Carbon stock assessment of mangrove ecosystem in Totok Bay, southeast Minahasa Regency, North Sulawesi, Indonesia

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Abstract. This study aims to analyze the blue carbon potential of mangrove ecosystem in Totok Bay waters, Southeast Minahasa Regency, North Sulawesi, using line transect method with 10 x 10 m^2 quadrat placed seaward perpendicular to the shore. Preliminary survey observation found 3 species of mangrove, *Rhizophora mucronata, Avicennia alba* and *Bruguiera gymnorhiza*. Vegetation analysis was to determine the role of mangrove species using Important Value Index (IVI). IVI obtained was 147.47% for *R. mucronata*, 60.99% for *A. alba*, and 91.53% for *B. gymnorhiza,* respectively. Biomass measurements provided information on carbon stock. Data obtained was analyzed using allometric equation. Results showed that mean carbon stock of the mangrove biomass in Totok Bay was 17.1 kg MgC ha^{-1}. Physical and chemical parameters analyses were also conducted as supporting data of carbon stock. Mean total carbon sink in mangrove sediment was 286.18 Mg ha^{-1}. Mean blue carbon potential absorption was 193. 28 ton C ha^{-1}. This research showed that mangrove ecosystem in Totok Bay held sufficiently high carbon stock. Nevertheless, the future study needs to be directed to carbon stock comparison with other locations in North Sulawesi.

Key Words: biomass, line transect, carbon stock, species dominance, Important Value Index.

Introduction. The potential for marine and coastal resources is abundant, and one of them is mangrove ecosystem. Indonesia has the largest mangrove ecosystem in the world after Canada (Giri et al 2011) which is a typical forest along the coast or estuaries affected by sea water tides. Mangroves grow in sheltered beaches or flat beaches, usually along the side of the island protected from wind or behind the coral reefs (Howard et al 2014; Paruntu et al 2017). Mangroves also have very important ecological roles, especially for coastal areas. One of the ecological functions is to play a role in mitigating global warming due to mangroves as carbon storage (Donato et al 2011; Murdiyarso et al 2015; Marchand 2017; Kepel et al 2017).

Mangrove ecosystem is one of the resources to reduce carbon dioxide (CO_2) emissions through photosynthesis (Komiyama et al 1988; Lee 1989, 1990; Ross et al 2001; Sherman et al 2003; Khan et al 2005), in which mangroves can bind and store carbon dioxide in the ecosystem (Wang et al 2013). Global warming is now a major environmental issue because it has a huge impact on the world that affects the climate change and sea level rise. Increasing the concentration of carbon dioxide in the atmosphere is one of the biggest causes of the global warming (Nelleman et al 2009; Naspriantoet al 2016). Mangroves play an important role to the total carbon budget (Kauffman et al 2011; Jardine & Siikamäki 2014). This article focuses on analyzing the potential of blue carbon in the mangrove ecosystem in Totok Bay, Southeast Minahasa Regency, to see the carbon stock in the coastal waters of North Sulawesi.

Material and Method

Site description. The research was conducted in Totok Bay, Southeast Minahasa Regency, North Sulawesi Province (Figure 1). Survey and tree sampling were carried out from February to June 2014. The mangrove ecosystem of Totok Bay consisted of natural mangroves and mangroves planted by local communities in 2001. The purpose of mangrove planting by local people is to prevent coastal abrasion and to support biological productivity. The natural mangroves and mangroves planted by local people are in good condition. The mangroves species in Totok Bay are dominated by *Rhizophora* sp. which is called as "Posi-posi" in the local language. Sediment sampling was also conducted to analyze the carbon content.

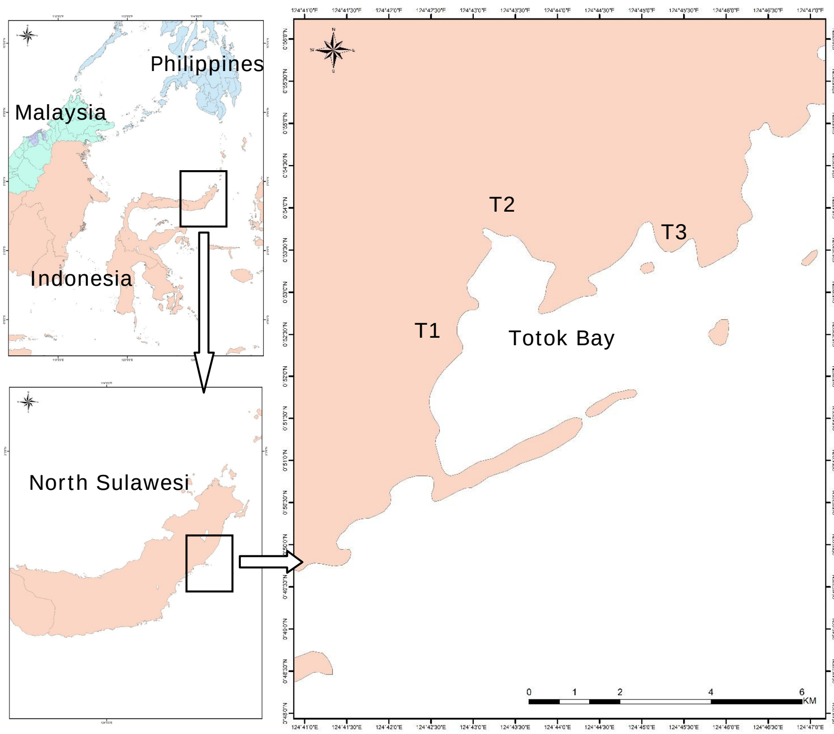

Figure 1. Location of Totok Bay Mangrove with the position of transects T1, T2 and T3.

Data collection. Three perpendicular transect lines were established randomly from the coast to the land of Totok Bay mangrove and used different length. Transect 1 (0°51'32.07"N 124°42'21.79"E) was laid 250 m distant from the shoreline to the end of the mangrove and transect 2 (0°53'47.70"N 124°43'4.29"E) was 125 m, and transect 3 (0°53'48.99"N 124°45'4.48"E) was 125 m. A total of 20 plots (10 m x 10 m) were placed at each 10 m distance along the transect line in order to determine species composition and diversity of the stand. Species name and diameter at breast height (DBH) bigger than 10 cm diameter were recorded as well. The procedure followed Kauffman & Donato (2012) and Ati et al (2014).

Data analysis. The Important Value Index (IVI) of mangrove species in a community is one of the parameters showing the role of mangroves in the community. The IVI was calculated by totalling the relative density, relative cover, and relative frequency. Allometric equations for Southeast Asian mangroves developed by Fromard et al (1998), Komiyama et al (2005), and Kauffman & Donato (2012) and were used in the estimation of the above-ground biomass (Wagb) and root biomass (WR). The following common allometric equations were used (Table 1).

Table 1

Allometric equations for calculating mangrove biomass

Species	*Equation*	*Source*
Avicennia alba	$B = 0.251\ \rho\ (D)^{2.46}$	Komiyama et al (2005)
Bruguiera gymnorhiza	$B = 0.0754D^{2.505*}\rho$	Kauffman & Donato (2012)
Rhizophora mucronata	$B = 0.128(D)^{2.60}$	Fromard et al (1998)

Results and Discussion

Species composition. Observations in transect I, II and III found 3 (three) mangrove species, *R. mucronata, A. alba* and *B. gymnorhiza*. There were also some other species in the study area, but not recorded in the transect, because the survey was not specifically designed to locate all mangrove species. This survey was also time consuming, and very high mangrove density made it difficult to reach certain sampling points.

Based on the analysis of mangrove vegetation at each transect, the relative density (RDi), the relative frequency of type (RFi) and the relative closure type (RCi), an important value of a mangrove species at the tree level was obtained. The species found taking the most important role in the research location were *R. mucronata* with an IVI of 165.39, *A. alba* with an IVI of 71.89 and *B. gymnorhiza* with IVI of 62.71. Important density value of mangrove ecosystem of Totok Bay, North Sulawesi is presented in Table 2. Furthermore, the data revealed that *R. mucronata* had relative cover of 16.97%), relative density of 85.25%, and relative frequency of 63.161%. Shah et al (2016) found that *R. apiculata* with the highest IVI tended to have high relative cover, relative density, and relative frequency. It is different from the present study, in which the highest IVI of *R. mucronata* in Totok Bay had low relative cover. It could result from that the IVI value is obtained from totalling the values of relative cover, relative density, and relative frequency. Relatively high density of *R. mucronata* is imposed in transect 3 that has muddy sand substrate. This type of substrate also becomes one of the substrate types preferred by *Rhizophora* sp. In general, genus *Rizhophora* can grow well on muddy soils (Setyawan & Ulumuddin 2012; Paruntu et al 2017).

Table 2

Importance Value Index of mangrove ecosystem in Totok Bay, North Sulawesi

Species	*Rdi*	*Rfi*	*RCi*	*IVI*
Rhizophora mucronata	85.25483	63.16138	16.97588	165.3921
Avicennia alba	8.158533	18.71693	35.83947	62.71493
Bruguiera gymnorhiza	6.586639	18.12169	47.18465	71.89298

Note: RDi = relative density; RFi = relative frequency; RCi = relative cover; IVI = Importance Value Index.

Mangrove biomass of Totok Bay. Mean mangrove biomass in transect 1 was the highest among transects, 14.26 Mg ha^{-1}. The allometric equation-based above-ground biomass assessment showed that *R. mucronata* had a range of 77.5-136.4 Mg ha^{-1} as the highest, then *A. alba*, 3.8-51.1 Mg ha^{-1}, and *B. gymnorhiza*, 1.5-5.5 Mg ha^{-1}, respectively (Figure 2). The biomass value was obtained from the extent of species density and the size of tree rim.

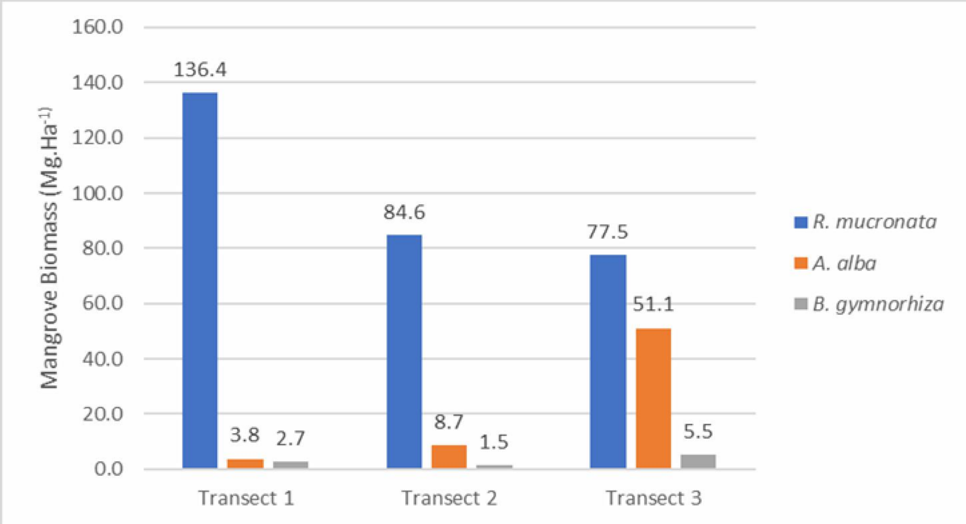

Figure 2. Mangrove biomass among transects (Transect 1, Transect 2 and Transect 3) in Totok Bay waters.

Furthermore, the highest density of *R. mucronata* also showed the highest biomass, However, tree diameter influenced the size of biomass with species as well. Figure 3 demonstrates that in transect 1, *R. mucronata* possessing high mean diameter has also the highest biomass among the dominant species as found in this study. Thus, tree density or tree diameter could influence the biomass as shown by *B. gymnorhiza* in transect 3.

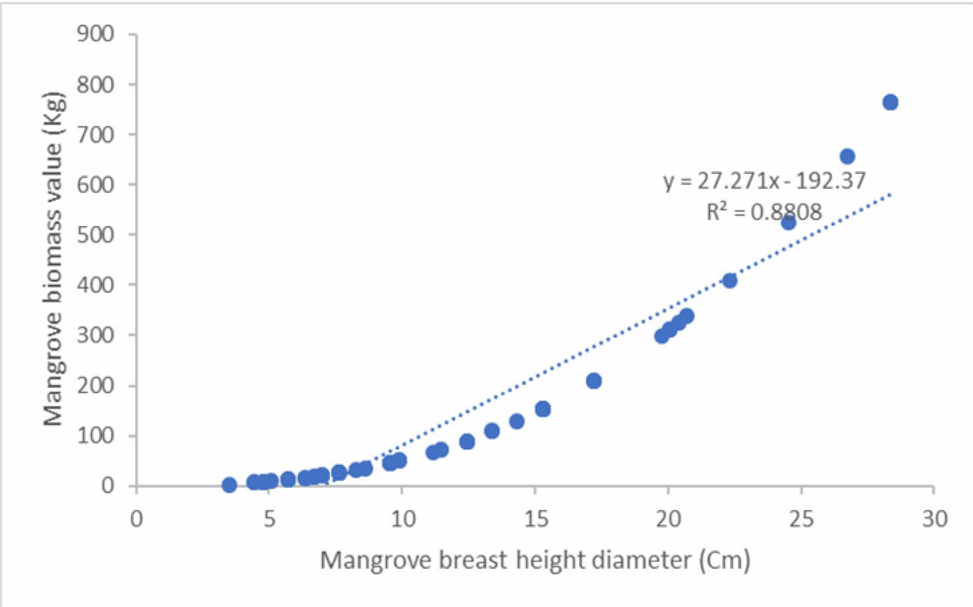

Figure 3. Relationship of breast height diameter with mangrove biomass value.

Figure 3 shows that the bigger the the breast height diameter (BHD) is, the bigger the tree biomass will be. Determination coefficient (R^2) is 0.8808, indicating that about 87% of BHD could affect the mangrove biomass in this area. Mangrove ecosystem is a type of coastal ecosystem possessing high productivity. Castaneda-Moya et al (2013) found that mangrove productivity in Florida, United States is 17.0±1.1 Mg ha^{-1} y^{-1} and even in Bangladesh it was 21.0 Mg ha^{-1} yr^{-1} (Kamruzzaman et al 2017).

Carbon stock of mangrove ecosystem. Carbon sink of the mangrove in Totok Bay, North Sulawesi, ranged from 35.7 to 62.7 MgC ha^{-1} for *R. mucronata*, 1.8 to 23.5 MgC ha^{-1} for *A. alba*, and 0.7 to 2.5 Mg C ha^{-1} for *B. gymnorhiza*, respectively (Figure 4). Mean carbon contained was 63.7 MgC ha^{-1}. It is slightly higher than that reported by Ati et al (2014) in Tanjung Lesung, Banten, 57.8 tonC ha^{-1} but lower than that found Murdiyarso et al (2010) in Bunaken National Park, 103.6 MgC ha^{-1}. The amount of carbon stock in a vegetation is dependent upon total biomass in the tree, soil fertility, and absorptibility of the vegetation (Komiyama et al 2005; Camacho et al 2011; Kangkuso et al 2016).

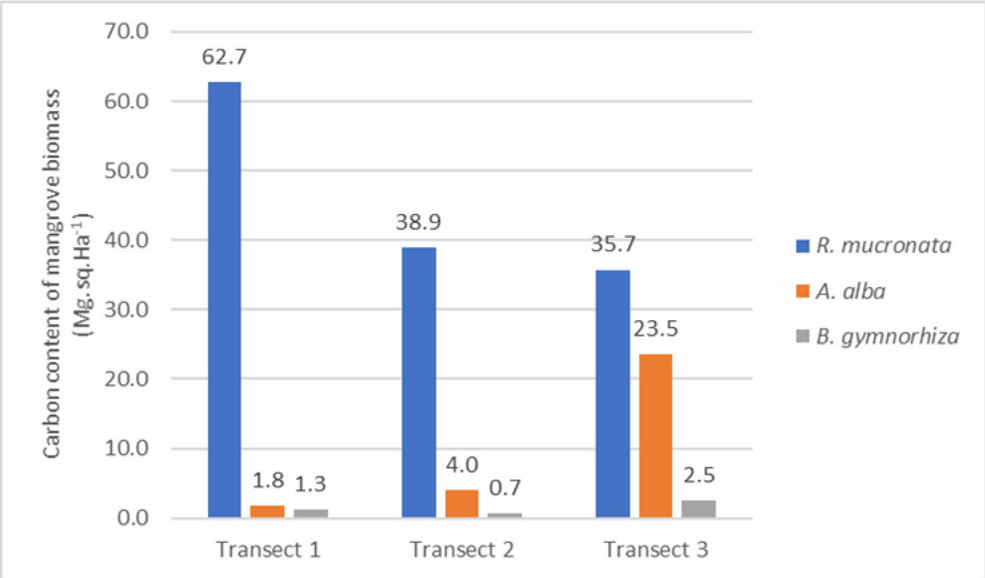

Figure 4. Carbon content of mangrove biomass with transects in Totok Bay.

Carbon stock of mangrove sediment. Estimation of carbon content stored in the sediment cannot be separated from 2 major parameters, soil density (SD) and carbon content. Mean bulk density of mangrove sediment in Totok Bay ranged from 0.53 to 0.65 g cm^{-3}. Transect 1 had the highest SD, 0.65 g cm^{-3}, while the lowest was recorded in transect 3, 0.53 g cm^{-3}. This finding is not much different than that previously reported by Alongi (2012) studying Indo-Pacific mangrove soils, 0.35-0.55 g cm^{-3}. SD is not significantly different with geomorphological factor, but it increases with depth (Donato et al 2011). However, SD is highly affected by soil texture, because it is related with soil density. SD at each depth interval is smaller and smaller due to denser and denser soil with depth (Boto & Wellington 1984; De Vos et al 2005).

Carbon deposit in muddy substrate of mangrove has very large potential (Rieley et al 2008). Therefore, the carbon stock estimation in muddy substrate can be a basic reference to value the economic benefit of the mangrove in environmental services C-sequestration (Purnobasuki 2012).

Transect 1 has the highest carbon content with an average of 334.87 Mg ha^{-1}, while transect 3 is recorded possessing the lowest carbon content with an average of 207.99 Mg ha^{-1} (Figure 5). The highest total soil organic carbon stock in transect 1 could result from high occurrence of relatively bigger DBH that directly influences the biomass. Mangrove with high biomass will produce high number of litters so that higher amount of carbon will be stored in the sediment. Figure 5 demonstrates soil organic carbon content in Totok Bay, averagely 5.37% or 286.18 Mg ha^{-1}. This result is much higher than that reported by Lunstrum & Chen (2014), 2.43%, in Futian, China.

The sediment type found was mud (dust and clay), dark colored, and sharply smelled. Mangrove species composition and growth are dependent upon the physical composition of the sediment. The proportion of particle size of sand, dust, and clay influences the permeability, fertility, and soil salinity. Nutrient occurrence is also affected by sediment composition. Much mud-containing sediment is generally rich in organic matters compared with sandy sediment (English et al 1994; Donato at al 2011).

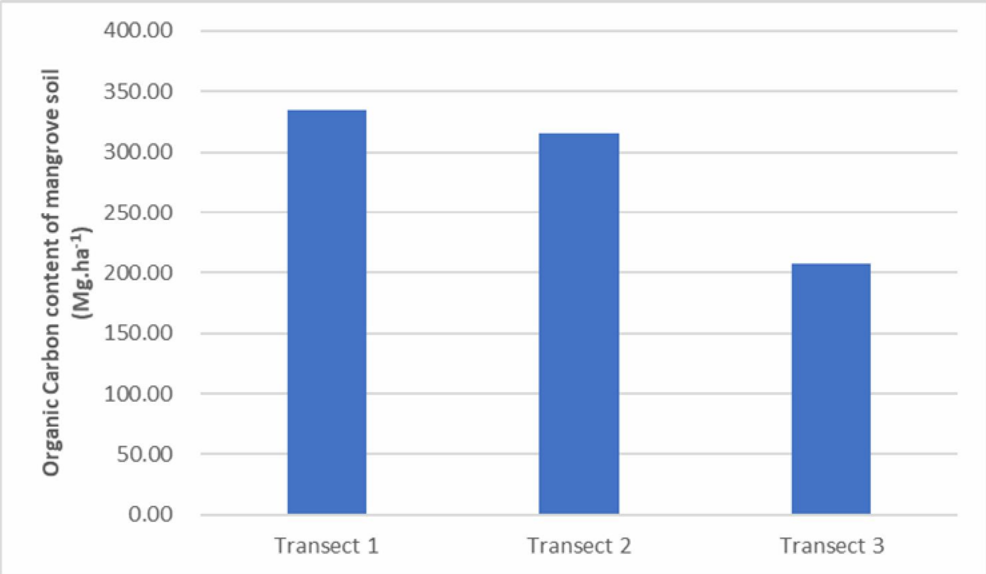

Figure 5. Organic carbon content of mangrove soil with transects in Totok Bay.

Sediment profiles in Totok Bay were different with transect even though they generally did not have significantly different textures (Figure 6) . Soil texture is closely related with particle size. Soil-constructing particles in mangrove are dominated by sand so that the soil pores are large. Consequently, the ability to hold water is very low and the soil density becomes low. Besides, such a soil condition will easily be prone to leaching, and it occurs from tides at the depth of 0-15 cm as also observed in the study site. It is supported by Ati et al (2014) that tides influence the amount of carbon stock in mangrove sediment.

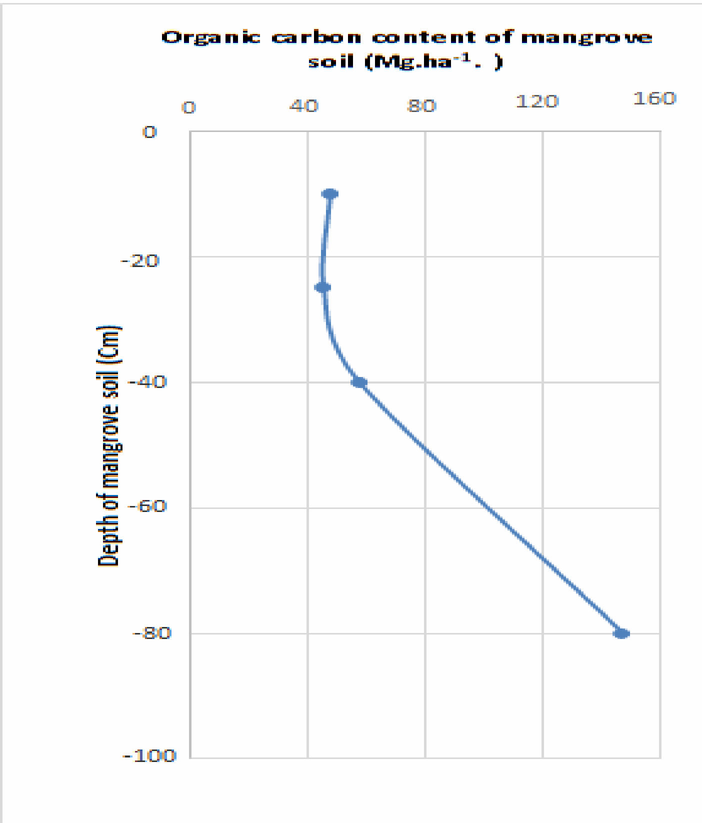

Figure 6. Organic carbon content profiles of mangrove soil with depth in Totok Bay.

Conclusions. This study has provided a crucial analysis in describing carbon content in Totok Bay, North Sulawesi, for sustainable mangrove conservation and management activities. There were 3 species of mangrove in the study transect *R. mucronata*, *A. alba,* and *B. gymnorhiza*. Carbon stock of mangrove biomass was high enough. The potential of carbon stock in each component, either carbon biomass or soil organic carbon will influence total carbon stock. The higher the mangrove biomass is, the higher the ability to absorb CO_2 gas. The future study needs to be directed to compare several ecosystem mangrove areas in North Sulawesi.

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