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WHAT IS THE TRUE CARBON FRACTION VALUE OF MANGROVE BIOMASS?

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Abstract: Carbon stock in mangrove stands is estimated through the biomass approach multiplied by the value of the mangrove carbon fraction which is generally set at 47% for all mangrove species to represent the actual carbon content value. This literature review analyzed relevant articles from Science Direct and Google Scholar using keywords: mangrove biomass, mangrove carbon stock, organic carbon of mangrove, carbon fraction of mangrove biomass, and chemical composition of mangrove biomass. The results showed that the carbon fraction value calculated based on organic carbon content was 46.4% which was lower than one calculated based on compounds making up mangrove biomass of 46.82% which consisted of 26.20% carbohydrates, 2.97% amino acids, 3.22% tannins, 3.38% lignins, 7.69% fatty acids, 3.17% triterpenoids, and 0.19% n-alkanes. The estimated homogeneous mangrove species carbon stock in a forest can be calculated based on the value of the carbon fraction of each mangrove species of 46.3% for B. gymnorrhiza, 45.9% for R. apiculata, and 47.1% for S. alba. Meanwhile, a carbon fraction value of 46.82% can be used for all true mangrove species to estimate the carbon stock in forests with heterogeneous mangrove species.

Keywords: *Carbohydrates, carbon fraction, carbon stock, mangrove, wood organic content.*

1. Introduction

Mangrove forests strongly contribute to the preventions of climate change for having the ability to absorb carbon dioxide (CO2) in the atmosphere through photosynthesis. The absorbed CO2 is then stored in the form of biomass in tree stands, fruit, roots, leaves, and other parts (Alongi 2008; Mandala et al., 2012; Alongi & Mukhopadhyay, 2015; Rahman et al., 2020b).

Mangroves also store huge amount of carbon in the substrate from the accumulation of residues from litters (Donato et al., 2012; Adame et al., 2015). Mangroves can absorb carbon three to four times better than other plants (Alongi 2008; Alongi 2014; Adame et al., 2015).

Carbon stock estimation in mangrove substrates can be made by analyzing the organic carbon content in sediments named total organic carbon (Komiyama et al., 2005). Meanwhile, carbon stock estimation in mangrove stands uses mangrove biomass value multiplied by mangrove carbon fraction value (Kauffman & Donato 2012).

Carbon fraction is the amount of carbon value of mangrove biomass. The mangrove carbon fraction values range between 46 – 51% (Kauffman & Donato 2012). Research on the carbon stocks estimation in mangrove stands have been carried out in different places in the world using destructive method in developing allometric equations to estimate the biomass in each mangrove species (Clough & Scott 1989; Fromard et al., 1998; Ong et al., 2004; Komiyama et al., 2005; Kusmana et al., 2018; Analuddin et al., 2020). After the biomass equation is obtained, the carbon stock value is calculated by multiplying the biomass value by the carbon fraction value. Most researchers used a mangrove carbon fraction value of 47% or 0.47 for all mangrove species despite the complete explanation of how the value was determined was unclear. In fact, mangrove biomass stock stored through photosynthesis is not only in the form of glucose (C6H12O6), instead several chemical compounds such as carbohydrates, tannins, fats, proteins, and other chemical compounds are also found. Each chemical compound contains a certain percentage of carbon thereby carbon stock estimation should be based on the accumulation of carbon percentage from each component of the compound that makes up mangrove biomass. The accumulation can be measured using a mass ratio approach to weigh every element according to its number and atomic mass.

The use of the carbon fraction value in estimating the carbon stock of mangrove stands should be based on the actual value of the carbon content. The difference in the value of the carbon fraction of more than 0.1% will significantly affect the results because the mangrove carbon stock can reach 956 mg C ha-1. Thus, even 0.1% difference can either increase or decrease the estimated value by 0.956

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Mg C ha-1 or equivalent to 956 kg C ha -1. Regarding these concerns, the actual value of the carbon fraction needs to be calculated to obtain more accurate carbon stock estimation results of mangrove stands.

2. Methodology

2.1 Literature Search

Relevant scientific articles published up to 2022 were retrieved from Science Direct and Google Scholar based on several keywords: mangrove biomass, mangrove carbon stock, organic carbon of mangrove, carbon fraction of mangrove biomass, and chemical composition of mangrove biomass. The articles were then screened based on the titles and abstracts. Only articles with full-text available were included, and a number of articles with low relevancy were excluded. Research on mangrove biomass has been done from 1986 (Putz & Chan 1986) to 2022 (Hasidu et al., 2022). However, they did not provide overview of the actual carbon fraction value in estimating the mangrove biomass and carbon stock. There were 3 journal articles published between 2008 - 2011 that matched the inclusion criteria to provide relevant information regarding mangrove carbon fraction value.

3. Results and Discussions

3.1 Carbon Fraction Based on Organic Carbon Content

Carbon fraction value is expressed in a percentage calculated by comparing the mass of organic carbon to the total biomass value. The carbon fraction is also known as wood carbon content (Kauffman et al., 2011). The value of carbon fraction in each mangrove species differs due to different wood density value of each mangrove species. Kauffman et al., (2011) reported that the carbon fractions for *B. gymnorrhiza, R. apiculata*, and *S. alba* species were 46.3%, 45.9%, and 47.1%, respectively. Meanwhile, the average value of carbon fraction for all species has been set at 46.4% (Table 1). The carbon fraction is the fraction value estimated based on the total organic carbon content in mangrove biomass.

The values of the carbon fraction, especially in *B. gymnorrhiza* and *R. apiculata* species, are much lower than the 47% value that is often used by researchers in estimating mangrove carbon stocks. The value of 47% is closer to the species S. alba (47.1) with 0.1% difference that is known to affect the true estimated carbon stock value of mangrove stands.

Mangrove forests generally consist of variety mangrove species that form zoning based on the character of the substrate or salinity (Rahman et al., 2017; Rahman et al., 2020b). Therefore, Kauffman et al., (2011) stated that the estimated mangrove carbon stock should be calculated based on the carbon fraction value of every species or based on the average value of 46.4% of all mangrove species. The value of 46.4% is much lower than the value of the carbon fraction which is often used in estimating the carbon stock of mangrove stands of 47%. Based on these differences, the estimated results of the mangrove carbon stock experienced an excess of 0.6% or equivalent to 5,736 Mg C ha^{-1}.

Although Kauffman et al., (2011) have reported the value of the carbon fraction in several mangrove species, information on the composition of compounds that make up mangrove biomass containing the C element remain unavailable, thereby the value cannot describe the actual carbon fraction value. This value was calculated based on the weight of organic carbon content in mangrove biomass without decomposing the components of the constituent compounds of mangrove biomass.

Table 1. The carbon fraction values of different mangrove species

Species	Carbon Fraction (%)
Bruguiera gymnorrhiza	46.3
Rhizophora apiculata	45.9
Sonneratia alba	47.1
Average of all species	46.4

Source: Kauffman et. al., (2011)

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3.2 Carbon Fraction Based on Compounds Composing Mangrove Biomass

The mangrove biomass stored in mangrove stands results from the photosynthesis process that occurs in the leaves and pneumatophore organs at the roots and the absorption of salts by root fibers through the xylem and phloem. Kristensen et al., (2008) found that mangrove biomass was composed of 65.5% carbohydrates, 9% protein, 6% tannins, 5.1% lignin, 10.68% fatty acids, 3.5% triterpenoids, and 0.22% n-alkane (Figure 1).

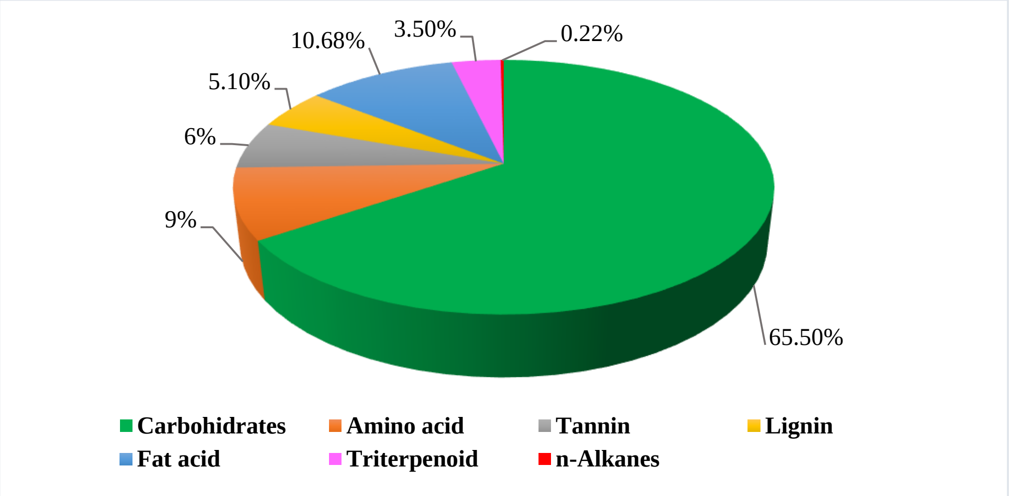

Figure 1. Chemical components of mangrove biomass

The components of biomass are relatively similar to *Bruguiera*, *Rhizophora*, and *Sonneratia* species, with slight difference only in the n-alkane of 26 – 31 n-alkanes (C_nH_{2n+2}, with n = 26 – 31). However, the percentage of n-alkanes in mangrove biomass is only around 0.22% thereby this different n-alkanes structure can be ignored.

3.2.1 Carbohydrate

Carbohydrates are the largest component of mangrove biomass found in mangrove tree stands, especially *Bruguiera, Rhizophora,* and *Sonneratia* species with 65.5% (Kristensen et al. 2008). Carbohydrates are compounds composed of glucose ($C_6H_{12}O_6$) and have the basic molecular formula ($C_6H_{12}O_6$)n. Based on the chemical formula, the molecular mass of the carbohydrate compound is 180 g mole^{-1} (Mr = (180)n g mole^{-1}). From a total of 180 g mole^{-1}, there are 72 g mole^{-1}, C atoms, or equivalent to 40% obtained from 6 C atoms with a relative atomic mass (Ar) of 12 g mole^{-1}.

Mangrove carbon fraction from carbohydrate compounds is calculated by multiplying the percentage of carbohydrates in mangrove biomass (65.5%) by the total mass of carbon in carbohydrates (40%), resulting in 26.20% (Table 2).

3.2.2 Amino Acid

The amino acid content in mangrove biomass is 9% which is mostly found in mangrove leaves, especially in *Bruguiera, Rhizophora,* and *Sonneratia* (Hernes et al., 2001). Amino acids are the smallest structures of protein compounds with the basic molecular formula of ($C_2H_3O_2N$)n. Based on the chemical formula, the molecular mass of the amino acid compound is 73 g mole^{-1} (Mr = (73)n g mole^{-1}). From a total of 73 g mole^{-1}, there are 24 g mole^{-1} C atoms or equivalent to 33% obtained from 2 C atoms with a relative atomic mass (Ar) of 12 g mole^{-1}.

Mangrove carbon fraction of amino acid compounds was calculated by multiplying the percentage of amino acids in mangrove biomass (9%) by the total mass of carbon in amino acids (33%), resulting in carbon contribution of amino acids in mangrove biomass of 2.97% (Table 2).

3.2.3 Tannin

The tannin content in the mangrove biomass is 6%. These levels are mostly found in mangrove leaves, especially from the *Bruguiera* species (Hernes et al., 2001). Tannins are compounds composed of polysaccharides with the molecular formula ($C_{38}H_{26}O_{23}$)n. The molecular mass of the tannin compound is 850 g mole^{-1} (Mr = (850)n g mole^{-1}). Out of 850 g mole^{-1}, there are 456 g mole^{-1} C atoms or equivalent to 53.65% obtained from 38 C atoms with a relative atomic mass (Ar) of 12 g mole^{-1}.

The mangrove carbon fraction from tannin compounds was calculated by multiplying the percentage of tannins in mangrove biomass (6%) by the total mass of carbon in tannins (53.65%) resulting in total carbon contribution of tannins in mangrove biomass of 3.22% (Table 2).

3.2.4 Lignin

Mangrove biomass contains 5.1% lignin found in the leaves and stands of mangrove trees, especially from true mangrove species such as Rhizophora, Avicennia, and Sonneratia (Marchand et al., 2005). Lignin is a co-polymer compound with free nitrogen that contains variety of phenylprophenyl alcohols. The molecular formula of lignin is $C_9H_{10}O_2(OCH_3)$n. The molecular mass of the lignin compound is 150 + (31)n g mole^{-1} (Mr = 150(31)n g mole^{-1}). From a total of 150 + (31)n g mole^{-1} there are 108 + (12)n g mole^{-1} C atoms or equivalent to 66.3% obtained from 9 C atoms + n C atoms with relative atomic masses (Ar) of 12 g mole^{-1}.

The mangrove carbon fraction from lignin compounds was calculated by multiplying the percentage of lignin in mangrove biomass (5.1%) by the total mass of carbon in lignin

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(66.3%), resulting in total carbon contribution of lignin in mangrove biomass of 3.38% (Table 2).

3.2.5 Fatty Acids

Fatty acids are the second-largest compound found in mangrove biomass that reached 10.68% and are mostly found in mangrove leaves and fruit, especially from true mangrove species such as Rhizophora, Avicennia, and Sonneratia. Fatty acids have the molecular formula of $C_{11}H_{23}COOH$ with molecular mass of 200 g mole^{-1} (Mr = 200 g mole^{-1}). From a total of 200 g mole^{-1}, there are 144 g mole^{-1} C atoms, or the equivalent of 72% obtained from 10 C atoms with a relative atomic mass (Ar) of 12 g mole^{-1}.

Mangrove carbon fraction from fatty acid compounds is calculated by multiplying the percentage of fatty acids in mangrove biomass (10.68%) by the total mass of carbon in fatty acids (72%), resulting in a total carbon contribution of fatty acids in mangrove biomass of 7.69% (Table 2).

3.2.6 Triterpenoid

Triterpenoids are hydrocarbons composed of C and H atoms that reached 3.5% in mangrove biomass (Kristensen et al. 2008). These compounds are mostly found in mangrove leaves, especially from true mangrove species such as Rhizophora, Avicennia, and Sonneratia. Triterpenoids have the molecular formula of $C_{38}H_{48}$ with 504 g mole^{-1} molecular mass (Mr = 504 g mole^{-1}). There are approximately 456 g mole^{-1} C atoms or the equivalent of 90.47% obtained from 38 C atoms with a relative atomic mass (Ar) of 12 g mole^{-1}.
The mangrove carbon fraction of triterpenoid compounds was calculated by multiplying the percentage of triterpenoids in mangrove biomass (3.5%) by the total mass of carbon in fatty acid (90.47%), resulting in total carbon contribution of 3.17% in mangrove biomass (Table 2).

3.2.7 n-Alkanes

n-Alkanes are hydrocarbons composed of C and H atoms which carbon chain length ranges between 22 and 35. In general, the length of the carbon chain of n-alkanes found in mangroves is 31 carbon chains and n-alkanes content in mangrove biomass is 0.22%. The compound has the least proportion in mangrove biomass which is mostly found in mangrove leaves, especially from true mangrove species such as *Rhizophora, Avicennia,* and *Sonneratia* (Versteegh et al., 2004; Mead et al., 2005). n-Alkanes have the molecular formula of CnH2n+2 and molecular mass with chain length C=31 is 436 g mole^{-1} (Mr = 436 g mole^{-1}). There are 372 g mole^{-1} C atoms or equivalent to 85% obtained from 31 C atoms with a relative atomic mass (Ar) of 12 g mole^{-1}.

The mangrove carbon fraction of the n-alkanes compound is calculated by multiplying the percentage of n-alkanes in mangrove biomass (0.22%) by the total mass of carbon in n-alkanes (85%), resulting in 0.19 total carbon contribution of n-alkanes in mangrove biomass (Table 2).

The total value of the mangrove carbon fraction is 46.82% consisting of carbohydrates (26.20%), amino acids (2.97%), tannins (3.22%), lignins (3.38%), fatty acids (7.69%), triterpenoids (3.17 %), and n-alkanes (0.19%) (Table 2). The value of the carbon fraction can be used in evaluating the carbon stock of mangroves in heterogeneous forests. The value of the carbon fraction gained using organic carbon content approach is 46.4% (Kauffman et al., 2011) that is approximately 0.42% lower than the value of the carbon fraction calculated based on the components that make up mangrove biomass of 46.82%. The estimated mangrove carbon stocks from palm species such as *N. Fruticans* is 39% can be used (Rahman et al., 2017; Rahman et al., 2020a).

Table 2. The value of carbon fraction in mangrove biomass

Compounds*	% compounds in litter*	Basic molecular formula	Mr of compound	Ar of C	% C in compound	% C in litter
Carbohydrate	65.5	$(C_6H_{12}O_6)n$	(180)n	(72)n	40	26.20
Amino acid	9	$(C_2H_3O_2N)n$	(73)n	(24)n	33	2.97
Tannin	6	$(C_{38}H_{26}O_{23})n$	(850)n	(456)n	53.65	3.22
Lignin	5.1	$C_9H_{10}O_2(OCH_3)n$	150+(31)n	108(12)n	66.3	3.38
Fatty acid	10.68	$C_{11}H_{23}COOH$	200	144	72	7.69
Triterpenoid	3.5	$C_{38}H_{48}$	504	456	90.47	3.17
n-Alkane	0.22	C_nH_{2n+2}	$_{n=31}$, 436	372	85	0.19
Total						46. 82%

Notes: *Sources: Hernes et al., (2001); Versteegh et al., (2004); Marchand et al., (2005); Mead et al., (2005); Kristensen et al. (2008); Ar = relative mass of atom (C = 12, O = 16, H = 1, N = 14), Mr = relative mass of compounds

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3.3 Chemical Elements of Mangrove Biomass

The chemical elements that makeup mangrove biomass consist of carbon (C), oxygen (O), hydrogen (H), and nitrogen (N). Elements C, O, and H obtained through photosynthesis – a process where CO_2 from the atmosphere is absorbed and stored in the mangrove biomass as carbohydrates, amino acids, tannins, lignin, fatty acids, triterpenoids, and n-alkanes. Meanwhile, the element N is calculated from the absorption of mineral salts by the xylem and phloem tissues in the roots. The N content is stored in the mangrove biomass as amino acids or proteins.

Based on the percentage of compounds, relative molecular mass, and relative atomic mass of compounds and elements that make up mangrove biomass, the value of the composition of C elements is 46.82%, O elements is 44.54%, H elements is 6.92%, and N elements is 1,72% (Figure 2). The composition of these constituent elements further emphasizes that the actual value of the carbon fraction of mangrove biomass is 46.82%.

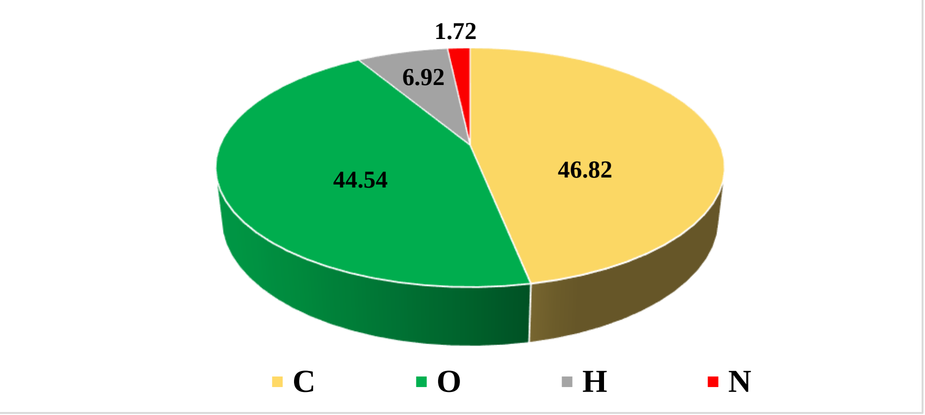

Figure 2. Composition of chemical elements that make up mangrove biomass

4. Conclusions

The value of the carbon fraction determined based on the organic carbon content is 46.4%, or about 0.42% lower than the value of the carbon fraction calculated based on the components of the compounds that make up mangrove biomass of 46.82%, which consists of carbohydrates (26.20%), amino acids (2.97%), tannin (3.22%), lignin (3.38%), fatty acid (7.69%), triterpenoids (3.17%), and n-alkanes (0.19%). The estimation of the carbon stock of mangrove trees in forests with homogeneous species can use the value of the carbon fraction of 46.3% for B. gymnorrhiza, 45.9% for R. apiculata, and 47.1% for S. alba. Meanwhile, to estimate the carbon stock of mangrove trees in forests with heterogeneous mangrove species, a carbon fraction value of 46.82% can be used for all true mangrove species found in the forest. Whereas, the carbon fraction value of 39% applies in the estimation of mangrove carbon stock from palm species such as N. fruticans.

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