Forest Ecology and Management 259 (2010) 1135–1140

Contents lists available at ScienceDirect

Forest Ecology and Management

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

# Tree biomass estimation in regenerating areas of tropical dry vegetation in northeast Brazil

Everardo Sampaio [a,1], Peter Gasson [b,*], Amelia Baracat [b], David Cutler [b], Frans Pareyn [c,**], Kleber Costa Lima [c,2]

[a] Departamento de Energia Nuclear, Universidade Federal de Pernambuco, Av. Prof. Moraes Rego, no. 1235, Cidade Universitária, Recife, PE, Brazil
[b] Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3AB, United Kingdom
[c] Associação Plantas do Nordeste - APNE, Rua Dr. Nina Rodrigues, 265, Iputinga, 50.731-280 Recife, PE, Brazil

ARTICLE INFO

*Article history:*
Received 10 September 2009
Received in revised form 10 December 2009
Accepted 24 December 2009

*Keywords:*
Allometry
Caatinga
*Caesalpinia pyramidalis*
*Croton sonderianus*
*Mimosa ophthalmocentra*
*Mimosa tenuiflora*
Weight equations

ABSTRACT

Allometric equations have been developed for various different vegetation types but have rarely been validated in the field and never for dry tropical forest such as caatinga. In three areas of semi-arid Brazil, with regenerating caatinga vegetation, we measured and weighed twelve hundred individuals of four tree species and used the data to validate equations previously determined in mature caatinga. They and several other equations developed for tropical vegetations overestimate the biomass (*B*) of trees from the regeneration areas by more than 20%, possibly because these trees have reduced crowns, with lower branch masses. We then determined new allometric equations for them, validating equations for one site against data of the others and pooling the data if they were cross-validated. The best equations were power ones, based on diameter at breast height (*D*), with little improvement by including height, crown area and/or wood density (*Caesalpinia pyramidalis*, $B = 0.3129D^{1.8838}$; *Croton sonderianus*, $B = 0.4171D^{1.5601}$; *Mimosa ophthalmocentra*, $B = 0.4369D^{1.8493}$; and *Mimosa tenuiflora*, $B = 0.3344D^{1.9648}$ and $0.4138D^{1.7718}$).



## 1. Introduction

Allometric equations for the estimation of biomass have been developed for a wide range of species (Ter-Mikaelian and Korzukhin, 1997; Zianis and Mencuccini, 2004) and types of vegetation (Haase and Haase, 1995; Sampaio and Silva, 2005; Chave et al., 2005; Medeiros and Sampaio, 2008). They are particularly useful for non-destructive estimation of biomass in large areas, replacing the expensive and time consuming task of cutting and weighing all the trees in these areas (Pilli et al., 2006). In temperate regions which are dominated by relatively few species, equations have been developed for particular species and many species have been the subject of study (Ter-Mikaelian and Korzukhin, 1997; Zianis and Mencuccini, 2004). In humid tropical regions with a wealth of low dominance species, equations have usually been developed for groups of species in a given area (Overman et al., 1994; Keller et al., 2001; Ketterings et al., 2001; Brown, 2002; Zianis and Mencuccini, 2004; Chave et al., 2005; Nogueira et al., 2008). The species diversity is lower in dry tropical regions than in the humid tropics and fewer equations have been developed (Chidumayo, 1997; Bellefontaine et al., 2000; Sampaio and Silva, 2005). In some cases they are for single species but there are a few for groups of species (Cairns et al., 2003; Sampaio and Silva, 2005). Although tropical dry forests are the most extensive land cover type in the tropics, fewer studies have been conducted to estimate their biomass and carbon stock (Urquiza-Haas et al., 2007). They depend on valid allometric equations.

The relatively abundant literature on the development of equations and on their theoretical aspects (Ter-Mikaelian and Korzukhin, 1997; Ketterings et al., 2001; Enquist, 2002; Zianis and Mencuccini, 2004; Pilli et al., 2006) contrasts with the scarcity of studies validating them in the field (Chave et al., 2005; Nogueira et al., 2008), which are essential before such equations can be reliably used in the estimation of biomass of large areas. This necessity is reinforced by the fact that many of these equations have been based on few plants (Brown et al., 1995; Ketterings et al., 2001), rarely more than a few dozens, and cover a large range of

* Corresponding author at: Jodrell Laboratory, Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3DS, United Kingdom. Tel.: +44 208 332 5330; fax: +44 208 332 5310.
** Corresponding author. Tel.: +55 81 3271 4256; fax: +55 81 3271 4256.
*E-mail addresses:* P.Gasson@kew.org (P. Gasson), franspar@rocketmail.com (F. Pareyn).
[1] Tel.: +55 81 2126 7979.
[2] Tel.: +55 81 3271 4256; fax: +55 81 3271 4256.

0378-1127/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2009.12.028

plant sizes (Brown et al., 1995), so that each size group is represented by only a few individuals (Fehrmann and Kleinn, 2006). In the dry tropics, the size range is more limited than in humid tropical and temperate forests and some studies have used a relatively large number of plants. Cairns et al. (2003), for instance, used 698 plants for the vegetation on the Mexican Yucatan Peninsula. A modified version of the Yucatan equation was later applied to a large set of plot data to estimate forest biomass in the peninsula (Urquiza-Haas et al., 2007). In the Brazilian caatinga, Sampaio and Silva (2005) developed equations for individual species and also for groups of species, using a relatively large set of plants: 30 for each of nine species. However, no validation of allometric equations for dry tropic species could be found in the literature of the last decade. In the humid Amazon forest, equations developed for the central region overestimated the biomass of about 300 plants of the southern region (Nogueira et al., 2008).

The semi-arid region of NE Brazil has approximately one million square km originally covered by a shrub and tree vegetation called caatinga. About half of this area is still covered by native vegetation that is used for the production of fuel wood and slash and burn agriculture, resulting in a mosaic of vegetation with different regeneration periods (Sampaio, 1995). Mature preserved caatinga areas are small and few in number. The regeneration areas are dominated by relatively few species and Sampaio and Silva (2005) developed aboveground biomass equations for the most important ones. Equations for their fuel wood biomass and volume have also been published (PNUD/FAO/IBAMA, 1992). However, the biomass equations were based on trees growing in mature areas, to cover a larger range of sizes, and have not been validated in field conditions, particularly in regenerating locations where the vegetation is cut every 10–15 years. At this growth stage, the range of sizes is narrower than in the mature areas and the range of trees cut for fuel wood (above 2–3 cm diameter at the base of the stem) still narrower. The architecture of plants in regenerating areas may also be different, since most of them coppice and the number of sprouts is progressively reduced as the plants grow taller (Sampaio et al., 1993, 1998).

This study was aimed at validating the equations already developed for the caatinga species and proposes the development of new ones specific for caatinga vegetation regenerating after being cut for firewood.

## 2. Materials and methods

The work was conducted, in 2002, in three localities in the caatinga of Pernambuco, two in the municipality of Sertânia and one in the municipality of Serra Talhada. In Sertânia, we chose one area of native vegetation of circa 40 ha, at the IPA Experimental Station (08°04′02.7″S and 37°12′33.1″W) and another privately owned site of circa 20 ha in the district of Caroalina (08°15′33.0″S and 37°32′52.1″W). In Serra Talhada, we chose an area of 80 ha, at the IPA Experimental Station (07°55′46.4″S and 38°17′20.0″W). The rainfall in these two municipalities is concentrated between January and May, with total annual means of 483 mm in Sertânia, and 626 mm in Serra Talhada, and high variation from year to year (Figueirôa et al., 2006). The mean annual temperatures vary little, ranging between 26 and 28 °C. The three localities have soils with a coarse sandy texture and medium fertility (Figueirôa et al., 2006).

In Serra Talhada and in Sertânia, at the IPA Experimental Station, we marked, both in the wet season and in the dry season, at each locality, 60 plants of each of the four species most used for production of fuel wood: catingueira, *Caesalpinia pyramidalis* Tul.; jurema preta, *Mimosa tenuiflora* (Willd.) Poir.; marmeleiro, *Croton sonderianus* Muell. Arg.; and jurema de imbira, *Mimosa ophthalmocentra* Mart. ex Benth. In Caroalina, *C. sonderianus* and *M. ophthalmocentra* were absent and the vegetation was dominated by *C. pyramidalis* and *M. tenuiflora*, so we cut 60 trees of each of the two species present. The trees, chosen at random, were at least 2 cm in diameter at breast height, measured 1.3 m aboveground level (DBH), which is the size cut for fuel wood in the region. For each tree, the circumferences at the stem base (CSB) and at breast height (CBH), total height ($H$) and the two major orthogonal axes of the crown projection area were measured. Each tree was then cut at the base and separated into pieces (stem, large and small branches, twigs and leaves) that were weighed in the field and sampled to determine the dry weight in the laboratory. To determine wood density (WD) we took discs 2.5 cm thick, from the trunk and largest branches, each metre up the plant, and the disc volumes were measured by immersion, and their weight determined after drying at 103 °C (Zakia et al., 1992).

At each locality, we collected fertile branches of the four species for confirmation of their identity. This voucher material is deposited at the Herbário Dárdano de Andrade Lima (IPA).

We developed allometric equations considering the dry weight of each plant as the dependent variable, and height, diameter at the stem base (DSB), diameter at breast height (DBH), crown area (CA) and wood density as independent variables, taken individually or combined in groups of two, three or four variables, used as single variables or as multiple variables. DSB and DBH were calculated assuming that the stems were circular and the area of the crown was calculated assuming an ellipse. The data were adjusted for different types of equation models (linear, quadratic, power, exponential and logarithmic), found in the literature, using the individual or combined variables. We developed equations for increasing sets of data, from the 60 plants of each species, at each season (wet or dry) and locality, to the total of all 1200 plants. The equations (model and parameter values) for one season and for each species and site were validated against the sets of data for the other season, using their real input variables ($H$, DSB, DBH, CA and WD) and comparing predicted and real biomasses (Nelson et al., 1999). If they were considered as valid, the data of the two seasons were pooled together, new equations developed and validated against the sets of data for the same species in the other sites. If they were also considered as valid, a single new equation was developed for each species. These equations were validated against the small set of data for the same species collected by Sampaio and Silva (2005) but were not validated using data from this present work because all of them had been used to develop the equation. These equations were also used to estimate the biomass of the other species, in the search for equations of more general use but these comparisons cannot be taken as validation. Fitness of the equations was compared by their regression coefficients ($R^2$), mean squares of residuals (MSR) or square root of MSR (SMSR), sum of squares of the differences between predicted and real values (PRESS) or error mean square (EMS) and mean difference between predicted and real values or aggregate difference (AD). The most important validation criterion was the sum of differences between predicted and real values in relation to sum of real values or AD in relation to the average real value (relative AD). In the estimates of the log-transformed equations we applied the correction factor (CF), described in the literature (Chave et al., 2005). If the relative AD was above 0.2 (20% deviation from the real value) the equation was considered as not valid, regardless of the other criteria; if it was below 0.2, the other criteria were considered. When comparing different equation models for the same data set, the best model was selected by ranking them according to the goodness of each criterion and summing the rank positions (Salas, 2002). The Furnival index was used to correct the SMSR of the transformed models (Segura and Andrade, 2008). When validating an equation against another data set, relative AD and EMS were used. We also compared our biomass data with estimates made with equations and their parameters developed