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RESEARCH ARTICLE

Biomass Carbon Stock Assessment of Mangrove Ecosystem in Pannikiang Island South Sulawesi Indonesia

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Abstract. One of the essential services provided by mangroves is carbon sequestration, and therefore climate change mitigation. While previous assessments of mangrove carbon stocks and sequestrations have focused on the estuarine and deltaic mangrove setting, there are still limited studies carried out at small island mangroves. The study aims to assess mangrove biomass carbon stocks in Pannikiang, a small island in South Sulawesi, Indonesia, which occupies 91.64 ha of species-rich pristine mangrove forests. A field-based data collection survey was performed using a circular plot approach, while above-ground tree carbon (AGC) and below-ground root carbon (BGC) stocks were estimated using available species-specific allometric equations. The mean AGC and BGC were 5.34 ± 0.17 and 1.68 ± 0.04 Mg C ha^{-1}, respectively. *Bruguiera gymnorrhiza* mangrove species stored the greatest of carbon stocks, followed by *Scyphiphora hydrophyllacea*. Carbon stocks obtained from small island mangroves in this study were lower than stocks assessed from other mangrove locations across Indonesia and Southeast Asia. However, historical rates of deforestation in Pannikiang Island may generate emissions to approximately 82.17 Mg CO_2-eq. Findings from this study will be beneficial in providing baseline data for policy decision-making on climate change mitigation in the region, specifically for improved land use management via a low carbon development agenda

1. Introduction

Climate change is amongst the most challenging in this century, and the increase of greenhouse gasses (GHGs), mainly from carbon dioxide (CO2) emissions to the atmosphere, are the primary cause of climate change (Bindu dkk., 2020). Climate change mitigation is not only an effort to reduce the level of CO2 emissions but also balance with managing ecosystem services as carbon sinks (Wahyudi et al., 2017).

Mangroves are one of the most important coastal ecosystems in tropical and subtropical regions (Giri et al., 2011). They play an essential role in climate change mitigation by sequestrating CO2 from the atmosphere via photosynthesis and carbon (C) from the ocean (Howard et al., 2014). Mangroves are among the most massive forest carbon sinks per hectare than other tropical forests (Donato dkk., 2011; Alongi, 2014). However, they are particularly vulnerable to detach CO2 and other GHGs to the atmospheres that could impact global climate change if disturbed, as a result of logging and conversion to other land use such as agricultural land and aquaculture ponds (Murdiyarso et al., 2015; Sukarna and Syahid, 2015). Both Friess (2016) and Murdiyarso et al (2015) noted the continuous global demands for mangrove commodities and land-use change activities resulted in the increasing degradation and deforestation in recent decades.

Since 1980, almost half of the global mangrove forests have disappeared (FAO, 2007), and Southeast Asia was the highest loser region (Richards and Friess, 2016). The loss of mangroves has resulted in carbon emissions into the atmosphere of about 0.08-0.48 Pg CO2 yr-1 or 10% of the total global CO2 emissions of the world (Donato et al., 2011; Murdiyarso et al., 2015). In particular, Indonesia, which has the most significant percentage of mangroves in the world (22%), has lost about 40% of its mangroves (FAO, 2007) and resulting in a 20% carbon emissions increase due to land-use change (Murdiyarso et al., 2015).

The coastal area of South Sulawesi is an important area for mangrove blue carbon storage in Indonesia (Cameron dkk., 2019; Malik dkk., 2020). Mangroves are found in the coastal area of Makassar city and regencies of Maros, Pangkep, Barru, Pinrang, East Luwu, Luwu, Bone, Sinjai, Takalar, Jeneponto, Bantaeng, and Bulukumba (Saputro, 2009). In the 1950s, South Sulawesi mangrove-covered area of approximately 100,000 hectares Giesen et al (1991), which decreased around 89.6% to 10,412 hectares by 2017 (Susanto et al., 2018; Rahadian et al., 2019). The main driver of mangrove deforestation is conversion to aquaculture pond (Malik et al., 2017; 2020 ; Jalil et al., 2020), with annual deforestation rates between one and five percent during 1979 – 2012 (Malik et al., 2017). If current trends continue, local mangroves could be lost in the next 20-150 years (Malik et al., 2017), and the carbon stocks stored in these areas will become a source of significant carbon emissions.

While most previous mangrove carbon studies focused on the estuarine and deltaic mangrove setting, there is still a lack of studies conducted at small island mangroves. Pannikiang Island is one of the small island mangrove hotspots in South Sulawesi. Mangroves occupied about 91.64 ha of the total area of the island (96.88 ha) in 2018. However, mangroves have disappeared by 3.19 ha since 1997 due to conversion into aquaculture ponds and settlements (Jaelani et al., 2021).

Although the historical rate of mangrove deforestation has occurred on a small scale during the period 1997-2018, it is critical to investigate the current carbon stock and carbon emissions from the mangrove deforested on this island. Therefore, this study's objectives are to assess spatial variation by comparing carbon stocks between Pannikiang Island study sites and are to estimate carbon emissions generated by deforestation in this region between 1997 and 2018. Our findings contribute to providing baseline data for policy decision-making in climate change mitigation and land use management.

2. Methods

Study Area

The research was carried out in the mangrove area of Pannikiang Island, Barru Regency. This island is located within the latitude of 4°20'00'' - 4°22'00'' and longitude of 119°35’28.38'' - 119°36'30'' (Figure 1), about 108 km from the capital of South Sulawesi, Makassar City, and 15 km from the center of Barru Regency.

Pannikiang island was selected as considered as one of the potential carbon sequestration projects based on the

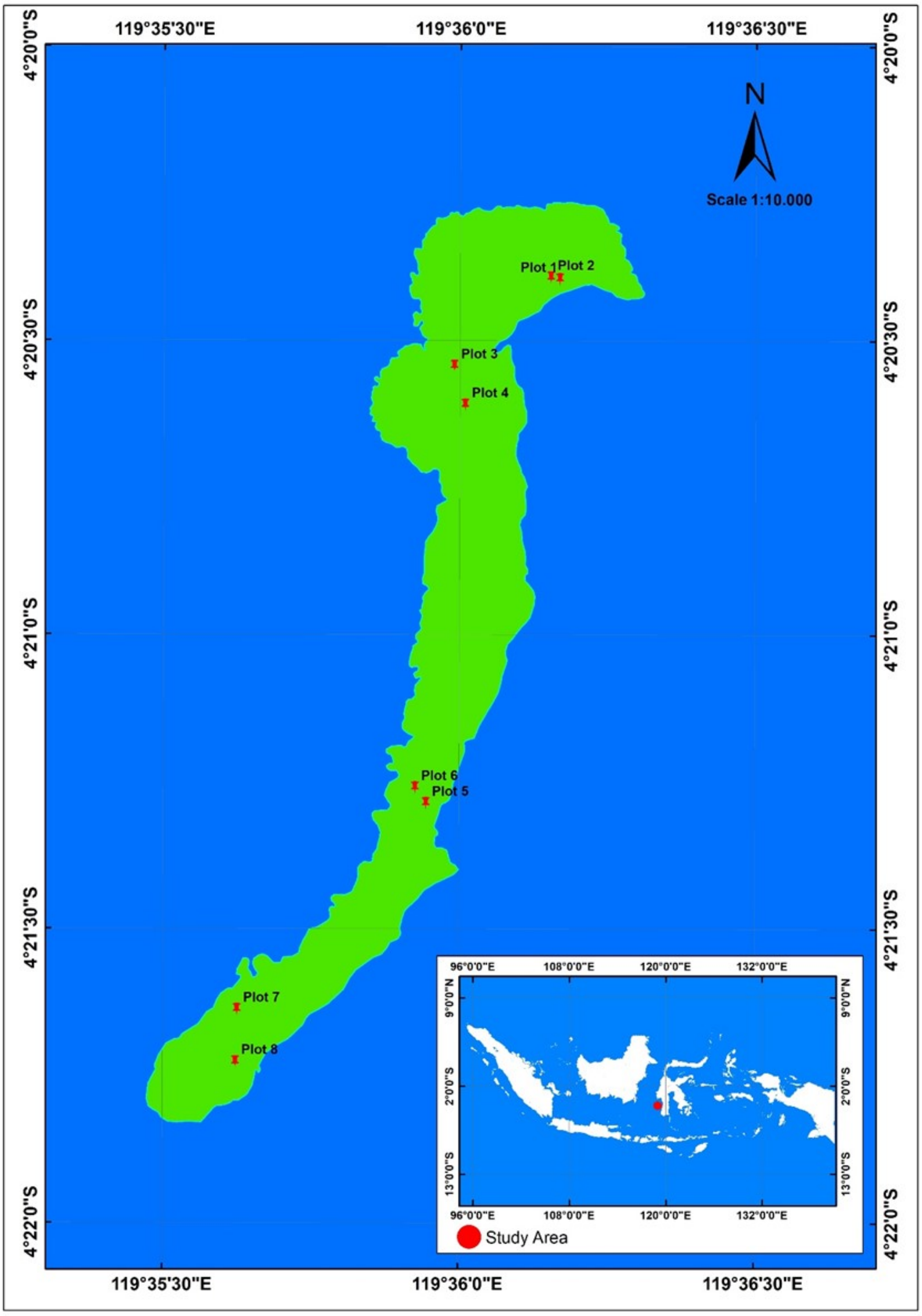

Figure 1. Pannikiang Island, Barru Regency, South Sulawesi, and plot locations

extent of the mangrove cover area. The mangrove area is dominated by Rhizophora stylosa (Suwardi, 2014) and habitat for many faunae, mainly for thousands of bats (Dinas Pariwisata Kabupaten Barru, 2017). About 55 households occupy this island, and most of the head households work as fishermen.

Data Collection

Data on biomass carbon stocks were collected in April 2019. We implemented a circular plot approach by adopting a sampling protocol developed by Kauffman dan Donato (2012) to measure above-ground tree biomass (AGB) and below-ground root biomass (BGB) stocks at the eight plots selected (Figure 1). For each plot, we established five circular subplots with a radius of 7 m and 25 m distance to each subplot center (Figure 2) using a measuring tape and marked the position using the Global Positioning System/ GPS. We also identified the species name and recorded the number of individual species of all mangrove trees using a tally counter. Finally, we measured stem diameter at breast height (DBH) 1.3 m above the ground or 30 cm above the highest prop root for Rhizophora sp. using measuring tape

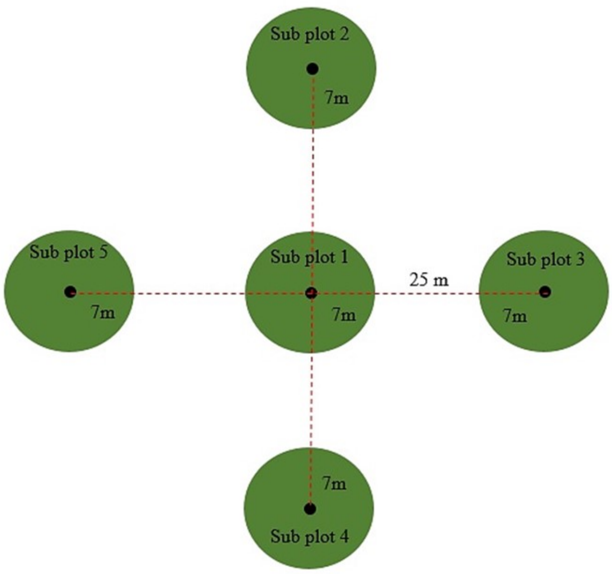

Figure 2. Plot layout for biomass carbon stock assessment (adopted from Kauffman dan Donato (2012).

Table 1. Wood density of mangroves

Species	Wood density (g cm^{-3})
Bruguiera cylindrica	0.72
Bruguiera gymnorrhiza (Bg)	0.81
Ceriops decandra	0.87
Ceriops tagal	0.85
Hibiscuse tiliaceocus	0.57
Rhizophora apiculata	0.87
Rhizophora stylosa	0.84
Rhizophora mucronata	0.83
Sonneratia alba	0.47
Scyphiphora hydrophyllacea	0.69
Xylocarpus granatum	0.61
Xylocarpus mollucensis	0.65

and tree heights using a clinometer (Malik et al., 2019; 2020).

Data Analysis

Species density, individual (ind.) tree basal area, and the total of tree basal area calculated using equations 1 - 3:

$D = \frac{ni}{A}$ (1); $ba_i = (\frac{1}{2}DBH)^2\pi$ (2); $BA = \Sigma\, ba_i$ (3)

where:
D: density of species i (ind. m-2). bai: ind. tree basal area (m2 ha-1). BA: total tree basal area per hectare (m2 ha-1). ni: number of standing species i. A: total area of the sample subplots per plot (769.3 m2). DBH: diameter at breast height (cm).

To calculate the AGB and BGB stocks of mangrove in this study, we used allometric equations 4 and 5 that were developed by Komiyama et al (2005) :

AGB = 0.251*r*DBH2.46 (4)

BGB = 0.199*r0.899*DBH2.22 (5)

where, AGB and BGB: above- and below-ground biomass on mangrove tree and root (kg). r: species-specific wood density (see Table 1).

Furthermore, to estimate the Above-ground tree carbon (AGC) and Below-ground root carbon (BGC) stocks, we used equations 6 and 7 (Kauffman and Donato, 2012; Howard et al., 2014):

AGC = AGB × 0.48 (6)

BGC = BGB × 0.39 (7)

where, AGC tree and BGC root: above- and below-ground carbon on mangrove tree and root (kg C m2). 0.48 and 0.39: carbon conversion factor for AGB and BGB.

Moreover, to calculate the loss of AGC and BGC stocks, we multiplied the mean value of AGC and BGC stocks by the historical rate of mangrove deforestation during the period 1997-2018 (3.19 ha) as reported by Jaelani et al (2021), while to calculate carbon emissions, we multiplied the loss value of AGC and BGC stocks by the ratio of molecular weights between carbon dioxide (44) and carbon (12) (Kauffman and Donato, 2012).

3. Results And Discussion

Species Composition of Mangrove

A total of mangrove tree (392 trees) was identified in this study. Twelve mangrove species were recorded include Bruguiera cylindrical (Bc), Bruguiera gymnorrhiza (Bg), Ceriops decandra (Cd), Ceriops tagal (Ct), Hibiscuse tiliaceocus (Ht), Rhizophora apiculate (Ra), Rhizophora

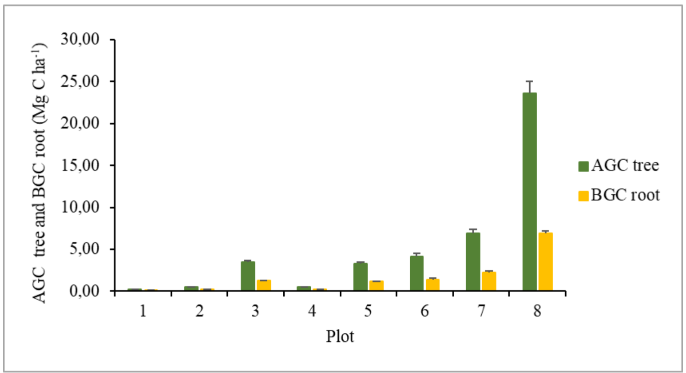

Figure 3. AGC and BGC stocks for each plot include the standard error of the mean

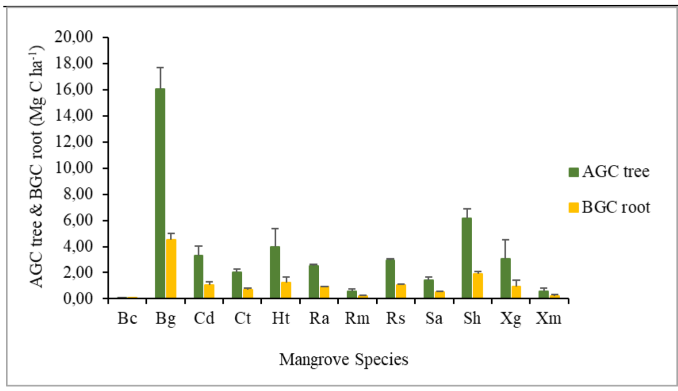

Figure 4. AGC and BGC stocks of mangrove species include the standard error of the mean.

mucronata (Rm), Rhizophora stylosa (Rs), Sonneratia alba (Sa), Scyphiphora hydrophyllacea (Sh), Xylocarpus granatum (Xg), and Xylocarpus mollucensis (Xm).

The number of mangrove species in this study area was higher than in the similar areas of South Sulawesi, such as in Takalar Regency (10 species) (Malik et al., 2015) and Pangkep Regency (11 species) (Jalil et al., 2020), but lower than in Sinjai Regency (15 species) as reported by Suharti et al (2016).

Rs was the dominating species (162 trees) and found in all plots and followed by Bg (70 trees). Malik et al. (2015) reported that the dominance of Rhizophora sp. in South Sulawesi is similar to other areas in Indonesia and Southeast Asia, such as in Segara Anakan Lagoon in Central Java and Matang in Malaysia. Duke et al (1998) stated the dominance of Rhizophora sp. in Indonesia and other Southeast Asia countries is influenced by physical, environmental, and climate factors, such as soil characteristics, moderately high and good rainfall distribution, and the suitable temperature range for the species growths.

Plot 1 was registered as the largest number of the tree (97 trees). The mean value of the tree density (0.03 ± 0.012 ind. m-2) is higher compared to other plots. The mean value of tree DBH and height were 11.05 ± 1.54 cm and 7.23 ± 0.74 m, respectively, whereas the mean stand basal area was 2.27 ± 0.55 m2 ha-1. Although Rs was dominating in all plots, Bg and Sh have higher tree DBH than other species.

Biomass Carbon Stocks of Mangrove

The mean concentration of AGC and BGC stocks at eight plots was 5.34 ± 0.17 Mg C ha-1 and 1.68 ± 0.04 Mg C ha-1, respectively. The greatest AGC and BGC stocks were found at plot 8 (23.60 ± 1.42 Mg C ha-1 and 6.86 ± 0.37 Mg C ha-1), whereas the lowest figure was at plot 1 (0.21 ± 0.02 Mg C ha-1 and 0.09 ± 0.01 Mg C ha-1) (Figure 3).

Considering the total area of mangroves (91.64 ha) in 2018 (Jaelani et al., 2021), the total of AGC and BGC stocks were 489.35 Mg C and 153.95 Mg C respectively. However, the mean value of AGC and BGC stocks were much lower compared to other places in Indonesia, such as in Bunaken, North Sulawesi (69.2 Mg C ha-1 and 14.9 Mg C ha-1), Kubu Raya, West Kalimantan (134.8 Mg C ha-1 and 14.3 Mg C ha-1), Sembilang, South Sumatra (300.5 Mg C ha-1 and 27.2 Mg C ha-1), and Timika, Papua (323.6 Mg C ha-1 and 43.6 Mg C ha-1) as reported by Murdiyarso et al (2015), and also to other places in Southeast Asia, such as in Palawan, Philippine 263.8 Mg C ha-1 and 92.3 Mg C ha-1 as reported

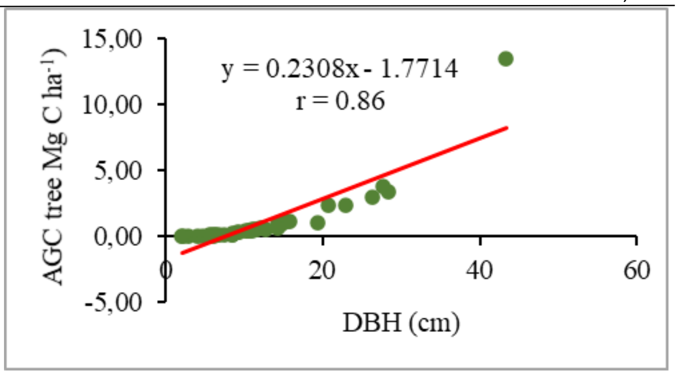

Figure 5a. Relationship between DBH and AGC-BGC stocks

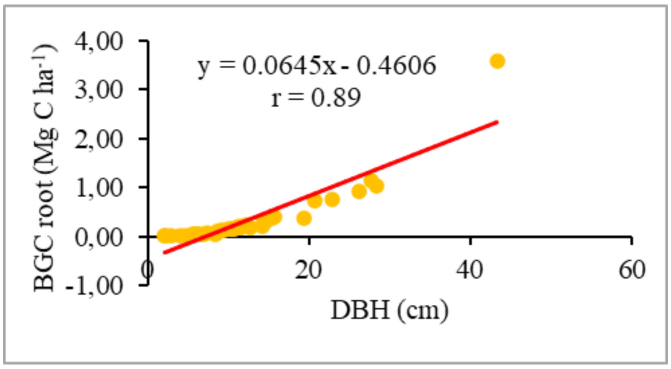

Figure 5b. Relationship between DBH and AGC-BGC stocks

by (Abino et al., 2014), and in Mekong Delta, Vietnam 61.4 Mg C ha-1 and 8.7 Mg C ha-1 as stated by Nam et al (2016). Low AGC and BGC stocks are likely due to the smaller size tree diameter (most of the tree diameter below 15 cm) compared to those places. Besides, this may be influenced by the high salinity that characteristic of the waters of small islands compared to the mainland estuary system. Therefore, it can affect mangrove growth.

Although Rs is the dominant species in this area, Bg represented the greatest AGC and BGC stocks (16.07 ± 1.64 Mg C ha-1 and 4.54 ± 0.43 Mg C ha-1), followed by Sh (6.18 ± 0.71 Mg C ha-1 and 1.90 ± 0.20 Mg C ha-1) (Figure 4). It is influenced by the larger tree diameter of this species compared to the other species.

The relationship between DBH and above-below ground carbon stocks is presented in Figure 5. The increased value of tree DBH influenced the trend concentration of AGC and BGC stocks. Plotted in linear regression showed that the correlation coefficient (r) between DBH and AGC and BGC stocks were 0.86 and 0.89, respectively. This finding confirms a study from Alavaisha dan Mangora (2016) that noted DBH mangrove trees' significant effect on the AGC stock concentration. The value of BGC stock is positively correlated with the tree diameter. Hence, if the tree diameter is large, the BGC stock is large as well (Perera and Amarasinghe, 2013).

Furthermore, considering the conversion of mangrove areas to aquaculture ponds and settlements that reach 3.19 ha during the period 1997 – 2018 (Jaelani et al., 2021), the loss of AGC and BGC stocks was 17.03 Mg C and 5.36 Mg C, respectively, or it causes the carbon emissions of 82.17 Mg CO_2-eq or 3.91 Mg CO_2-eq per year into the atmosphere. It suggests that if deforestation is halted and mangrove is restored, historical emissions from the past 21 years can be effectively offset over the same period (4.76% each year over 21 years).

Conclusion

This study has demonstrated the biomass carbon stocks in Pannikiang Island, Barru Regency, South Sulawesi, Indonesia. The mean value of AGC and BGC stocks is 5.34 ± 0.17 Mg C ha^{-1} and 1.68 ± 0.04 Mg C ha^{-1}, respectively. Although *Rs* is the dominant species, *Bruguiera gymnorrhiza* was the highest AGC and BGC stocks (16.07 ± 1.64 Mg C ha^{-1} and 4.54 ± 0.43 Mg C ha^{-1}), followed by *Scyphiphora hydrophyllacea* (6.18 ± 0.71 Mg C ha^{-1} and 1.90 ± 0.20 Mg C ha^{-1}). Tree DBH has a significant effect on the value of the AGC and BGC stocks. The mean value of AGC and BGC stocks is much lower than other places in Indonesia and Southeast Asia due to the lower tree diameter. However, mangrove clearing for different land uses has resulted in carbon emissions of 82.17 Mg CO_2-eq in the last two decades. Therefore, preventing mangroves from conversion to other land uses and conserving intact mangroves are essential actions to reduce CO_2 emissions and help mitigate climate change.

Acknowledgment

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Supplementary Materials

Table S1. Species Composition of Mangrove in Pannikiang Island South Sulawesi

Plot	Species	n	D (ind. m^{-2})	DBH (cm)	H (m)	BA (m^2 ha^{-1})
1 (4° 20'23,73''S - 119°	Bc	4	0.01	2.87	2.75	0.09
	Bg	8	0.01	4.02	2.75	0.18
	Rm	8	0.01	2.11	1.88	0.05
	Rs	53	0.07	2.28	3.41	0.08
	Sa	24	0.03	8.44	5.54	2.01
Subtotal		97	0.13	-	-	-
Mean ± SE			0.03 ± 0.012	3.94 ± 1.17	3.27 ± 0.62	0.48 ± 0.38
2 (4°20'23,54''S - 119° 36'9,06''E)	Bc	4	0.01	4.70	8.00	0.34
	Bg	10	0.01	6.05	4.50	0.58
	Rm	4	0.01	5.57	9.75	0.34
	Rs	12	0.02	7.43	10.00	0.74
	Sa	21	0.03	6.85	6.24	0.52
Subtotal		51	0.07	-	-	-
Mean ± SE			0.01 ± 0.004	6.12 ± 0.48	7.70 ± 1.05	0.50 ± 0.08
3 (4°20'32.58"S - 119° 35'59.29"E)	Bg	13	0.02	14.80	7.23	2.24
	Ra	10	0.01	11.08	7.10	12.60
	Rm	4	0.01	11.07	7.75	1.26
	Rs	32	0.04	11.16	7.31	1.28
	Sa	4	0.01	19.35	8.00	4.28
Subtotal		63	0.08	-	-	-
Mean ± SE			0.02 ± 0.007	13.49 ± 1.63	7.48 ± 0.17	4.33 ± 2.14
4 (4°20'36.53"S - 119° 36'0.41"E)	Bg	22	0.03	6.46	4.32	0.45
	Ra	7	0.01	5.82	4.00	0.37
	Rs	16	0.02	6.27	4.31	0.42
	Sa	9	0.01	8.56	4.67	1.27
Subtotal		54	0.07	-	-	-
Mean ± SE			0.02 ± 0.004	6.78 ± 0.61	4.32 ± 0.14	0.63 ± 0.21
5 (4°21'17.2"S - 119° 35'56.5"E)	Bg	6	0.01	10.46	8.17	1.25
	Ct	4	0.01	15.37	9.25	2.58
	Ra	9	0.01	12.28	8.44	1.63
	Rs	16	0.02	15.72	9.38	2.93
Subtotal		35	0.05	-	-	-
Mean ± SE			0.01 ± 0.003	13.46 ± 1.26	8.81 ± 0.30	2.10 ± 0.39
6 (4°21'15.6"S - 119° 35'55.4"E)	Bg	6	0.01	11.57	9.00	1.51
	Cd	1	0.001	20.70	11.00	4.37
	Ct	2	0.00	9.39	8.00	0.91
	Ra	6	0.01	11.46	10.17	2.03
	Rs	17	0.02	10.55	9.24	1.22
Subtotal		32	0.04	-	-	-
Mean ± SE			0.01 ± 0.004	12.74 ± 2.03	9.48 ± 0.51	2.01 ± 0.62

Table S1. Species Composition of Mangrove in Pannikiang Island South Sulawesi

7 (4°21'38.25"S - 119°35'37.39"E)	Bg	4	0.01	10.75	4.38	1.31
	Ht	5	0.01	28.41	7.62	10.53
	Ra	2	0.003	9.08	9.35	0.93
	Rs	3	0.004	8.70	7.97	0.85
	Sh	5	0.01	22.87	9.88	6.65
	Xg	1	0.001	6.05	4.30	0.37
	Xm	1	0.001	5.41	4.40	0.30
Subtotal		21	0.03	-	-	-
Mean ± SE			0.004 ± 0.001	13.04 ± 3.38	6.84 ± 0.92	2.99 ± 1.51
8 (4°21'43.60"S - 119°35'37.24"E)	Bg	1	0.001	43.31	12.50	19.14
	Cd	1	0.001	14.33	9.00	2.10
	Ct	1	0.001	12.10	8.00	1.49
	Ht	2	0.003	14.17	8.90	2.06
	Ra	10	0.01	10.13	7.08	1.11
	Rs	13	0.02	8.50	7.23	0.75
	Sh	8	0.01	27.64	11.81	9.07
	Xg	2	0.003	26.27	13.40	8.66
	Xm	1	0.001	12.74	11.80	1.66
Subtotal		39	0.05	-	-	-
Mean ± SE			0.01 ± 0.002	18.80 ± 3.80	9.97 ± 0.81	5.12 ± 2.05
Total		392	-	-	-	-
Grand Mean ± SE			0.01 ± 0.002	11.05 ± 1.54	7.23 ± 0.74	2.27 ± 0.55

Bc: *Bruguiera cylindrica*. Bg: *Bruguiera gymnorrhiza*. Cd: *Ceriops decandra*. Ct: *Ceriops tagal*. Ht: *Hibiscuse tiliaceocus*. Ra: *Rhizophora apiculate*. Rm: *Rhizophora mucronata*. Rs: *Rhizophora stylosa*. Sa: *Sonneratia alba*. Sh: *Scyphiphora hydrophyllacea*. Xg: *Xylocarpus granatum*. Xm: *Xylocarpus mollucensis*. n: individual number of species *i*. D: density of species *i*. DBH: diameter of breast height. H: height. BA: basal area. SE: the standard error of the mean.

Table S2. Biomass carbon stocks of mangroves for each plot in Pannikiang Island South

Plot	AGB ($Mg\ ha^{-1}$)	BGB ($Mg\ ha^{-1}$)	AGC ($Mg\ C\ ha^{-1}$)	BGC ($Mg\ C\ ha^{-1}$)
1	0.44 ± 0.05	0.24 ± 0.03	0.21 ± 0.02	0.09 ± 0.01
2	1.07 ± 0.05	0.56 ± 0.02	0.51 ± 0.02	0.22 ± 0.01
3	7.33 ± 0.27	3.19 ± 0.11	3.52 ± 0.13	1.24 ± 0.04
4	1.03 ± 0.02	0.53 ± 0.01	0.49 ± 0.01	0.21 ± 0.003
5	6.92 ± 0.38	2.95 ± 0.15	3.32 ± 0.18	1.15 ± 0.06
6	8.73 ± 0.79	3.65 ± 0.30	4.19 ± 0.38	1.42 ± 0.12
7	14.38 ± 1.04	5.72 ± 0.39	6.90 ± 0.50	2.23 ± 0.15
8	49.17 ± 2.96	17.60 ± 0.96	23.60 ± 1.42	6.86 ± 0.37
Grand Mean ± SE	11.13 ± 0.35	4.31 ± 0.11	5.34 ± 0.17	1.68 ± 0.04
Max	49.17 ± 2.96	17.60 ± 0.96	23.60 ± 1.42	6.86 ± 0.37
Min	0.44 ± 0.05	0.24 ± 0.03	0.21 ± 0.02	0.09 ± 0.01

AGB tree: above-ground tree biomass. BGB: below-ground root biomass. AGC tree: above-ground tree carbon. BGC tree: below -ground tree carbon. SE: the standard error of the mean.

Table S3. Biomass carbon stocks of mangrove species in Pannikiang Island South Sulawesi

Species	AGC (Mg C ha^{-1})	BGC (Mg C ha^{-1})
Bc	0.07 ± 0.02	0.03 ± 0.01
Bg	16.07 ± 1.64	4.54 ± 0.43
Cd	3.31 ± 0.70	1.07 ± 0.21
Ct	2.05 ± 0.23	0.72 ± 0.07
Ht	3.97 ± 1.38	1.24 ± 0.40
Ra	2.53 ± 0.08	0.93 ± 0.03
Rm	0.58 ± 0.15	0.22 ± 0.05
Rs	2.92 ± 0.13	1.07 ± 0.04
Sa	1.45 ± 0.24	0.52 ± 0.08
Sh	6.18 ± 0.71	1.90 ± 0.20
Xg	3.05 ± 1.44	0.95 ± 0.44
Xm	0.60 ± 0.23	0.22 ± 0.08
Grand Mean ± SE	3.56 ± 0.17	1.12 ± 0.05
Max	16.07 ± 1.64	4.54 ± 0.43
Min	0.07 ± 0.02	0.03 ± 0.01

Bc: *Bruguiera cylindrica*. Bg: *Bruguiera gymnorrhiza*. Cd: *Ceriops decandra*. Ct: *Ceriops tagal*. Ht: *Hibiscuse tiliaceocus*. Ra: *Rhizophora apiculate*. Rm: *Rhizophora mucronata*. Rs: *Rhizophora stylosa*. Sa: *Sonneratia alba*. Sh: *Scyphiphora hydrophyllacea*. Xg: *Xylocarpus granatum*. Xm: *Xylocarpus mollucensis*. AGC: above-ground tree carbon. BGC: below-ground root carbon. SE: