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Close relationship between diameters at 30cm height and at breast height (DBH)

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ABSTRACT

This paper proposes the establishment of a second diameter measuring standard at 30cm shoot extension ('diam30') as input variable for allometric biomass estimation of small and mid-sized plant shoots. This diameter standard is better suited than the diameter at breast height (DBH, i.e. diameter at 1.30m shoot extension) for adequate characterization of plant dimensions in low bushy vegetation or in primary forest undergrowth. The relationships between both diameter standards are established based on a dataset of 8645 tree, liana and palm shoots in secondary and primary forests of central Amazonia (ranging from 1-150mm dbh). Dbh can be predicted from the diam(30) with high precision, the error introduced by diameter transformation is only 2-3% for trees and palms, and 5% for lianas. This is well acceptable for most field study purposes. Relationships deviate slightly from linearity and differ between growth forms. Relationships were markedly similar for different vegetation types (low secondary regrowth vs. primary forests), soils, and selected genera or species. This points to a general validity and applicability of diameter transformations for other field studies. This study provides researchers with a tool for the allometric estimation of biomass in low or structurally heterogeneous vegetation. Rather than applying a uniform diameter standard, the measuring position which best represents the respective plant can be decided on shoot-by-shoot. Plant diameters measured at 30cm height can be transformed to dbh for subsequent allometric biomass estimation. We recommend the use of these diameter transformations only for plants extending well beyond the theoretical minimum shoot length (i.e., >2m height). This study also prepares the ground for the comparability and compatability of future allometric equations specifically developed for small- to mid-sized vegetation components (i.e., bushes, undergrowth) which are based on the diam(30) measuring standard.

KEYWORDS: Allometry, Measuring standard, Amazonia, Biomass estimation, Thin shoots.

Relações entre diametros a 30 cm de altura e à altura do peito (DAP)

RESUMO

Este estudo propõe o estabelecimento de um segundo padrão de medição de diâmetro a 30 cm de extensão do tronco ('diam30') para a estimativa alométrica da biomassa de plantas de pequeno até médio porte. Considera-se este padrão de diâmetro mais adequado do que o diâmetro à altura do peito ('DAP', a 1,30m de extensão do tronco) para a caracterização das dimensões de plantas em vegetação baixa ou no sub-bosque da mata primária. O presente trabalho investiga as relações entre os dois padrões de diâmetro, baseado em 8645 troncos de árvores, cipós e palmeiras arbóreas (com diâmetros entre 1 e 150mm DAP) em capoeiras e mata primária da Amazônia Central. Conclui-se que se pode estimar o DAP do diam30 com alta precisão, o erro causado pela transformação dos diâmetros é somente 2-3% para árvores e palmeiras e 5% para os cipós, níveis bem aceitáveis para a maioria dos estudos de campo. As relações entre os diâmetros desviaram levemente da linearidade e são diferentes para os três hábitos de crescimento. No entanto, as equações são bastante similares entre os diferentes tipos de vegetação (capoeira baixa vs. mata primária), solos e gêneros ou espécies, indicando sua aplicabilidade e validade geral para outros estudos de campo. Esse trabalho fornece ao pesquisador de campo uma ferramenta para a estimativa alométrica da biomassa de vegetação baixa ou estruturalmente heterogênea. Em vez de utilizar um único padrão uniforme de diâmetro pode-se escolher livremente e individualmente qual posição de diâmetro melhor representa cada tronco. Os diâmetros a 30 cm de extensão do tronco podem ser transformados para o dap para uma subseqüente estimação alométrica da sua biomassa. Recomenda-se o uso destas transformações de diâmetros somente acima de uma extensão mínima do tronco (>2m de altura). Os resultados do presente trabalho também preparam a base para a comparabilidade e compatibilidade de futuras equações alométricas baseadas no diam(30) para uma melhor estimação da biomassa dos componentes de vegetação baixa e média (arbustos, sub-bosque da mata primária).

PALAVRAS-CHAVE: alometria, padrão de medição, Amazônia, estimativa da biomassa, plântulas

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INTRODUCTION

Contrary to destructive measurement procedures, allometric biomass estimation avoids disturbance of the ecosystem under investigation, which is an important prerequisite in many experimental settings. Furthermore, allometric biomass estimation is far more efficient in terms of labor requirements than the tedious destructive measurements. This makes allometric biomass estimations the preferred method for biomass estimations in field studies, ideally reducing the destructive measurements to some small biomass fractions (i.e., grasses and herbs, stemless palms, litter layer of the O-horizon). Efforts for the development of allometric equations have so far been largely limited to large trees which dominate biomass in mature forests.

A series of allometric equations have been developed for biomass estimation of lowland tropical forests, for primary-forest trees (Overmann *et al*., 1994; Brown *et al*., 1995; Araújo *et al*., 1999; Chave *et al*., 2005), for trees in secondary forest (Nelson *et al*., 1999; Ketterings *et al*., 2001) and for multistrata agroforestry systems (Schroth *et al*., 2002), for lianas (Putz, 1983; Gerwing & Farias, 2000) and for arborescent palms (Brown, 1997; Hughes *et al*., 1999). Stem diameter is used either as a single input-variable or in combination with height or wood density. A common feature of all studies is that they use the standard diameter definition as 'measured at breast height' (DBH, i.e. at 1.30m shoot extension or just above buttress).

Diameter at breast height is a measure well suited for studies investigating large plants. However, dbh does not adequately reflect the dimensions of many small and mid-sized plants of bushy vegetation, lianas and woody undergrowth of primary forests. In a 25-site inventory in central Amazonia, Gehring (2003) found that even though a minimum diameter threshold of 10 cm DBH, commonly used in forest research, covered 90% of total (aboveground) primary forest biomass, such diameter threshold must be considered inadequate for young secondary regrowth with the stems of plants ranging 2½ - 5cm dbh accounting for 16% of the biomass, and shoots thinner than 2½cm dbh adding another 9% to the total biomass in 2- to 3-yr.-old secondary forests. Diameter at breast height is an unsatisfactory measuring standard for such vegetation components, as it only inadequately represents the dimensions of small shoots, thus making allometric biomass estimations hazardous.

We therefore propose the establishment of a second diameter standard at 30cm shoot extension ('diam30') for the allometric biomass estimation of bushes and understory treelets, lianas and palms. We find this measuring standard advantageous in field application, since it adequately represents such small and mid-sized shoots, but at the same time is located well above the thickened stem bases (buttresses) of practically all of these shoots. The diameter at 30cm shoot extension has sporadically been used in other field studies (i.e., Alvarez-Buylla & Martínez-Ramos, 1992; Brown, 1997; Toriola et al., 1998), but systematic research on this diameter standard is so far lacking.

The present paper investigates the relationship between dbh and diam(30), based on a large dataset of tree, liana and tree palm shoots for which the diameter was measured at both heights. We establish diameter transformations and thereby make both measuring standards compatible with each other. This introduces flexibility in the transition range between 'small/thin' and 'large/thick' shoots, and the researcher in the field may choose freely between either dbh or diam(30), deciding case-by-case which diameter standard best represents the actual shoot dimensions. The present study also provides the ground for the urgently needed development of a set of allometric equations for small and mid-sized woody vegetation components and based on diam(30), Gehring *et al.* (2004) make a beginning with their liana allometric equations. Again, the diameter transformations established in the present study ensure the comparability between dbh- and diam(30)-based biomass estimation procedures.

MATERIAL AND METHODS

The study was carried out in central Amazonia at 3°S60°W and 120-150m a.s.l., at 70 – 100km to the north or northeast of the city of Manaus, Brazil. Annual rainfall is 2180mm (average of seven years), with four months of reduced precipitation. Seven primary and thirteen secondary forest sites are clustered in five chronosequences (Figure 1), each containing differently aged secondary forest regrowth ('capoeira') and 1-2 primary forest sites. Secondary regrowth constitutes a successional time series ranging from 2-25 years fallow age and 60-220t ha^{-1} aboveground biomass, the primary forest biomass is estimated at 440t ha^{-1} (Gehring *et al*., 2005). Secondary regrowth developed after first-cycle manual slash-and-burn of primary forest and one year cassava cultivation, two 'degraded' sites suffered a second burn or a prolonged cultivation phase. Soils of most sites are clayey Oxisols (Aplic Acrorthox). Two primary forest sites on sandy Ultisol (Spodic Paleudult) and one secondary forest site on more fertile Humic Paleudult ('terra preta do índio') are included for comparisons. The study sites are described with more detail in Gehring (2003).

For non-round stems, cross-sectional area is best characterized with two or more diameter measurements around the stem. However, the disadvantage of such a procedure is in the large number of measurements required on-field, resulting in elevated labor costs. The present study, therefore, opted for a single-measure diameter-standard as input-variable. Our definition of 'minimum diameters'

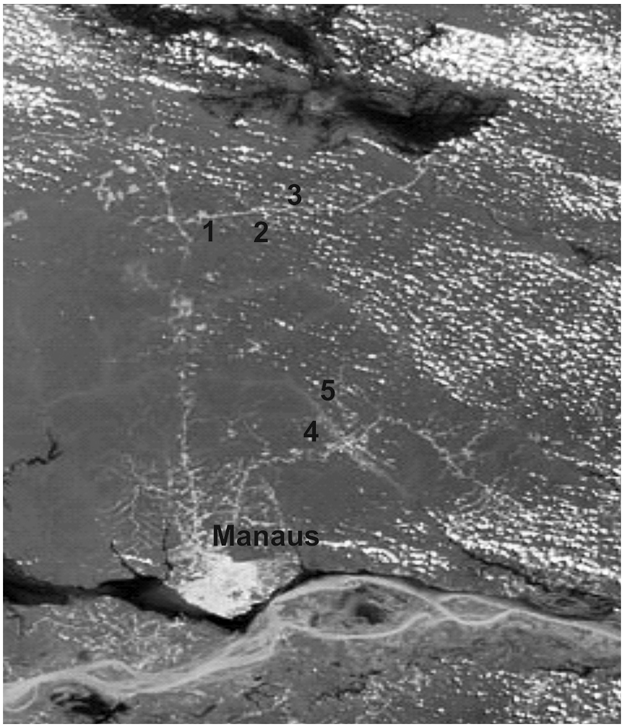

Figure 1 - Satellite image of the Central Amazonian study region and location of the five chronosequences in which the twenty study sites were clustered (image source: NASA).

(diameters measured in the thinnest possible direction of the stem) was both easy to use and not susceptible to measurement bias. We preferred the 'minimum diameter' over the likewise conceivable 'maximum diameter' (applied, i.e., by DeWalt et al., 2000). This decision was based on pre-tests which had shown the minimum diameter to be better correlated with shoot length than the maximum diameter.

Diameters were measured to the next millimeter at 30cm and 1.30m shoot extension from the plant base. Plants with buttresses extending beyond 20cm were excluded from this study.

We measured a total of 8645 stems of trees, lianas and arborescent palms with diameters ranging from 1-150mm dbh. A subset of 2155 trees and 2615 lianas were identified to the species level. Species ranged from representatives of the primary forest undergrowth to fast-growing pioneer species. Some of the characteristic genera also common in other regions of Amazonia are *Cecropia* (Cecropiaceae), *Vismia* (Clusiaceae), *Inga* (Mimosaceae), *Davilla* (Dilleniaceae) and *Memora* (Bignoniaceae).

The data structure represented the actual distribution of plant sizes encountered in the twenty study sites, which was strongly positively skewed (Gehring et al., 2005). Normality was achieved by data transformation to a natural logarithmic (ln) scale preceding the regression analyses. We explored the general validity of our transformation equations with General Linear Modelling (GLM), introducing vegetation type (secondary regrowth vs. primary forest), and the genus (within trees and lianas) as categorical predictors. Generalized linear models differ from the more commonly used multiple regressions as they allow the inclusion of categorical variables and permit the use of interaction terms (McCullagh & Nelder, 1989). All statistical analyses were calculated with STATISTICA 5.1 (StatSoft Inc., 1998), the significance of coefficients is given as * ($p<0.05$), ** ($p<0.01$) and *** ($p<0.001$).

RESULTS AND DISCUSSION

Figure 2 shows the relationship between diameter at 30cm shoot extension and at breast height, the relative difference between diam(30) and dbh was largest in thin stems and asymptotically approached 1:1 inclination with increasing stem girth.

The relationship of ln-transformed dbh and diam(30) can be best described by the polynomial models given in Table 1. The diameter at breast height can be predicted from the diameter at 30cm height with high precision. The error introduced by diameter transformation was only 2-3% for trees and palms, and 5% for lianas, well acceptable in the field for most study purposes.

Generalized Linear Modelling revealed significant effects of vegetation type (secondary vs. primary forest plants) and of taxonomy (main tree and liana genera) on the relationships between diam(30) and dbh (all $p<0.001$), but these factors explained only a very small fraction (0.01 – 0.3%) of total

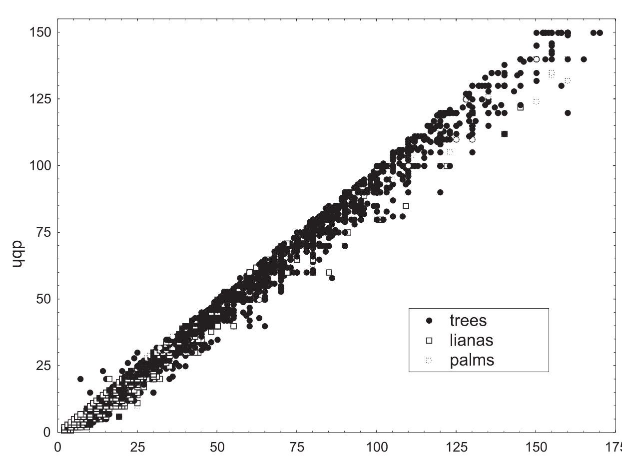

Figure 2 - Relationship between diam(30) and dbh for trees, lianas and palms.

variation any equations between differing groups of plants were very similar. We also did not detect and systematic soil-related differences (clayey Oxisol, sandy Ultisol, organic-rich terra preta do índio; data not shown). Diameter relationships were also very similar among species and genera. Table 2 compares the overall equations of shoots of secondary regrowth and of primary forest.

We exemplarily compare the diameter relationships for two characteristic pioneer trees which differ markedly in their shoot architecture: *Cecropia* spp. and *Vismia guianensis*. Comparison was over the common size range of 10-150mm dbh, the relationship was ln-linear in both cases.

Cecropia spp. ln (dbh) = -0.128 + 1.012 * ln (diam30); $R^2=0.989^{***}$, n=611

Vismia guianensis ln (dbh) = -0.251 + 1.041 * ln (diam30); $R^2=0.971^{***}$, n=154

Both the ratios of diameter to height, and the allometric equations for biomass estimation are known to differ widely between the genera *Cecropia* and *Vismia* (Williamson *et al.*, 1998; Nelson *et al.*, 1999). In contrast, the diameter relationships shown above were similar and do not support systematic differences of this plant trait.

Table 1 - Equations for the prediction of DBH from diam(30) of trees, lianas and palms model: dbh = a + α * $(\text{diam30})^2$ + β * diam30 (using ln-transformed data)

		Coefficient	±SE	p	Adjusted R^2
All plants (n=8645)	a	-0.778	0.015	***	
	α	-0.028	0.000	***	0.978
	β	1.261	0.010	***	
Trees (n=5264)	a	-1.038	0.031	***	
	α	-0.045	0.002	***	0.978
	β	1.416	0.018	***	
Lianas (n=3140)	a	-0.689	0.027	***	
	α	-0.014	0.005	**	0.945
	β	1.198	0.023	***	
Palms (n=241)	a	-0.477	0.131	***	
	α	-0.022	0.010	*	0.980
	β	1.185	0.073	***	

Table 2 - Comparison of equations for the prediction of dbh from diam(30) in secondary regrowth and in primary forest plants model: DBH = a + α * $(\text{diam30})^2$ + β * diam30 (using ln-transformed data).

		Coefficient	±SE	p	Adjusted R^2
Secondary forest plants	a	-0.744	0.020	***	
(n=6422)	α	-0.023	0.002	***	0.980
	β	1.255	0.013	***	
Primary forest plants	a	-0.731	0.027	***	
(n=2223)	α	-0.009	0.003	***	0.972
	β	1.192	0.020	***	

The similarity of diameter relationships for stems from a wide spectrum of differing plant and vegetation types and the low portion of variability explained by the introduction of differing plant categories (vegetation types, taxonomy) points to a general validity of the diameter transformations established by this study. Development of equations for each specific situation will, therefore, only result in small increases of the overall precision. Nevertheless, a verification of such general validity of diameter relationships in other biomes (i.e., cerrado and other savanna types) poses a necessary and rewarding task.

The present study provides researchers with a tool for the allometric biomass estimation in low or structurally heterogeneous vegetation. Plant diameter can be measured at 30cm height and subsequently be transformed to dbh for application of the wide array of allometric biomass equations initially cited. This procedure is valid only for plants extending well beyond the theoretical minimum shoot length (i.e. >2 meters) and above the minimum dbh covered by the respective allometric biomass equations. Future research in allometry needs to give more attention to smaller vegetation components and should establish proper allometric biomass equations for bushes, treelets and undergrowth palms, based on the diam(30cm) standard. Gehring et al. (2004) made a beginning, opting for the diam(30cm) as input variable for their liana allometric biomass equations, because this diameter better represented the liana vegetation in the study area.

We see the main improvement achieved by this study in the flexible choice of diameter measurement standards. Instead of applying a uniform diameter standard, the measuring position which best represents the respective plant can be decided on shoot-by-shoot. The here established diameter transformations are furthermore an important prerequisite for the development of a set of allometric equations for small- and mid-sized vegetation components based on diam(30) as input variable but nevertheless comparable and compatible with the existing dbh-based equations of larger plant shoots.

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