

Crown Area as a Parameter for Biomass Estimation of *Croton sonderianus* Müll. Arg.

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ABSTRACT

Current tree biomass estimation techniques generally use remote sensing data and allometric models for validation, which relate non-destructive parameters to plant biomass, usually employing diameter at the plant base or breast height and plant height. In the Caatinga Biome, many plants present multiple stems, thus making it difficult to measure the plant diameter, and lost branches, which are difficult to correct for. Hence, there is a need for suitable models for Caatinga plants, as well as studies on the possibility of using other parameters. For this study, plant and branch basal diameter, plant height, and crown area of *Croton sonderianus* plants were measured, and plants were also collected and weighed. Several classic models and their variations were tested. The best models were variations of Naslund ($R^2 = 0.92$; $rmse = 1,221$) and Schumacher & Hall ($R^2 = 0.92$; $rmse = 1,217$). Plant height and crown area enables a better biomass estimation than using plant or branch basal diameter.

Keywords: allometric models, Schumacher & Hall, Naslund.

Área da Copa como Parâmetro para Estimar Biomassa de *Croton sonderianus* Müll. Arg

RESUMO

As técnicas modernas para estimar biomassa arbórea geralmente usam dados de sensoriamento remoto e modelos alométricos para validação, que relacionam parâmetros não destrutivos com a biomassa da planta, normalmente empregando diâmetro basal ou diâmetro à altura do peito e altura da planta. No bioma Caatinga, muitas plantas apresentam múltiplas ramificações, o que dificulta a medição do seu diâmetro, e ramos perdidos, de difícil correção. Assim, são necessários modelos adequados para plantas da Caatinga, além de estudos sobre a possibilidade de uso de outros parâmetros. Para este estudo, foram mensurados diâmetro basal de plantas e ramos, altura das plantas e área da copa de indivíduos de *Croton sonderianus*, e plantas foram coletadas e pesadas. Vários modelos clássicos e variações foram testados. Os melhores modelos foram variações de Naslund ($R^2 = 0,92$; $rmse = 1.221$) e Schumacher & Hall ($R^2 = 0,92$; $rmse = 1.217$). Altura das plantas e área da copa permitem estimar melhor a biomassa do que diâmetro basal de plantas ou ramos.

Palavras-chave: modelos alométricos, Schumacher & Hall, Naslund.

1. INTRODUCTION AND OBJECTIVES

Environmental restoration projects begin with the assumption that a certain area is degraded. This means that the first stage of a recovery process is to prepare an environmental diagnosis that provides indicators of a certain environment status, as well as the main difficulties to be overcome in the recovery or restoration process (Moraes et al., 2010). An important degradation (Romero-Sanchez & Ponce-Hernandez, 2017) and desertification indicator is biomass density (Elijah et al., 2017; Zhang; Huisingsh, 2018).

The main methodology for biomass estimation uses remote sensing techniques accompanied by field allometric estimates (Galidaki et al., 2017). The main parameters applied in these biomass estimates (for woody plants) are the diameter at breast height (DBH) or circumference at breast height (CBH) and plant height (H) (Balbinot et al., 2017). These values are then related to plant biomass through specific mathematical models.

There are published models for several species such as *Tectona grandis* (Tonini et al., 2009), *Nectandra grandiflora* (Barbeiro et al., 2009), *Anadenanthera colubrina* (Abreu et al., 2016), and studies in biomes such as Cerrado (Santos et al., 2017), Amazonia (Sanquetta et al., 2017), and Caatinga (Silva & Sampaio, 2008). However, the models developed for the Caatinga region (Silva & Sampaio, 2008) were made for non-degraded areas. Plants from areas degraded by overuse usually show signs of cutting, which are from logging for various purposes (firewood, charcoal, fence posts etc.). Logging causes overcrowding of stumps along with new stems and leads to canopies formed by several small branches, making it very difficult to obtain DBH. In these cases, the DBH is obtained by the sum of individual areas (Moro & Martins, 2011).

Another problem related to obtaining the DBH is the need for multiple measurements (one for each branch), increasing the probability of measurement errors and the need for labour during assessments. Due to these problems, the use of diameter at soil height (DSH) has been indicated for the Caatinga biome (Moro & Martins, 2011). Nevertheless, the use of DSH in cut plants may not be suitable, since it refers to the remaining stump of the previous trunk and does not reflect the current status of plants, but

actually the mass lost during logging. An alternative for measuring plants with multiple stems can be crown diameter (CD) (Parvaresh et al., 2012).

Thus, there is a need to obtain appropriate models to estimate biomass in degraded areas of Caatinga and to conduct studies to determine the most suitable allometric parameters for biomass estimation. For this study we used *Croton sonderianus*, a quite rough plant commonly found in the Caatinga biome, suitable for recovery programs of degraded areas.

2. MATERIALS AND METHODS

The experiment was conducted in a 100 ha area of degraded Caatinga in Angicos, Rio Grande do Norte, where *C. sonderianus* Müll. Arg. is a dominant plant. The dominance of this species in the floristic composition was assessed using three transects. Total biomass was preliminarily estimated by measuring basal DSH and total height of all plants with DSH > 3 cm in two quadrants with 20 m edges. Total biomass was then estimated in these quadrants based on the model proposed by Silva & Sampaio (2008) ($W = 0.2368 \times \text{DBH}^{2.2219}$), where biomass density was classified as very low, indicating a high degree of degradation.

Based on the abovementioned assessment, four DSH classes were selected for modelling (2-5, 5-10, 10-15, and 15-20 mm), and an even number of representative individuals from each class was collected. The number of plants to be used was defined based on the significance of R^2 values (above 90%) and coefficients of variation (below 30%) for the best models tested. There were two collections from August to November 2010, totalling sixteen individuals.

Measurements consisted of DSH, calculated according to the circumference at 15 cm height; DBH, measured as the equivalent diameter at breast height (Moro & Martins, 2011), H and CD, with the latter being the average value obtained from two orthogonal measures. Crown diameters were used for calculating CA as a regular ellipse. Then plants were cut at ground level with a chainsaw and weighed to determine fresh weight.

Non-destructive measurements were used in developing models for estimating fresh biomass of plants. Most models used were listed by Gama et al. (2015) and Samalca (2007). Models for using

CA and the combined use of CA and H were also developed. In the latter case, these models have been modified from those used for DSH and H. Models were adjusted by the Levenberg-Marquardt method using a computer program (Data Master 2003) to calculate the coefficient of determination (R^2), root mean square error (rmse), coefficient of variation of the root mean square error (CVrmse) and Furnival's index (Fi) (Samalca, 2007). Furnival's index was calculated according to Marangon et al. (2017) and Samalca (2007). This index has been used to compare models with different dependent variables (Hossain et al., 2016; Samalca, 2007).

Model residuals were plotted against the measured mass to visually inspect the independence of residuals and the dispersion degree. The value of measured mass was plotted on the x-axis, and the residuals percentage on the y-axis. The best models were chosen based on R^2 and smaller rmse, CVrmse and Fi values.

3. RESULTS AND DISCUSSION

The produced models and the determined indicators are shown in Table 1. It is observed that models based solely on DSH should not be used, since they have low correlation coefficients when compared to models that use other parameters. Moreover, it is possible to observe trends in the distributions of residuals, with proportionality between the magnitude of the residual and the magnitude of the mass (Figure 1). This goes against the independence assumption of sampling error (homoscedasticity), which is a common problem in biomass equations (Pérez-Cruzado & Rodríguez-Soalleiro, 2011). On the other hand, using only DBH as a parameter provides much more useful models, which are almost comparable to models that use DSH and H together. However, these models also have problems related to error distribution, where it is possible to observe larger residuals for small mass plants (Figure 1).

Table 1. Models for estimating fresh biomass using plant base diameter (DSH), diameter at breast height (DBH), plant height (H), and crown area (A).

Param.	Name	Model	R^2	rmse	CVrmse	Fi
DSH	Linear	$-1081.6+575.5 \cdot Dpb$	0.43	3,193	67.09	1.05
DSH	Quadratic	$560.2+117.5 \cdot Dpb+23.8 \cdot Dpb^2$	0.44	3,157	66.33	1.04
DSH	Cubic	$-4381.3+2581.8 \cdot Dpb-282.7 \cdot Dpb^2+10.8 \cdot Dpb^3$	0.49	3,037	63.80	1.00
DBH	Linear	$-4688.6+1488.1 \cdot Dbr$	0.66	2,480	52.11	0.82
DBH	Quadratic	$-79.4-214.8 \cdot Dbr+136.0 \cdot Dbr^2$	0.69	2,353	49.44	0.78
DBH	Cubic	$4257.5-2916.0 \cdot Dbr+619.5 \cdot Dbr^2-26.0 \cdot Dbr^3$	0.69	2,330	48.95	0.77
H	Linear	$-6641.1+5089.5 \cdot H$	0.47	3,090	64.93	1.02
H	Quadratic	$8713.0-13222.5 \cdot H+4806.3 \cdot H^2$	0.64	2,552	53.62	0.84
H	Cubic	$-16198.1+37185.3 \cdot H-24861.5 \cdot H^2+5339.2 \cdot H^3$	0.72	2,260	47.49	0.75
H	Hyperbolic	$2836.3/(3.1-H)$	0.77	2,035	42.75	0.67
H	Logistic	$83312.1/(1+\exp(-2.615 \cdot (H-6.2)))$	0.73	2,185	45.90	0.72
CA	Linear	$-2724.1+3232.2 \cdot A$	0.83	1,822	38.29	0.60
CA	Quadratic	$-1952+2505.4 \cdot A+132.9 \cdot A^2$	0.83	1,814	38.12	0.60
CA	Cubic	$963.41-1996.9 \cdot A+2098.0 \cdot A^2-248.2 \cdot A^3$	0.83	1,785	37.51	0.59
DSH, H	Spurr Combined Variable	$737.8+12.7 \cdot (Dpb^2 \cdot H)$	0.58	2,740	57.58	0.91
DSH, H	Naslund	$-115.0 \cdot Dpb^2+66.6 \cdot Dpb^2 \cdot H-119.0 \cdot Dpb \cdot H^2+1034.9 \cdot H^2$	0.79	1,957	41.12	0.65
DSH, H	Ogaya	$Dpb^2 \cdot (-85.3+47.0 \cdot H)$	0.71	2,263	47.55	0.75
DSH, H	Schumacher & Hall	$4.6 \cdot Dpb^{1.0} \cdot H^{4.9}$	0.77	2,025	42.55	0.67
DSH, H	Spurr logarithmic	$9.1 \cdot (Dpb^2 \cdot H)^{1.1}$	0.57	2,777	58.35	0.92
DBH, H	Spurr Combined Variable	$-283.4+44.0 \cdot (Dbr^2 \cdot H)$	0.76	2,090	43.92	0.69

Table 1. Continued...

Param.	Name	Model	R ²	rmse	CVrmse	Fi
DBH, H	Naslund	$-175.7 \cdot \text{Dbr}^2 + 94.3 \cdot \text{Dbr}^2 \cdot \text{H} + 50.0 \cdot \text{Dbr} \cdot \text{H}^2 - 13.4 \cdot \text{H}^2$	0.81	1,868	39.24	0.62
DBH, H	Ogaya	$\text{Dbr}^2 \cdot (-176.0 + 109.4 \cdot \text{H})$	0.80	1,900	39.93	0.63
DBH, H	Schumacher & Hall	$3.7 \cdot \text{Dbr}^{1.7} \text{H}^{4.2}$	0.84	1,699	35.69	0.56
DBH, H	Spurr logarithmic	$20.8(\text{Dbr}^2 \cdot \text{H})^{1.1}$	0.76	2,073	43.57	0.69
H, CA	Spurr Combined Variable	$1043.7 + 210.6 \cdot (\text{H}^2 \cdot \text{A})$	0.85	2,364	49.67	0.78
H, CA	Spurr Combined Variable	$-561.7 + 371.8 \cdot (\text{H} \cdot \text{A}^2)$	0.90	3,737	78.51	1.23
H, CA	Naslund	$-511.6 \cdot \text{H}^2 + 678.0 \cdot \text{H}^2 \cdot \text{A} - 25.1 \cdot \text{H} \cdot \text{A}^2 - 280.3 \cdot \text{A}^2$	0.92	1,221	25.65	0.40
H, CA	Ogaya (a)	$\text{H}^2 \cdot (-221.7 + 412.5 \cdot \text{A})$	0.91	1,307	27.46	0.43
H, CA	Ogaya (b)	$\text{A}^2 \cdot (-413.8 + 390.9 \cdot \text{H})$	0.83	1,805	37.93	0.60
H, CA	Schumacher & Hall	$85.4 \cdot \text{H}^{3.3} \cdot \text{A}^{1.1}$	0.92	1,217	25.56	0.40
H, CA	Spurr logarithmic	$158.2 \cdot (\text{H}^2 \cdot \text{A})^{1.2}$	0.92	1,258	26.44	0.42
H, CA	Spurr logarithmic	$646.4 \cdot (\text{A}^2 \cdot \text{H})^{0.7}$	0.87	1,599	33.59	0.53
DSH, H, CA	Schumacher & Hall variation	$66.4 \cdot \text{Dpb}^{0.2} \cdot \text{H}^{3.0} \cdot \text{A}^{1.1}$	0.92	1,207	25.35	0.40
DSH, H, CA	Schumacher & Hall variation	$27.4 \cdot \text{Dbr}^{0.8} \cdot \text{H}^{2.8} \cdot \text{A}^{1.0}$	0.95	946	19.88	0.31

Using H produces models with coefficients that are similar to those from models that use DBH (Table 1). Furthermore, in Caatinga areas, such as the Serido region in Rio Grande do Norte, it becomes much easier to measure H thanks to the open vegetation and low total biomass (Amorim et al., 2005). The problem is that the measurement process is more difficult for taller plants. In addition, small measurement errors may promote large estimation residuals due to the hyperbolic tendency of the relationship between H and plant biomass. Meanwhile, the use of CA produces better models than those obtained using DSH or H. Similar results were obtained with the mangrove plant (Parvaresh et al., 2012), which also has the characteristic of multiple stems. For Caatinga areas with open and disturbed vegetation, CA can be easily measured in the field.

In considering the combined use of DSH and H, Table 1 shows that the best results were obtained using the Naslund model and the Schumacher & Hall model. It can be noticed that these were the

best models for all the indicators used, and that all these indicators provide similar classification. It is also observed that the aforementioned models give greater importance to H. This is consistent with the observation that DSH is not well related to biomass, since the trees assessed during this study had lost part of their crown.

Despite the greater importance given to H, coefficients of models that use both DSH and H are better than those obtained from models that are based exclusively on H. This may be due to a still existing relationship between the basal diameter of a plant and its biomass even after logging, or because the plant capacity to produce new branches depends on root size, as observed by Anbari et al. (2011) for *Sonchus arvensis*. Therefore, larger roots lead to increased shoot growth, and stem diameter may have a high correlation with root system mass (Kuyah et al., 2012). Nevertheless, it is observed that models produced through the combined use of these parameters are still less efficient than those that only use CA.

A variation of the Schumacher & Hall model was also used by Soares & Oliveira (2002) to determine the carbon content in the shoot biomass of Eucalyptus, also with high R^2 values and low coefficient of variation, which is expected due to greater stem uniformity of Eucalyptus when compared to Caatinga biome plants. When DBH and H are used together, the Schumacher & Hall method also presents the

best coefficients, differentiating it from the other models. A gain in accuracy of all models is observed when DBH is used. This is consistent with the observation that branches represent a large part of the plant biomass, and that DBH is more accurately measured than DSH. Thus, the occurrence of any shoot biomass loss is better measured when the model used is based on DBH.

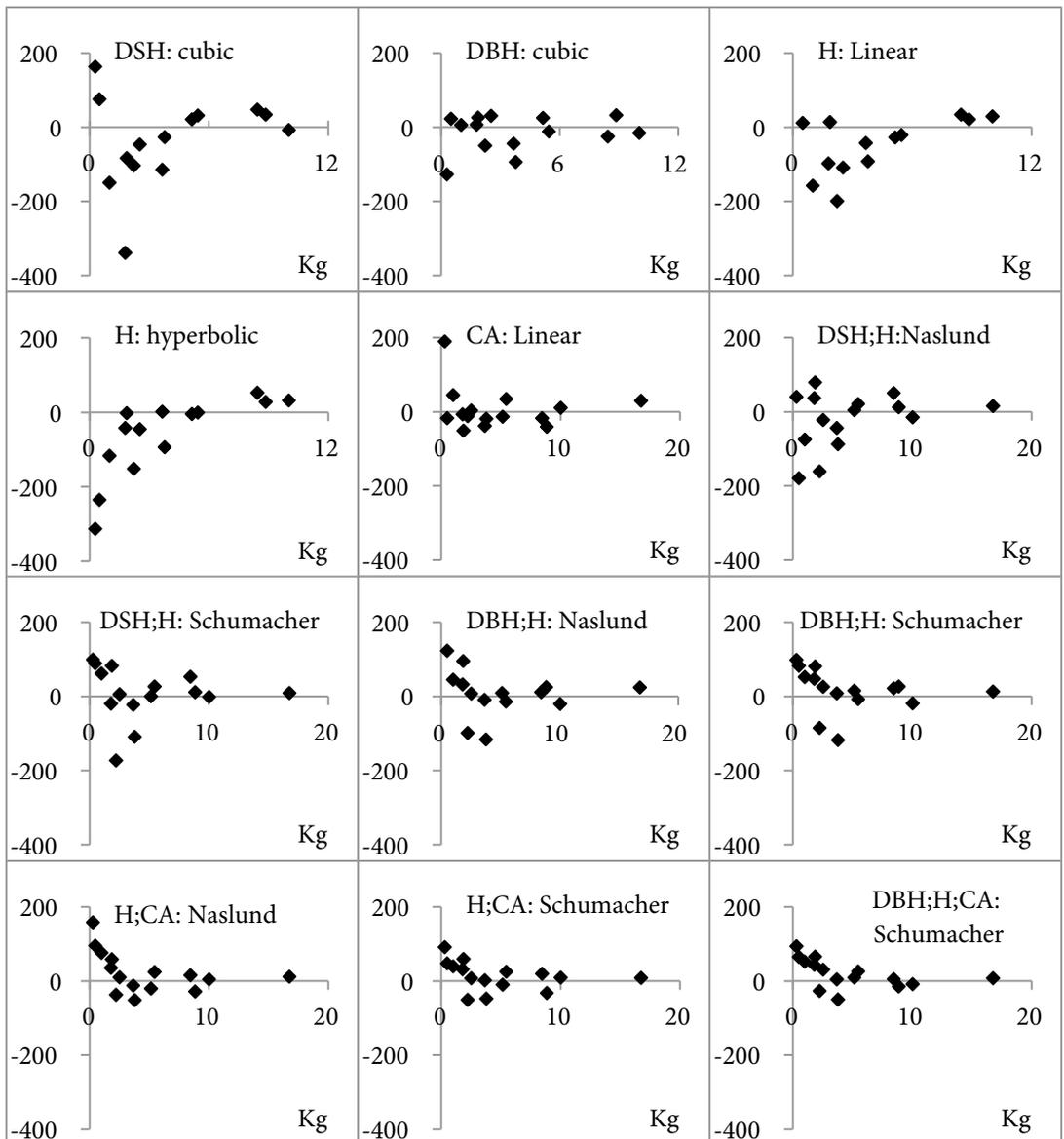


Figure 1. Residual distribution graphs for the developed models expressed in percentage. The y-axis shows the value of the residuals (%) and the x-axis shows the measured mass. In the graph titles, letters before colon indicate the parameters used: plant base diameter (DSH), diameter at breast height (DBH), plant height (H) and crown area (A). The text after colon indicates the model used (see Table 1).

The use of plant height and crown area led to better models, with R^2 of 0.922 for variations of the Naslund model and the Schumacher & Hall model. In both cases, error distribution is fairly uniform around the axis (Figure 1). Lastly, the use of the three parameters (plant and branch base diameter, plant height, and crown area) produced models with little further improvement in relation to models based on plant height and crown area. The small gain in accuracy is not enough to justify the amount of work required to measure DSH.

Regarding the use of coefficients for assessing model adjustment, it can be observed that the model classifications based on the regression coefficient (R^2) are the same provided by the other coefficients in all the studied models. Thus, we did not identify any reason to prefer other indicators rather than R^2 , especially because they demand special calculation steps that are not necessary for calculating R^2 , which is provided by statistical programs after calculating model parameters. However, plotted residuals offer information about trends that are not shown by any of the coefficients used. For instance, it is observed in Figure 1 that the linear model for H produces an error proportional to plant height, which goes against the independence assumption of errors.

Biomass estimation models are traditionally based on measuring plant height and trunk diameter or circumference. Nevertheless, in the case of open savannas, such as degraded areas of Caatinga, the use of crown diameter as a modelling parameter provides an alternative that reduces the need for labour during assessments and may eventually produce better estimates than the traditional method. Models based on CA are more accurate than models based on the combination of DSH and H. The best models are those that combine CA and H. In addition, when we used these parameters, the best coefficients were obtained through variations of the Naslund model and Schumacher & Hall model.

4. CONCLUSIONS

Models based on crown area alone are more precise than models based on plant base diameter and plant height together. The best models use crown area and height together, and were variations of the Naslund and Schumacher & Hall models. The indicators of goodness of fit, rmse, CVrmse and Furnival's index

do not produce differences in classification when compared to the regression index (R_2).

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