Blue carbon stock and green tea potential in mangroves of coral triangle eco-region, Southeast Sulawesi, Indonesia

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Abstract

This study aimed to elucidate the potential roles of mangroves as blue carbon stock and green tea material in coral triangle eco-region, Southeast Sulawesi, Indonesia. Blue carbon stock in mangroves organs of leaves, branches and stems was estimated including *Rhizophora apiculata*, *R. mucronata* and *Ceriops tagal*, while the compounds of catechin, simple polyphenol and flavonoid as green tea materials were analysed in their leaves. Results showed that high aboveground carbon stock (ton ha^{-1}) was found in protected mangroves forest, which were estimated as 96.83 for *C. tagal*, 369.71 for *R. apiculata* and 146.75 for *R. mucronata*. On the other hand, low blue carbon stock was found in unprotected mangrove forest, which estimated as 81.197 (ton ha^{-1}) for *R. apiculata*, 116.399 (ton ha^{-1}) for *R. mucronata* and 22.842 (ton ha^{-1}) for *C. tagal* forests. It seemed that higher blue carbon loss was happen in unprotected mangrove forest, which approximated about 73.99 (ton ha^{-1}) in *C. tagal* forest and 299.51 (ton ha^{-1}) in *R. apiculata* forest. Low blue carbon stock on unprotected mangrove due to land conversion and illegal logging, which will have negatively impact on productivity of coastal areas in this region. On the other hand, higher blue carbon stock indicated pure stands or undisturbed mangrove areas, which will support the coastal productivity. However, the mangroves in this coral triangle eco-region have potentiality as green tea material as of *Ceriops sp* contains compounds of 1.83% catechin, 5.58% simple polyphenol and 1.13% flavonoid, while the *R. apiculata* contains 0.81% of catechin and 4.81% of simple polyphenol. Similarly, the *R. mucronata* contains 1.14% of catechin and 6.41% of simple polyphenol. Therefore, the mangroves in the coral triangle ecoregion are important as blue carbon stock and might be potential to use as green tea material.

Key words: Mangroves, blue carbon stock, green tea material, Southeast Sulawesi, Indonesia

1 Introduction

The coral triangle ecoregion is recognized as the global centre of marine biodiversity [1] and a global priority for conservation [2]. The coral triangle areas consist of various coastal ecosystems including mangroves, seagrass, and coral reef, which lie from subtropical zone of Okinawa Island, Japan up to tropical zone of Philiphines and Indonesia coastal areas. It is well known that the mangroves, saltmarsh and seagrass are large carbon sink and they are considered as "blue carbon sources" in the coastal zones. However, these ecosystems are projected to be dispropostionately impacted by climate change and anthropogenic pressure and are expected to alter the blue carbon stock in coastal estuaries. Mangrove forest is a highly productive ecosystem and known to export organic matter to support a variety of organisms and enhances phytoplankton production [3]

Recent condition of mangrove ecosystems throughout the world suffered not only sea level rise but as an increasing human population, wide areas of mangroves are destructed due to development of aquaculture and urban in the coastal region as well as heavy metals pollutant at coastal areas, those of together with global climate change to be affect the blue carbon status of mangrove ecosystems, which play very important roles as primary producers to suppor the productivity of coastal zone at the coral triangle ecoregion. The exchange of carbon between mangroves and coastal ocean is increasingly recognized as potentially important components in the ocean carbon budget. Therefore, elucidation on blue carbon status and new potential uses of mangroves are needed for the development of the realistic carbon stock, and for projecting how does the mangroves to be developed for new potential uses for examples green tea material and antioxidant sources.

Mangroves comprise an extensive expanse in the coastal of the tropical and subtropical regions of the world with an economic value on the order of 200,000-900,000 USD ha^{-1} [4]. Despite of their economic value, mangrove ecosystem are known to play a key role in the coastal zone. Many studies realized the role of mangroves as important nursery grounds and breeding sites for various animals, a renewable resource of wood; sites for accumulation of sediment and nutrients [5;6].

Southeast Sulawesi coastal zone is part of coral triangle, which occupied a lot coastal biodiversity including mangroves, seagrass and coral reef. Mangroves at Southeast Sulawesi have been recognized as an important conservation area mainly dominated by mangrove rhizophoraceae includinh *Rhizophora apiculata*, *Rhizophora mucronata* and *Ceriops tagal* [7] as well as *Lumnitzera racemosa*, which shows different aboveground biomass between young and mature stands [8]. On the other hand, recent mangroves condition realized that wide areas of mangroves in the Southeast Sulawesi province are degraded due to conversion of mangrove land for marine pond, which mangroves loss was about 47% for unprotected mangroves near the RAWN park [9] (Analuddin et al. 2015*a*). There was no study have been done about blue carbon status and potential uses of mangroves as green tea material in the coral triangle eco-region of Southeast Sulawesi, Indonesia. Thus, estimation of blue carbon stock on remaining mangroves is needed, because this is important data for the development of the realistic carbon budgets in the coastal ecosystem. This study attempts on (1) estimation the blue carbon stock in protected and unprotected mangrove forest, and (2) elucidation the potential uses of mangroves leaves as green tea material.

2 Materials and Methods

2.1. Study Site

This study was carried out at the mangrove forest of Southeast Sulawesi, Indonesia [10]. The mangrove condition provides an excellent site for studying mangroves degradation and loss biomass due to land conversion. The mangroves of family *rhizophoracee* are dominant at surrounding areas of RAWN Park, and shows different growth stages [11, unpublished].

2.2. Tree Census and measurement of carbon

Tree censuses were done by quadrat method both in protected and unprotected mangroves forests. The growth parameters including Tree height *H*, and diameter at breast height DBH all individuals mangroves were measured. The allometric model was established for estimation of aboveground biomass [11, unpublished]. The carbon content was measured in Analytical Laboratory at Halu oleo University. The samples organs of leaf, branch and stem for dominant mangroves of *Ceriops tagal*, *Rhizophora apiculata* and *R. mucronata* were taken from Rawa Aopa Watumohai National Park.

2.3. Green tea compounds measurement

Green tea compound measurement was done for mangroves *Rhizophora apiculata, R. mucronata* and *Ceriops* sp. The new leaves of these three mangroves were taken from Rawa Aopa Watumohai National Park. The leaves kept in the box contained dry ice. The preparation of leaves samples was done in Laboratory of Forensic and Molecular. The compounds analyses of catechins, simple polyphenol and flavonoids were done by GCMS.

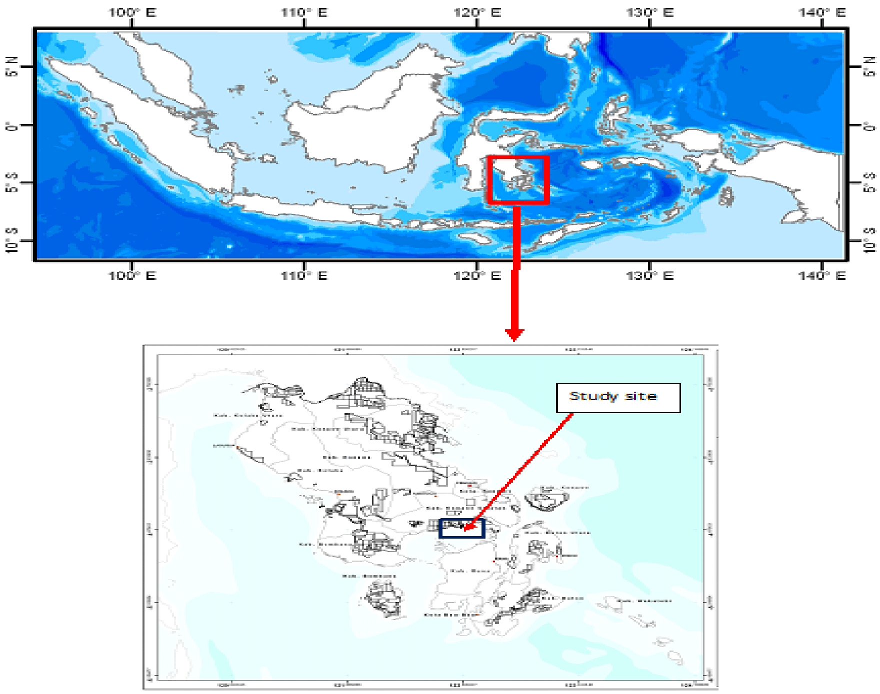

Figure 1. Maps of study site (Indonesia, upper) and of Southeast Sulawesi (below). Small box is study site [10]

3 Results and discussion

3.1. Blue carbon stock on protected mangroves

Spatial trend of carbon stock in stem, branches/twigs and leaf of mangroves seemed to be different for mangroves of *C. tagal* stands (Table 1), *R. apiculata* stands (Table 2) and *R. mucronata* (3) As shown in Table 1 that stock carbon in stem of *C. tagal* stands ranged from 19.28 (ton ha^{-1}) to 140.51 (t ha^{-1}) with an average of 65.42 (ton ha^{-1}). Branch carbon ranged 3.98 (ton ha^{-1}) to 52.03 (ton ha^{-1}) with an average of 25.14 (t ha^{-1}). On the other hand, leaf carbon stock ranged from 1.76 (ton ha^{-1}) to 13.43 (ton ha^{-1}) with an average of 6.27 (ton ha^{-1}). However, aboveground carbon stock in *C. tagal* stands varied among stands, i.e. it ranged from 25.02 (t ha^{-1}) to 205.97 (ton ha^{-1}) with an average of 96.83 (ton ha^{-1}).

Table 2 shown that stem carbon of *R. apiculata* stands ranged from 84.36 (ton ha^{-1}) to 533.50 (ton ha^{-1}) with an average of 304.67 (ton ha^{-1}). Branch carbon ranged from 29.31 (ton ha^{-1}) to 134.91 (ton ha^{-1}) with an average of 81.16 (t ha^{-1}). On the other hand, leaf carbon ranged 6.33 (ton ha^{-1}) up to 16.08 (ton ha^{-1}) with an average of 10.87 (ton ha^{-1}). However, aboveground carbon stock in *R. apiculata* stands varied among stands, i.e. it ranged from 120.00 (ton ha^{-1}) to 684.49 (ton ha^{-1}) with an average 396.71 (ton ha^{-1}).

Table 3 shown that stem carbon of *R. mucronata* stands ranged from 22.06 (ton ha^{-1}) to 140.85 (ton ha^{-1}) with an average of 80.91 (ton ha^{-1}). Carbon stock in branch ranged from 14.37 (ton ha^{-1}) to 106.60 (ton ha^{-1}) with an average of 57.61 (ton ha^{-1}). On the other hand, carbon stock in leaf ranged 2.53 (ton ha^{-1}) up to 12.97 (ton ha^{-1}) with an average of 8.22 (ton ha^{-1}). However, aboveground carbon stock in *R. mucronata* stands varied among stands, which ranged from 38.96 (ton ha^{-1}) to 260.42 (ton ha^{-1}) with an average 146.75 (t ha^{-1}).

3.2. Blue carbon stock unprotected mangroves

Table 4 represents blue carbon stock in mangroves *R. apiculata*, *R. mucronata* and *C. tagal* forests outside of RAWN Park. Blue carbon stock in stem of *R. apiculata* stands ranged from 0.613 (ton ha^{-1}) to 177.416 (ton ha^{-1}) with an average of 60.653 (ton ha^{-1}). Blue carbon in branch ranged 0.444 (ton ha^{-1}) to 55.303 (ton ha^{-1}) with an average of 20.544 (ton ha^{-1}). On the other hand, blue carbon in leaf ranged 0.333 (ton ha^{-1}) up to 10.089 (ton ha^{-1}) with an average of 4.678 (ton ha^{-1}). However, aboveground blue carbon stock in *R. apiculata* stands varied among stands, which ranged from 1.057 (ton ha^{-1}) to 229.087 (ton ha^{-1}) with an average of 81.197 (ton ha^{-1}). Meanwhile blue carbon stock in *R. mucronata* stands was much higher, i.e. carbon stock in stem ranged from 5.976 (ton ha^{-1}) to 239.582 (ton ha^{-1}) with an average of 88.136 (ton ha^{-1}). Branch carbon ranged 2.734 (ton ha^{-1}) to 65.624 (ton ha^{-1}) with an average of 24.430 (ton ha^{-1}). On the other hand, leaf carbon ranged 0.816 (t ha^{-1}) up to 7.818 (t ha^{-1}) with an average of 3.833 (t ha^{-1}). However, aboveground carbon stock in *R. mucronata* stands varied among stands, i.e. it ranged from 9.569 (ton ha^{-1}) to 313.025 (ton ha^{-1}) with an average of 116.399 (ton ha^{-1}). Similarly, blue carbon stock in *C. tagal* stands was much lower than that of other mangroves. Stem carbon stock ranged from 1.645 (ton ha^{-1}) to 34.772 (ton ha^{-1}) with an average of 14.125 (t ha^{-1}). Branch carbon ranged 0.318 (t ha^{-1}) to 18.935 (ton ha^{-1}) with an average of 6.621 (ton ha^{-1}). Carbon stock in leaf ranged 0.153 (t ha^{-1}) up to 3.701 (ton ha^{-1}) with an average of 2.096 (t ha^{-1}). However, aboveground blue carbon stock in *C. tagal* stands varied among stands, i.e. it ranged from 2.116 (ton ha^{-1}) to 57.323 (ton ha^{-1}) with an average of 22.842 (ton ha^{-1}). Therefore, blue carbon stock unprotected mangroves forests was much lower than that of protected mangroves. Higher blue carbon loss was happen on unprotected mangrove due to mangrove land conversion. This study realized the important of mangroves as blue carbon stock. [12] stated that the carbon fixation capacity of mangrove forests is higher than that of the terrestrial forest. For this reason, mangroves have been considered as an important carbon sink in coastal ecosystems [13] (Ong, 1993). Thus, although mangrove forests occupy less than 1 % of tropical forested areas but account for approximately 3 % of global carbon sequestration by tropical forests [14]. Our results of carbon stock comparable as reported by [14] that ecosystem C stocks ranged from 570 Mg C ha-1 in the Pacific coast to ~1000 Mg C ha-1 in Caribbean coast and the Bay Islands. However, ecosystem C stocks on the basis of mangrove structure were 1200, 800 and 900 Mg C ha^{-1}, in low, medium and tall mangroves, respectively [14]. Meanwhile, there were no significant differences in ecosystem C stocks on the basis of location for Pacific coast, Caribbean coast and Bay Islands, even among mangrove structure [14]. On the contrary, the carbon stock on mangrove forest in coral triangle eco-region of Southeast Sulawesi seemed to associate with forest structure, stands age as well mangrove destruction. The lower carbon stock was found in unprotected mangroves. It seemed that higher blue carbon loss was happen in unprotected mangrove forest, which approximated about 73.99 (ton ha^{-1}) in *C. tagal* forest and 299.51 (ton ha^{-1}) in *R. apiculata* forest. Low blue carbon stock on unprotected mangrove will have negatively impact on productivity of coastal areas in this region. On the other hand, higher blue carbon stock indicated pure stands or undisturbed mangrove areas, which will support the coastal productivity. Therefore, protected mangroves in the coral triangle eco-region are stocked high blue carbon.

Table 1. Trends of carbon in stem, branch/twig, leaf of *Ceriops tagal* stands

Stands	Stem carbon (t ha^{-1})	Branch carbon (t ha^{-1})	Leaf carbon (t ha^{-1})	Aboveground carbon (t ha^{-1})
1	88.29	24.86	8.26	121.41
2	23.33	7.43	2.21	32.97
3	19.28	3.98	1.76	25.02
4	55.48	29.45	5.47	90.40
5	30.11	9.06	2.84	42.01
6	38.96	12.96	3.69	55.60
7	43.31	19.94	4.22	67.47
8	35.62	14.94	3.45	54.00
9	102.48	53.51	10.10	166.09
10	59.28	30.10	5.83	95.21
11	54.01	24.36	5.26	83.62
12	73.39	18.08	6.80	98.27

13	85.21	27.05	8.06	120.31
14	132.02	49.33	12.66	194.01
15	140.51	52.03	13.43	205.97
Average	**65.42**	**25.14**	**6.27**	**96.83**

Table 2. Trends carbon stock in stem, branch/twig, and leaf of *Rhizophora apiculata* stands

Stands	Stem carbon (t ha^{-1})	Branch carbon (t ha^{-1})	Leaf carbon (t ha^{-1})	Aboveground carbon (t ha^{-1})
1	394.06	97.35	11.55	502.95
2	84.36	29.31	6.33	120.00
3	199.65	58.73	9.55	267.94
4	319.88	82.76	10.41	413.05
5	252.20	69.68	9.74	331.61
6	384.90	100.01	12.27	497.19
7	533.50	134.91	16.08	684.49
8	256.00	66.48	8.42	330.91
9	331.39	81.33	9.14	421.85
10	433.88	108.64	12.79	555.30
11	157.58	40.54	5.79	203.90
12	311.87	90.99	14.03	416.90
13	415.79	108.55	13.84	538.19
14	319.21	84.68	11.14	415.03
15	346.98	94.56	12.81	454.35
16	267.30	74.95	10.82	353.07
17	332.02	95.42	14.27	441.71
18	143.53	42.05	6.67	192.26
Average	304.67	81.16	10.87	396.71

Table 3. The trends in carbon stock of stem, branch/twig and leaves of *Rhizophora mucronata* stands

Stands	Stem carbon (ton ha^{-1})	Branch carbon (ton ha^{-1})	Leaf carbon (ton ha^{-1})	Aboveground carbon (ton ha^{-1})
1	48.67	30.12	6.03	84.82
2	140.85	106.60	12.97	260.42
3	87.73	56.31	10.29	154.33
4	107.68	81.16	10.02	198.86
5	110.97	78.37	11.39	200.73
6	22.06	14.37	2.53	38.96
7	103.99	75.71	10.25	189.96
8	58.96	40.97	6.10	106.03
9	70.03	49.70	7.08	126.81
10	58.18	42.81	5.57	106.56
Average	**80.91**	**57.61**	**8.22**	**146.75**

Tabel 4. Trend of blue carbon stock in mangrove forest outside of RAWN Park

Stands	Mangroves	WS (ton ha^{-1})	WB (ton ha^{-1})	WL (ton ha^{-1})	W (ton ha^{-1})
1		2.876	1.752	0.981	4.628
2		13.174	6.718	2.913	19.892
3		56.669	24.534	7.933	81.203
4		0.613	0.444	0.333	1.057
5		173.781	55.305	10.089	229.087
6		53.611	19.500	4.506	73.111
7	*R. apiculata*	71.560	24.867	5.275	96.427
8		49.211	15.910	2.980	65.121
9		177.416	49.876	7.855	227.293
10		4.994	2.591	1.126	7.585
11		69.212	24.287	6.171	93.499
12		30.510	12.887	4.276	43.397
13		23.702	9.975	3.185	33.677
14		91.809	31.308	7.079	123.117
15		90.656	28.211	5.463	118.867
	Average	**60.653**	**20.544**	**4.678**	**81.197**
1		84.644	22.452	4.161	111.257
2		239.582	65.624	7.818	313.025
3		10.645	2.734	0.816	14.195
4		67.040	17.719	3.887	88.646
5		172.328	46.866	6.165	225.359
6		134.917	36.677	5.108	176.702
7		63.024	16.623	3.373	83.019
8	*R. mucronata*	145.886	39.330	6.028	191.243
9		123.752	33.370	5.152	162.274
10		5.976	2.734	0.860	9.569
11		22.316	7.200	1.221	30.737
12		22.121	7.685	1.604	31.410
13		63.244	17.027	2.562	82.833
14		78.424	25.983	4.906	109.313
	Average	**88.136**	**24.430**	**3.833**	**116.399**
1		5.702	0.974	0.526	7.202
2		26.743	12.726	2.716	42.185
3		5.948	1.206	0.557	7.711
4		1.645	0.318	0.153	2.116
5	*C. tagal*	34.772	18.935	3.616	57.323
6		15.376	5.346	1.523	22.245
7		17.407	8.837	3.701	29.946
8		13.000	6.883	3.120	23.004
9		7.722	4.213	2.037	13.972
10		12.939	6.767	3.010	22.716
	Average	**14.125**	**6.621**	**2.096**	**22.842**

Tabel 5. Green tea compounds on levaes for 3 mangrove species

No	Mangroves	Catechins (%)	Simple Polyphenol (%)	Flavonoid (%)
1	*Rhizophora apiculata*	0.81	4.81	
2	*R. mucronata*	1.14	6.41	
3	*Ceriops sp*	1.83	5.58	1.13

3.3. Mangroves green tea compounds

Green tea compounds on mangroves leaves represented by Table 5. Concentrations of catechins and flavonoid compounds vary in mangroves *Ceriops* sp, *Rhizophora apiculata* and *R. mucronata*. The concentration of catechins on mangroves leaves was about 0.81% for *Rhizophora apiculata*, 1.14% for *R. mucronata*, and about 1.83% for *Ceriops* sp. On the other hand, the concentration of simple polyphenol was much higher in the leaves those of mangroves, which was about 4.81%, 6.41% and 5.58% in leaves of *R. apiculata*, *R. mucronata* and *Ceriops* sp, respectively. However, the flavonoids were found only in leaves of *Ceriops* sp with lower concentration (1.13%). This study realized that new leaves of these mangroves have high potentiality to use as green tea material. The compounds of tea are polyphenols that are plant metabolites produced to against insects and other animals and are the most abundant compounds in tea comprising as much as 30-40% of both freshly plucked tea leaves and solids in tea liquor [15], which are derived from amino acids via sunlight and therefore tea grown in the shade has a smaller concentration of polyphenols and a higher concentration of amino acids [16]. However, concentration of green tea compounds are known to associate with leaves sequence plant leaves with the bud and first leaf have the highest concentration of polyphenols [16]. The flavonoids are arguably the most important group of polyphenols in tea and are the source of the many health claims surrounding tea, and specifically tea antioxidants [17]. The major flavanols in tea are catechin, epicatechin, epicatechin gallate, gallocatechin, epigallocatechin, and epigallocatechin gallate [15]. In addition, they argued that tea flavonoids also include flavonols, flavones, isoflavones, and anthocyanins; all of which contribute to the color of a tea's infusion and its taste.

4 Conclussions

Our present study provide important analysis for elucidation the blue carbon stock and new potential uses of mangroves as source of green tea material. Higher aboveground carbon stock was found in protected mangroves forest. However, higher blue carbon loss was happen in unprotected mangrove forest, which will have negatively impact on productivity of coastal areas in this region. On the other hand, higher blue carbon stock indicated pure stands or undisturbed mangrove areas, which will support the coastal productivity. Meanwhile, the mangroves in this coral triangle eco-region have potentiality as green tea material as of contains compounds catechin, simple polyphenol and flavonoid. Therefore, the mangroves in the coral triangle ecoregion are important as blue carbon stock and might be potential to use as green tea material.

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