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Tree allometric equations for estimation of above, below and total biomass in a tropical moist forest: Case study with application to remote sensing

Adrien N. Djomo [a,*], Cédric D. Chimi [b]

[a] Department of Geography and Planning, Queen's University, Kingston, ON K7L 3N6, Canada
[b] Laboratory of Plant Systematic and Ecology, Department of Plant Biology, Faculty of Science, University of Yaoundé I, P.O. Box. 812, Yaoundé, Cameroon

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ABSTRACT

The unavailability of site-specific allometric equations to estimate forest biomass has promoted the use of general equations in tropical moist forests which may result to errors in the estimates. The aim of this study was to develop site-specific allometric equations to estimate biomass of trees in tropical moist forests of Cameroon. For this study, 237 trees ($1 \leq D \leq 121$ cm) obtained by destructive method were used to develop allometric equations for the estimation of aboveground biomass. Allometric equations to estimate belowground and total biomasses were developed with 25 trees and 13 trees respectively. Trunk and crown biomass estimators were also developed in this study using 96 sample trees. Predictor variables considered were diameter, tree height, wood density and crown diameter. 237 and 235 trees were also used to develop regressions equations to estimate tree height and crown diameter respectively. For remote sensing applications, this study developed allometric equations to estimate aboveground biomass using crown diameter as predictor variable. Comparison of our biomass data to existing models showed that the equation of Djomo et al. (2016) provided the best estimator of total and mean biomass. Our study contributes to site-specific allometric equations and to the knowledge of belowground, above, trunk, crown and total biomass, which lack in most of the biomass data in tropical moist forests. Also, adding allometric equations with application to remote sensing, this study is a significant input for the implementation of REDD+ in Central Africa.

1. Introduction

Cameroon's forests which belong to Congo basin forest, cover about 190,000 km^2 (FAO, 2011) and represents about 42% of the national territory. These forests are characterized by a remarkable plant biodiversity, making it the second richest country in Atlantic Central Africa (Maréchal et al., 2013). However, human activities such as deforestation for agriculture and human settling, forest degradation due to logging, forest fires impact each year this forest cover (Hairiah et al., 2011). According to FAO (2010), a rate of 0.94% was lost per year during the period 1990–2000, 1.02% during the period 2000–2005 and 1.07% during the period 2005–2010. East and South region are the most forested area of the country constituted essentially by moist evergreen or semi-deciduous forest (Letouzey, 1985).

As countries try to fulfil their commitments regarding the aim of reducing greenhouse gas emissions (GHG), it becomes necessary and urgent to better understand how the forest sector contributes to climate change mitigation (Kurz et al., 2016). Forests are the largest terrestrial carbon sink (Zianis, 2008) and they have absorbed about 25% of global emissions from fossil fuel combustion during the last twenty years (Le Quéré et al., 2015). The study of Stephens et al. (2007) showed that tropical forests absorb 1.4 billion metric tons of carbon dioxide out of a total global absorption of 2.5 billion. Photosynthesis is the process used by plants to absorb carbon dioxide present in the atmosphere which are stored as carbon compounds in the plants (Brown and Pearson, 2005; Basuki et al., 2009).

Tropical forests represent approximately 33% of global land area (FAO, 2011), and contain more carbon per unit area than any other land cover type (Hairiah et al., 2011). Despite the strong carbon dioxide absorption rate of these forests which represents about 1.3 Pg C yr-1 (Lewis et al., 2009), they are increasingly exposed to degradation and deforestation representing about 20% of global emission (Canadell et al., 2009). As a result, forests have become a major issue of international negotiations to fight against climate change. Therefore, it has become necessary to make precise

* Corresponding author.
E-mail address: djomoa@queensu.ca (A.N. Djomo).

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estimate of the carbon content in these forests in order to determine a reliable policy for the implementation of REDD+ (Reducing Emissions from Deforestation and Forest Degradation and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks).

Most studies on forest biomass estimations have been limited to aboveground biomass without accounting belowground biomass component because their extractions are difficult in the field. Yet the roots of trees, in addition to playing an important role in the dynamics of forest ecosystems store significant quantities of carbon (Helmisaari et al., 2007; Mugasha et al., 2013). According to Ryan et al. (2011), Mugasha et al. (2013) and Mokany et al. (2006), belowground biomass can represent up to more than a quarter of the aboveground biomass. Therefore, this compartment also plays a significant role in the climate change mitigation.

Estimation of tree components from the forest ecosystem is usually done with the help of allometric equations which are regressions linking the biomass to some independent variables such as diameter, height and wood density. However, the lack of reliable equations or site-specific regression equations in many tropical forests most especially in Africa may constitute a major source of uncertainty in estimates of biomass (Henry et al., 2011). The most accurate method for determination of tree biomass is the destructive method (e.g. Brown et al., 1989; Djomo et al., 2010; Fayolle et al., 2013; Chave et al., 2014) but this technique requires high financial resources and may also lead to forest degradation (Basuki et al., 2009). A better way to minimize these issues has been the use of mathematical models developed with destructive biomass for the prediction of forest biomass of stand trees (Alvarez et al., 2012; Chave et al., 2014). The development of allometric equations for biomass estimation depends on the availability of destructive data. Once tested and validated, these allometric equations can be used to convert dendrometric variables such as diameter, height and wood density to tree biomass (Brown et al., 1989; Chave et al., 2014).

Up to 2005 there were no elaborated allometric equations to measure biomass from Central Africa. This has led to extensive use of the pan-tropical equation of Chave et al. (2005) developed without using trees of Africa. Few equations have been developed recently (Djomo et al., 2010; Fayolle et al., 2013; Ngomanda et al., 2014). The equations of Ngomanda was developed from biomass collected in a moist forest in Gabon on 103 trees with diameter between 12 and 109 cm. The equations of Djomo and Fayolle were developed for moist Cameroon forest; site-specific equations of Djomo were limited in number (71 trees) and size (dbh between 1 and 79 cm) and the ones of Fayolle to diameter and wood density as predictor variable. Recently, Chave et al. (2014) developed new pan-tropical equation added biomass from Africa, but did not make distinction between forest ecosystem types. Djomo et al. (2016) used data from Africa to develop ecosystem-specific equations and argued that these equations should estimate biomass better than pre-existent pan-tropical allometric equations.

Remote sensing is another alternative method for the estimation of biomass which is particularly suitable in large-scale areas (Kumar et al., 2015). According to Dube et al. (2016), this technique provides a better alternative for monitoring aboveground biomass (AGB) most especially in the tropics where accessibility can be an issue when monitoring biomass stocks. It has been combined with GIS and allometric equations to estimate forest cover, crown cover and forest inventories (Avtar et al., 2014). These models must incorporate precise allometric equations that provide estimates of biomass and carbon stocks in forest ecosystems using easily-measured input variables such as diameter, height (Djomo et al., 2016). These predictive models can also be linked to forest biophysical properties and multi-temporal Landsat satellite images with ground and Airborne Lidar data to estimate the biomass change over time (Badreldin and Sanchez-Azofeifa, 2015). Korhonen et al. (2006) showed that crown diameter is an important predictor which can be used to convert remote sensing data to biomass estimation (Ploton et al., 2015). This study tested the reliability of crown diameter for the development of allometric equations that can be used for the conversion of remote sensing data to biomass estimation.

Allometric equations were developed for estimating tree biomass using diameter, tree height, wood density and crown diameter as explanatory variables. Therefore, the objectives of the present study were to 1. Develop site-specific allometric equations to estimate forest tree aboveground, belowground, trunk, crown and total (above and below) biomasses, and 2. Use crown diameter as predictor variable for the development of allometric equations that will allow conversion of remote sensing data to biomass data.

2. Materials and methods

2.1. Study area

This study was carried out in the District of Belabo, Department of Lom and Djerem in the Eastern region of Cameroon. Data were collected in the forest management unit (FMU) 10 065 belonging to the forest company La Cotière Forestière. The topography of the area is relatively flat with altitude varied between 600 and 750 m. It is characterized by lateritic soil and the bed rock essentially constituted by granite in the Eastern part, and metamorphic rocks in the Western part of the District (Moby et al., 1979). The climate is typical Guinean equatorial with four seasons including two dry seasons (a long dry season from December to February and a short dry season from July to August) and two rainy seasons (a long rainy season from September to November and a small rainy season from March to June). The annual temperature ranges from 22 to 25 °C and the average annual rainfall is 1500 mm (Anonymous, 2012). This area is mainly irrigated by the Sanaga and its tributaries such as the Lom, Sessé, Yasso. According to Letouzey (1985) this area belongs to the semi-deciduous rainforest marked by Sterculiaceae and Ulmaceae and it is essentially characterized by the abundance of species of the genus *Cola*, *Sterculia* and *Celtis*. However, the most representative commercial species of flora are *Triplochiton scleroxylon, Pterocarpus sayauxii, Terminalia superba, Mansonia altissima, Entandophrama cylindricum,* etc.

2.2. Data collection

2.2.1. Selection of sample trees and measurements

Biomass data were collected on 237 trees with diameter between 1 cm and 121 cm. Trees with diameter below 5 cm and between 5 cm and 10 cm were collected in 3 plots of 10 m × 10 m and 3 other plots 10 m × 20 m respectively (Ibrahima et al., 2002; Djomo et al., 2010). Trees with diameter at breast height (dbh) between 10 cm and 50 cm were measured along the road construction which allowed minimizing the impact of the destructive sampling on the forest ecosystem (Fayolle et al., 2013). Trees with dbh above 50 cm were collected following the logging operations; The reference level for diameter measurement was 0.30 m aboveground for trees with diameter below 5 cm, 1.30 m aboveground for trees with diameter ≥5 cm and at 0.30 m above buttresses for trees having buttresses of more than 1.30 m. For each tree, local and scientific names were identified and recorded, and the variables diameter, total height, and crown diameter measured. Crown diameter of the trees was obtained from the average of four diameters measured along the North/South, East/West, North-East/South-West and North-West/South-East orientation.