 1984 (mean the age of mangroves is about 33 years in 2017). Although, the age of the trees is an important variable affecting plant mangrove growth and biomass. However, our findings show the diameter of the trees of mangroves rehabilitated in these areas was lower (average 6.92 cm) compared to another mangrove rehabilitated area such as in Can Gio, Vietnam (average 10.5 cm), which have similar age (33 years). In addition, related to landscape location that bordering with two rivers (see fig 1), where input sediment (soil nutrients) mostly coming from the two rivers, however, it could not affect mangrove trees growth and biomass carbon stock in these areas.

4. Are there any substantial differences between the location of 1st, 2nd, 3d plots within the transects (for instance, the altitude, tidal regime, type of sediments, stage of succession of the vegetation, human impact, etc.). The features of mangrove ecosystem pattern may be important to understand the values of AGC and BGC.

   Response: Thanks for the comments. You right, the features of mangrove ecosystem pattern, such as, the altitude, tidal regime, type of sediments, stage of succession of the vegetation, human impact, etc. are important variables that may be affect to the values of biomass carbon stocks. However, between the location of 1st, 2nd, 3rd plots within the transects in this study area do not have a substantial difference.

   In general, the location of plots within transects is characterized by flat topography with a slope of 0.12% and 0.28%. The type of substrate is generally composed of mud that suitable for mangrove growth from *Rhizophora* sp. The location influenced by the tidal regime of mixed Semidiurnal (the inundation occurred twice a day, but a few days happened once a day), with the mean sea level about 90 cm. Mangroves were planted since 1984 by initiated by the local communities. However, mangroves are still threatened by human anthropogenic activities mainly from the development of aquaculture ponds and settlements.

5. According to the Table 2 there is no clear regularity in the change of the above- and below-ground biomass and carbon stocks within the sequence of the plots. Is it possible to give explanations of the significant difference in AGC and BGC between various sites and plots.

   Response: Thanks for the comments. In general, the significant difference in AGC and BGC influenced by different sizes of DBH between various sites and plots. A linear regression analysis (Fig 2.) showed, AGC(tree) and BGC(root) stocks strongly depend on DBH, where the increased value of tree DBH influenced the trend values of AGC and BGC stocks.

- The paragraphs below Tables 1 and 2 repeat their contents.

  Response: Thanks for the correction. We have deleted the paragraphs.

- The authors are addressing the destruction of mangroves mainly due to human activities and pressures. At the same time the area under study is subject to sea level rise, storms, etc. There are no evidences in the article of these events, but the mangrove are ecotone ecosystems very vulnerable for natural turbulences. They are worth saying in the Discussion.

Response: Thanks for the correction. You right, we have addressed in the discussion section (see lines 261-267 of the revised version of manuscript).

REVIEWER C:

We would like to thank you for the comments and suggestions and include improving the language of the manuscript. Our responses to each of the comments and suggestions can be seen directly in the revised version of the manuscript.

UNM

Abdul Malik <abdulmalik@unm.ac.id>

GES Editor Decision

1 message

GES Editor <no-reply@ojs0x00.elpub.science> Sun, May 10, 2020 at 3:38 PM
Reply-To: GES Editor <ges-journal@geogr.msu.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!

We have reached a decision regarding your submission to GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY, "BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT SOUTH SULAWESI INDONESIA".

Our decision is revisions required. We kindly ask you to log in to the website and find the reviews both embedded as text and attached in separate files (file of your manucript with corrections). Please revise your manuscript and re-upload it to the website within 10 days. You don't need to compile the answers to the reviewer's questions. After the revision please send the final version of the manuscript and the figures in raster formats of high resolution to our email: ges-journal@geogr.msu.ru

GES Editor
Editorial Board of Geography, Environment, Sustainability journal
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Reviewer A:

The article may be accepted.

The authors took into account the comments of reviewers and made appropriate corrections to the text

But there still are minor inaccuracies that must be corrected.

1. The abbreviations T-AGC and T-BGC in the Table 2 must be indicated under the table.

2. The lines 221-222 are unclear - "There is an indication that"?

Reviewer B:

Dear authors,

Thank you for your correction. I have four comments only:
• You must separate above-belowground carbon stocks per tree and per site (per hectare). Currently these two terms are indicated by the same symbols, AGCtree and BGCroot both per tree and per site. But they are two different parameters. In the second table carbon stocks per site are marked as T-AGCtree and T-BGCroot, correspondingly. Introduce this abbreviature throughout the text.
• There are some repeats, when the same ideas are written in two neighbor paragraphs or sentences. Choose only one variant.
• Check your text again to differ “mangrove” (adjective) and “the mangroves” (noun).
• Look at some small mistakes I'd corrected in the text

After correction, the article may be included in the issue.

____
Editorial Office
http://ges.rgo.ru/

UNM

Abdul Malik <abdulmalik@unm.ac.id>

The final version of the manuscript & the figures in raster format

2 messages

Abdul Malik <abdulmalik@unm.ac.id> Wed, May 13, 2020 at 3:06 AM
To: GES Editor <ges-journal@geogr.msu.ru>

Dear GES Editor

We have sending The final version of the manuscript with entitled "BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT SOUTH SULAWESI INDONESIA" based on the comments and suggestions of the reviewers in round 2, and the figures in raster format of high resolution (attached)

Best regards,
Abdul Malik
(Corresponding author)

--
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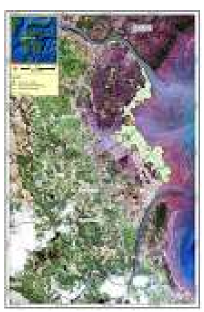
6 attachments



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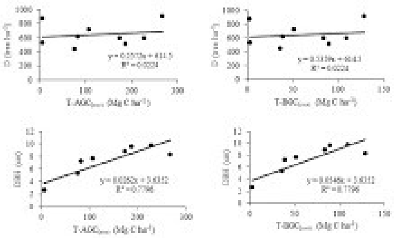

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BIOMASS CARBON STOCKS ESTIMATION IN THE MANGROVE REHABILITATED AREA OF SINJAI DISTRICT, SOUTH SULAWESI, INDONESIA

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.

KEYWORDS: Mangrove; biomass carbon stocks; climate change mitigation; South Sulawesi.

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 object 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).

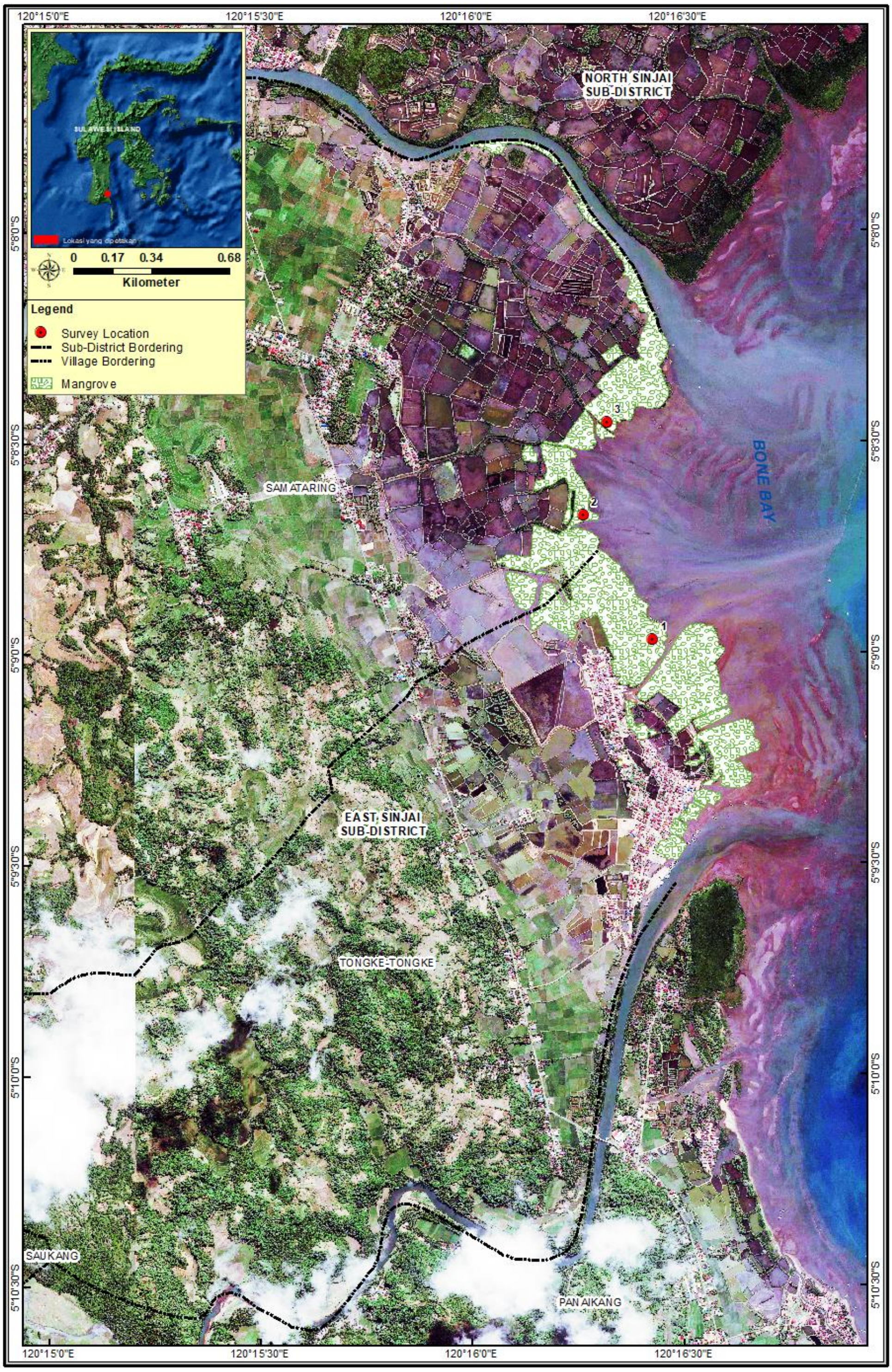

Fig. 1. Study area: Tongke-Tongke and Samataring Villages in Sinjai District, South Sulawesi Province, Indonesia

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):

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

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

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

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):

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

Leaf biomass $Lb = 10^{(-1.8571 + (2.1072 \times (LOG(DBH)))}$

Wood biomass $Wb = Wv \times \rho \times 1000$

Wood volume $Wv = 0.0000695 \times DBH^{2.64}$

Prop roots biomass (PRb):

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

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

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

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):

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

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

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):

$$\mathrm{T-AGC_{(tree)}\ and\ T-BGC_{(root)}} = \frac{\mathrm{Cb}}{1000} \times \frac{10000}{\mathrm{A\ plot}} \quad (7)$$

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}).

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

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).

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)	$T\text{-}AGC_{(tree)}$ (Mg C ha^{-1})	$T\text{-}BGC_{(root)}$ (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; $T\text{-}AGC_{(tree)}$ – aboveground carbon of mangrove tree per hectare; $T\text{-}BGC_{(root)}$ – belowground carbon of mangrove tree per hectare.

As linear regression analysis showed, $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$ 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).

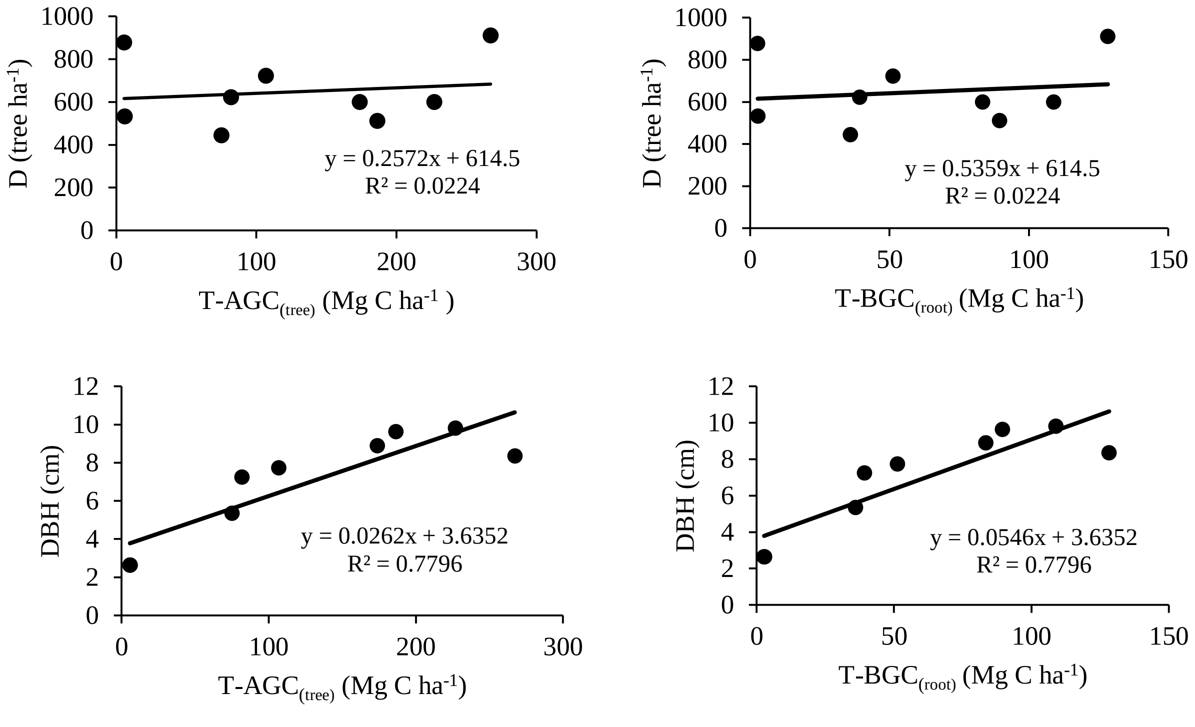

Fig. 2. The relationships between a mangrove tree density (D) and diameter at breast height (DBH), and $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$

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 × 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.

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).

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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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 rehabilitated; 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 object 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).

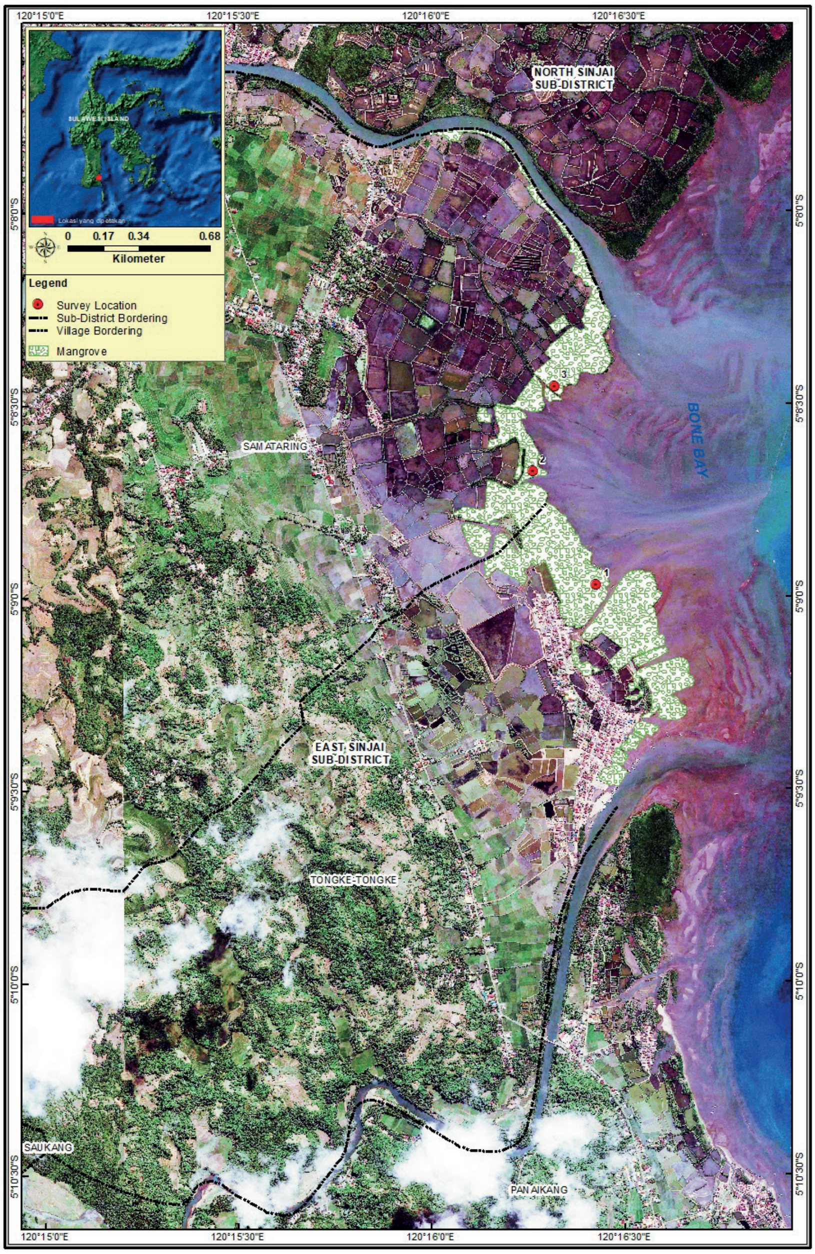

Fig. 1. Study area: Tongke-Tongke and Samataring Villages in Sinjai District, South Sulawesi Province, Indonesia

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):

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

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.

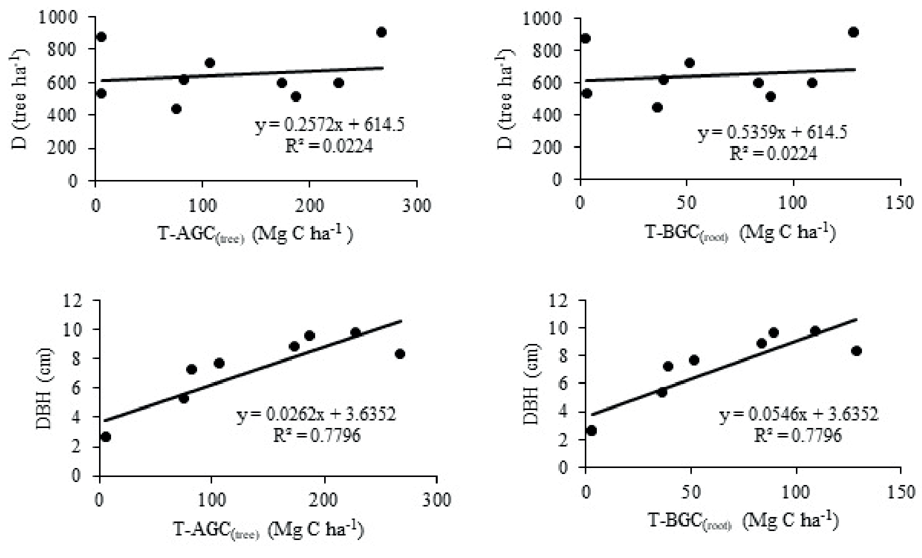

Fig. 2. The relationships between a mangrove tree density (D) and diameter at breast height (DBH), and T-$AGC_{(tree)}$ and T-$BGC_{(root)}$

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 $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$ 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 $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$ stocks are approximately equal to 129,1 Mg C ha^{-1} and 58,5 Mg C ha^{-1}, respectively.

The highest values of $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$ 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 $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$ 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 $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$ 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 $T\text{-}AGC_{(tree)}$ and $T\text{-}BGC_{(root)}$ 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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