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Original Research Article

Allometric models for above- and below-ground biomass of *Sonneratia* spp.

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ABSTRACT

Allometric models are needed to estimate the stored carbon stocks in a mangrove forest ecosystem (blue carbon). Nevertheless, the development of allometric models for above- and below-ground biomass models for *Sonneratia* spp. species specifically has not yet been carried out either at global, regional and local scale and therefore it is very important to conduct a research on it. This is because this species is a pioneer species in the mangrove forests and a CO_2 absorber, has a very important role in reducing wave energy and retain sediments. Therefore this research was conducted to formulate an allometric model for the above- and below-ground biomass of *Sonneratia* spp. The biomass data of *Sonneratia* spp. (*S.alba* and *S. caseolaris*) were acquired through destructive sampling technique of 30 tree samples that have a stem diameter (diameter breast height/DBH)) within the range of 1.27 −20.06 cm. The allometric model is obtained through non-linear regression analysis (using GNLS function in R), with a combination of the stem diameter, tree heights and wood density as estimated variables. The largest biomass proportion is found on the part of the stem (31.28%), which was followed by the below-ground roots (23.40%), twig (13.35%), branches (12.96%), foliage (12.50%), while the smallest proportion is present on the pneumatophore (6.51%). The biomass comparison of the above- and below-ground is 3:1 (76.60%:23.40%). The result of the analysis indicate that the belowground, aboveground and total biomass can be estimated well with the power function. The aboveground and total biomass can be estimated with just the stem diameter variable, while the below-ground biomass can be well estimated with a combination of the stem diameter, tree height, and wood density. Overall, the addition of the tree heights or wood density variable in biomass allometric model development can increase the accuracy of the model, however the results are not significantly different than the model that uses only the stem diameter variable.

1. Introduction

Mangrove ecosystems that are located at the border between the land and sea are believed to produce high productivity (Kusmana, 2014), of both goods and environmental services. One of the most important environmental services related to

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climate change and global warming is the absorption of CO_2 emissions from the atmosphere and carbon storage (Bouillon et al., 2008; Chmura et al., 2003; Donato et al., 2011; Istomo et al., 2017; McKee et al., 2007; Murdiyarso et al., 2015).

Mangrove forests are able to store carbon stocks three times more than a tropical forest (Donato et al., 2011) and five times more than highland tropical forests (Murdiyarso et al., 2015). Nevertheless, the difficulty in estimating biomass and carbon stocks of mangrove forests can impede the implementation of the $REDD^+$ (Reducing Emissions from Deforestation and Forest Degradation) mechanism as one of the climate change mitigation efforts.

The estimation of mangrove forest biomass is needed to estimate the stored carbon stocks in a mangrove forest ecosystem. Based on ecological terms, biomass can be used to determine the productivity, stocked stands, and the allocation of organic matter in a tree and its effects on carbon (C) (Istomo et al., 2017; Kusmana, 1997; Morikawa, 2002; Nelson et al., 1999). Biomass information also can be used for management and conservation of mangrove forest (Kangkuso et al., 2016, 2018). Therefore, mangrove forest biomass estimation needs to be conducted accurately based on allometric tree biomass models that were developed through destructive sampling technique. Many models used in ecology and forestry are non-linear models (Zeng and Tang, 2011a). This is due to the non-linear models are more able to anticipate the influence of heteroscedasticity and minimize errors in the estimation compared to the linear models. Moreover, the methods of developing biomass models for individual trees and their components have evolved with simple least squares regression (Fu et al., 2016). With this method, tree component biomass models separately relate total tree biomass and its components, to predictors or tree variables such as diameter at breast height, total tree height, and wood density, that is one model for each component is built.

Research on allometric mangrove forest biomass modelling has already been conducted since several decades ago and around 17 species of mangrove have had their allometric model created (Duke et al., 2013; Komiyama et al., 2008). However, allometric models developed in a certain region may not necessarily be suitable for other sites (Clough et al., 1997; Smith and Whelan, 2006), especially those with tropical and temperate differences. This is because tree growth is influenced by genetic and environmental factors.

Available allometric mangrove species biomass models include those of *Rhizophora* spp., *Bruguiera* spp., *Avicennia* spp., *Ceriops* spp., *Laguncularia racemosa*, *Lumnitzera racemosa*, and *Xylocarpus granatum*, which are mostly focused on the aboveground biomass (Abd Rahman et al., 2014; Anitha et al., 2015; Duke et al., 2013; Komiyama et al., 2008; Krisnawati et al., 2012). Meanwhile, there are very few allometric models that developed by partial organs (Deshar et al., 2012; Khan et al., 2005; Hoque et al., 2010; Clough et al., 1997; Kangkuso et al., 2016, 2018; Kusmana et al., 1992), whereas partial organ allometric models are very useful to measure dead standing trees (status 1, 2 and 3) as mention in mangrove carbon stock protocol (Kauffman and Donato, 2012). Overall, the data suggest that the development of allometric models for above- and below-ground and it's partial organs biomass models for *Sonneratia* spp. species specifically has not yet been carried out and therefore it is very important to conduct a research on it. This is because this species is a pioneer species in the mangrove forests and according to Ren et al. (2009) since its character is fast-growing and spreads easily, it quickly forms a community of natural mangrove stands. *Sonneratia* spp. is usually found in the intertidal zone of a mangrove forest and situated closest to the sea or river. This makes the species very important role in reducing wave energy and retain sediments. Therefore, this study aims to formulate allometric models of the above- and below-ground biomass of *Sonneratia* spp.

2. Materials and methods

2.1. Study site

The study was carried out in the mangrove forests of Cilacap, Central Java, Indonesia ($108^0 42'$–$109^0 2'$ E and $7^0 30'$–$7^0 44'$ S; Fig. 1). Mangrove forests in this region are formed by buffering from the Nusakambangan Island and the flow of the Citanduy River that carries sediment. The Citanduy River flow that enters the Segara Anakan area basin is immediately mixed with seawater from the Indian Ocean and form brackish bodies. There are streams and rivers, such as Citanduy River, Cibeureum River, Donan River, and other small rivers in the area. This study site is located between 0 and 5 m above sea level with an average rainfall of 3444 mm $year^{-1}$. The average monthly temperature is 26.9 °C, while the windspeed ranges between 3 and 7 knots. The soil type is mostly alluvial soil with a smooth soil texture (silty clay). The salinity of its waters ranges between 34 and 37%0 with a pH of 6–8. Furthermore, according to Hidayat et al. (2017), the type of trees in the mangrove forest area is dominated by *Avicennia alba*, *Sonneratia alba*, and *S. caseolaris*.

2.2. Data collection

Amounted to 30 *Sonneratia* spp. (*S. alba* and *S. caseolaris*) trees were cut (Parde and Bouchon, 1988) as samples. The tree calculations conducted include: diameter of stem measured at breast height (D), total tree height (H), and wood density (ρ). The wood density testing is performed by taking a wood from the base of the stem of each tree and making them into a plate as thick as 3–5 cm, then the green weight and volume were measured using the principle of water displacement (Picard et al., 2012). Others part of the tree that are measured are those aboveground biomass (stem, branches (a division or subdivision of the stem or axis of a tree), twigs (a slender shoot of a tree), foliage, and pneumatophores) and below ground biomass (belowground roots). Pneumatophore and belowground root were sampled by modify trench method (Komiyama et al.,