Forest Ecology and Management 376 (2016) 276–283

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Aboveground biomass equations for evergreen broadleaf forests in South Central Coastal ecoregion of Viet Nam: Selection of eco-regional or pantropical models

Bao Huy [a,b], Krishna P. Poudel [c], Hailemariam Temesgen [d,*]

[a] Department of Forest Resources and Environment Management, Tay Nguyen University (TNU), 567 Le Duan, Buon Ma Thuot, Dak Lak, Viet Nam
[b] Department of Forest Engineering, Resources and Management, 117 Peavy Hall, Oregon State University, Corvallis, OR 97333, USA
[c] Department of Forest Engineering, Resources and Management, Oregon State University (OSU), Corvallis, OR 97333, USA
[d] Department of Forest Engineering, Resources and Management, 233 Peavy Hall, Oregon State University (OSU), Corvallis, OR 97333, USA

ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 14 June 2016
Accepted 16 June 2016

Keywords:
Aboveground biomass
Allometric equation
Eco-region
Evergreen broadleaf forest
Pantropic equations
South Central Coastal Region of Viet Nam

ABSTRACT

As part of Viet Nam's effort to participate in REDD+ (reducing emissions from deforestation and forest degradation), selected biomass equations were evaluated for their predictive abilities using data collected from destructively sampled 110 trees from 41 species of the evergreen broadleaf forests of the South Central Coastal region of Viet Nam. Different power models that used diameter at breast height (DBH), tree height (H), wood density (WD), and crown area (CA) as covariates to predict aboveground biomass (AGB) were evaluated. Best models were selected based on the coefficient of determination (R^2), the Akaike information criterion (AIC), and root mean square percent error (RMSE). AGB was strongly related to four covariates - DBH, H, WD, and CA. While seldom mentioned in the existing literature, CA improved the accuracy of the AGB estimation. Accuracy of the selected models was validated using the random validation dataset and the model with four explanatory variables ($AGB = a \times (DBH^2HWD)^b \times CA^c$) had the lowest mean absolute percent error of 16.9%. Using local data, a simple power model based on DBH only ($AGB = a \times DBH^b$) produced higher accuracy than the generic pantropical models that used up to three variables.

1. Introduction

Accurate biomass estimation is critical component in quantifying forest carbon stocks and sequestration rates and assessing potential impacts due to climate change. Biomass equations will remain a key component of future carbon measurements and estimation (Temesgen et al., 2015). As part of the country's effort to engage and prepare for REDD+ (reducing emissions from deforestation and forest degradation) program, biomass equations are being examined in Viet Nam. Allometric equations for converting national forest inventory data to biomass and converting it to forest carbon stock estimates were proposed for each of the main forest types and ecological regions of Viet Nam (Sola et al., 2014a, 2014b; Huy et al., 2012; Huy, 2014).

Broadly, allometry is the linear or non-linear correlation between increases in tree dimensions (Picard et al., 2012). The most important covariates for biomass equations are tree diameter at breast height (DBH) (Brown et al., 1989, 2001; Brown, 1997; Brown and Iverson, 1992), wood density (WD), and tree height (H) (Chave et al., 2005; Basuki et al., 2009; Ketterings et al., 2001). WD converts volume to weight and varies over a considerable range (factor 4) between species (Picard et al., 2012; Chave et al., 2006). As WD is often not measured in the field, averages at the species level can be associated with trees (Fayolle et al., 2013) and such data is often available in international databases (IPCC, 2006; Chave et al., 2009). Further database is found at http://db.worldagroforestry.org/wd. Furthermore, some authors suggested that crown diameter (CD) or crown area (CA) helps to improve accuracy and reliability of biomass estimates (Dietz and Kuyah, 2011; Henry et al., 2010). Numerous publications suggest power models for building allometric equations based on one or more variables (e.g. Pearson et al., 2007; Picard et al., 2015). Sometimes the second-order exponential function of parabola has been used (e.g. Brown et al., 1989; Brown, 1997). Basuki et al. (2009) used the logarithm model for dipterocarp forest biomass and compared with the higher-order parabolic functions of Brown et al. (1989) and Chave et al. (2005). Their results

* Corresponding author.
E-mail addresses: Baohuy.frem@gmail.com, Bao.Huy@oregonstate.edu (B. Huy), Krishna.Poudel@oregonstate.edu (K.P. Poudel), Temesgen.Hailemariam@oregonstate.edu, hailemariam.temesgen@oregonstate.edu (H. Temesgen).

http://dx.doi.org/10.1016/j.foreco.2016.06.031
0378-1127/

indicated that the transformed exponential function gives smaller deviation and higher reliability.

In countries with a limited tree flora, allometric functions are available for most of the tree species (Jenkins et al., 2003). For example, Jenkins et al. (2004) compiled 2640 DBH based allometric equations for predicting total and component biomass for tree species found in North America. Given the diversity of tropical forests, developing species-specific equations is not realistic and researchers have focused on multi-species models with larger sample sizes, e.g. Brown (1997) used 371 trees with DBH ranging from 5 cm to 148 cm and Chave et al. (2005) used 2410 trees with DBH ranging from 5 cm to 150 cm. These generic models provide valuable information for the tropical regions characterized by lack of data and difficulties in accessing it. These models, however, may face limitations and are potentially biased in some case where a particular ecosystem was not represented in the development of the generic models. Jara et al. (2015) and Chave et al. (2014) indicated that such generic equations might lead to systematic errors of up to 400% at the site level. Locally developed models may be a better alternative and are expected to provide less uncertainty than generic equations (Chave et al., 2014). Temesgen et al. (2007, 2015) suggested developing comprehensive biomass estimation methods that account for differences in site and stand density, and improve forest biomass modeling and validation at a range of spatial scales.

For natural forests, Huy and Anh (2008) conducted a preliminary study on CO_2 absorption capacity of evergreen broadleaf forests in the Central Highlands of Viet Nam. In preparation for the implementation of the UN-REDD+ program, biomass equations, common guidelines, and sets of biomass models are being developed for each ecoregion in Viet Nam (Sola et al., 2014a, 2014b). It has also been part of the development of database and guidelines for the use models in Viet Nam (Henry et al., 2015).

In this context, this study aims to develop and validate local allometric equations for evergreen broadleaf forests in the South Central Coastal ecoregion of Viet Nam, and compare them to the generic pantropical equations developed using data that do not include data from Viet Nam.

2. Materials and methods

2.1. Study site

This study was carried out in the evergreen broadleaf forests of the South Central Coastal region, which is one of the eight important agro-ecological regions in Viet Nam and has the highest rate of forest cover. Evergreen broadleaf forests are also common in all ecological zones surrounding the Central Highlands and in adjacent forest ecosystems of Cambodia and Laos.

Sample plots were located in Quang Nam Province (15°28′13.3″N to 15°28′16.1″N and 107°48′56.6″E to 107°48′59.6″E), at an elevation of 574–624 m.a.s.l. with slopes of 10–40°. The site soils are yellow brown, developed on ancient alluvium, with pH values 6.0–6.3 and soil depth layers greater than 100 cm. Mean annual precipitation is 3150–3500 mm with minimum and maximum precipitations 1857 mm and 5337 mm respectively. The average annual temperature is 21.8 °C, with an annual range between 16.0 °C and 39.4 °C. The location has two distinct seasons: the dry season from February to August and the rainy season from September to January. Average humidity is 90% and mean evaporation is 800 mm and fog usually occurs from November to February (Hydrometeorology Center in Central Viet Nam, 2012).

2.2. Sample plot design, tree selection, and measurement

This study was conducted in two sample plots of 1 ha (100 m × 100 m) that were each divided into 100 sub-plots of 10 m × 10 m. Within the plots, attributes measured were (i) plot location; (ii) stand information: forest types and status, canopy cover, numbers of vertical forest layer, and basal area (BA); (iii) topography: slope and location on the mountain; (iv) soil characteristics: pH, depth, and color; and (vi) standing trees measurements: species name (local and scientific), DBH (cm), and tree height (H, m) of all trees with DBH ⩾ 5 cm.

Within the one-ha sample plots, the number of trees sampled was determined by the ratio of trees in each diameter class, while for the larger diameter classes (i.e., DBH ⩾ 45 cm) at least three trees were sampled. Fig. 1 shows the number of trees and basal area by DBH class in each of the inventory plot. The sample trees were also selected based on their dominance in the stand. A total of 110 trees, 55 from each plot, were sampled. Average DBH of the sample trees was 25.6 cm (range 4.9–87.7 cm) and average height was 17.5 m (range 4.7–41.4 m). The distribution of DBH and H of the destructively sampled trees is shown in Fig. 2. Table 1 shows a summary for each of the predictors and the response variables of the destructive sample trees.

DBH, H, CD (m) (measuring in two cardinal directions – North-South and East-West), and species of each sample tree were recorded before the tree was felled. Tree height was re-measured after the sample trees were felled. The fresh-weight of tree components (leaves, branches and stem with bark) were also recorded in

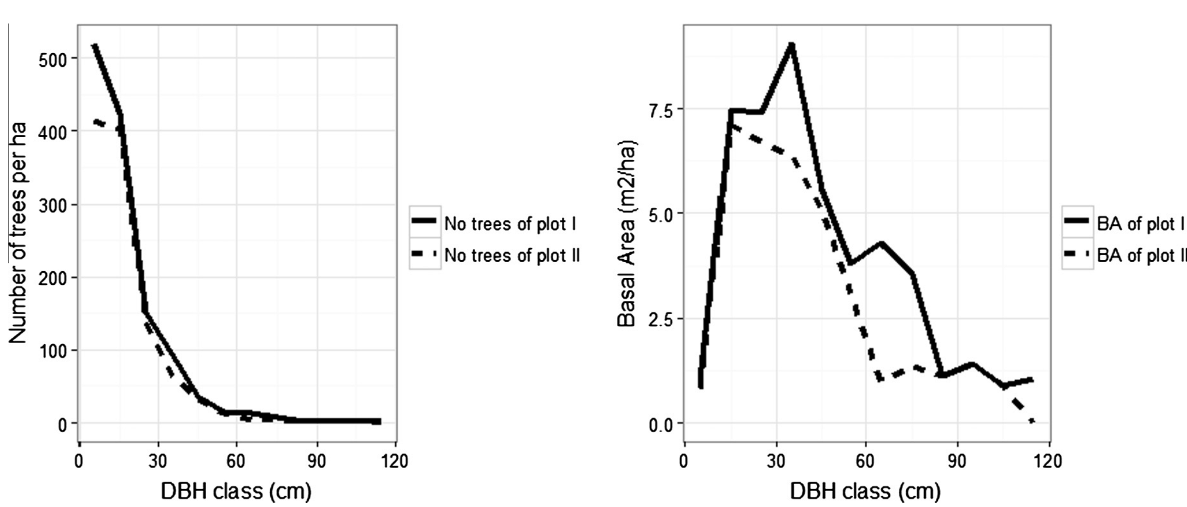

Fig. 1. Structure of evergreen broadleaf forests in the South Central Coastal region of Viet Nam.