Available online at www.sciencedirect.com
SCIENCE DIRECT®
Forest Ecology and Management 228 (2006) 61–68
Forest Ecology and Management
www.elsevier.com/locate/foreco

Estimating the aboveground biomass and wood volume of savanna woodlands in Brazil's Pantanal wetlands based on allometric correlations

Suzana M. Salis [a],*, Marco A. Assis [b], Patrícia P. Mattos [c], Antonio C.S. Pião [b]

[a] Embrapa Pantanal, Caixa Postal 109, 79320-900 Corumbá, MS, Brazil
[b] Universidade Estadual Paulista, Caixa Postal 199, 13506-900 Rio Claro, SP, Brazil
[c] Embrapa Florestas, Caixa Postal 319, 83411-000 Colombo, PR, Brazil

Received 8 March 2005; received in revised form 16 February 2006; accepted 18 February 2006

Abstract

The quantity and distribution of vegetal biomass are important aspects to consider in ecosystem studies. However, little information is available about Brazil's Pantanal woodland savannas. This work involved the development of regression equations of the aerial biomass and wood volume of native tree species in a region of woodland savanna on Rio Negro farm in the Pantanal of Nhecolandia, Brazil. Samples were taken from 10 trees of each of five species: *Protium heptaphyllum* (Aubl.) Marchand, *Magonia pubescens* A. St.-Hil., *Diptychandra aurantiaca* Tul., *Terminalia argentea* Mart. and Zucc. and *Licania minutiflora* (Sagot) Fritsch and from a miscellaneous group of 11 different species. Linear and nonlinear regression analyses were developed relating the diameter at breast height to the dry weight of wood, branches and leaves, wood volume and total aerial biomass. All the regressions showed a significance of $P < 0.05$ and an R^2 close to or above 0.8. The biomass curve predicted by linear regression analysis of the studied species was similar to the nonlinear regression, with the exception of *L. minutiflora* and the miscellaneous group. The breast height diameter proved a good choice for estimating biomass and wood volume. The estimated wood volume and biomass of the Pantanal woodland savanna is crucial information for understanding the carbon cycle and for ensuring the region's conservation and sustainable use.

Keywords: Dry weight; Linear regression; Nonlinear regression; Wood volume

1. Introduction

Knowledge of the quantity and distribution of vegetal biomass is important information in ecosystem studies. Details of succession studies, nutrient cycles, production and competition in vegetal communities usually require estimation of vegetal biomass and production (Tausch and Tueller, 1988). Despite their importance these aspects are not well known, particularly in the case of tropical forests, due to the difficulties involved in obtaining field data.

Anderson and Ingram (1993) recommended the use of direct biomass estimation (destruction of samples) in natural forests with large numbers of species or by indirect biomass estimation (regression equation) of the main species that contribute individually with 10% or more of the total biomass. Other species whose biomass contributes with less than 10% can be combined in a single category or estimated by regression equation. The destructive sampling method involving the formulation of regression equations based on more easily measured variables is a technique frequently used for predicting biomass (Hay et al., 1982). The most common parameters used are trunk or stem diameter, plant height, and crown volume of the plant (Tausch and Tueller, 1988). One advantage of this method is that, after a specimen has been destroyed, the remaining specimens are easier to estimate, thus saving time, energy and money (Hay et al., 1982) while simultaneously saving the vegetation under study.

In a study to determine biomass in a tropical area, Brown et al. (1989) came up with a more precise global equation for rain forests (R^2 above 0.8) compared with dry forests (R^2 below 0.7), to offset the paucity of data available on tropical dry forests (rainfall of less than 1500 mm per year). The literature contains few reports about the vegetal biomass produced in Brazil's ecosystems, and most of the available data consists only of estimates of the biomass in the Amazonian Tropical Rain Forest (Fittkau and Klinge, 1973; Jordan and Uhl, 1978; Hase et al., 1985; Brown et al., 1989; Dantas, 1989; Figueiredo

---

* Corresponding author. Tel.: +55 67 3233 2430; fax: +55 67 3233 1011.
E-mail address: smsalis@cpap.embrapa.br (S.M. Salis).

0378-1127/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2006.02.025

et al., 2000; Cummings et al., 2002). However, the literature does include reports on Brazil's tropical regions with forest vegetation and drier climates containing estimates of biomass production in gallery forests (Imaña-Encinas et al., 1995; Moreira-Burger and Delitti, 1999), in semiarid tropical woodland (Schacht et al., 1988), in savannas (Castro and Kauffman, 1998) and in the Pantanal (Haase and Haase, 1995).

In this study, regression equations were developed for the more abundant tree species and for a group of species in a woodland savanna on the Rio Negro farm in Nhecolandia, Pantanal, which allowed for an indirect estimation of the aerial biomass and for an investigation of their variations. Our purpose is to contribute with information on biomass and wood volume for ecology studies and for the sustainable management of the region's natural resources. Estimates of the biomass and wood volume in woodland savanna areas of the Pantanal wetlands are essential for an understanding of the carbon cycle and for establishing sustainable forest management in the region, considering the annual wood production rate.

2. Material and methods

2.1. Study area

The trees were sampled in a woodland savanna ('cerradão') in the Rio Negro farm in, Nhecolandia, Pantanal, state of Mato Grosso do Sul, Brazil (19°30′S, 56°12.5′W). The Nhecolandia Pantanal is a low-lying floodplain, 75–170 m in altitude and consisting of a patchwork of ponds, seasonal ponds, and seasonally flooded field with patches of slightly elevated ground (1–2 m above the seasonal flood field) bearing forest or savanna vegetation (Ratter et al., 1988). The woodland savanna occurs in elevations called regionally 'cordilheiras' (ridges). The trees possessed an average height of 7–12 m, with some trees as tall as 20 m. The more common species in the canopy are *Protium heptaphyllum*, *Diptychandra aurantiaca*, *Magonia pubescens*, *Terminalia argentea* and *Licania minutiflora* (Salis, 2004). The region has a tropical/megathermal climate of the Aw type according to the Köppen's classification, with an average temperature of over 18 °C in the coolest month, dry winters and rainy summers. The average annual rainfall and temperature from 1977 to 1995 were, respectively, 1183 mm and 25.5 °C (Soriano, 1999). The highest average rainfall, 216.8 mm, occurs in January and the lowest, 19.7 mm, in July (Soriano, 2002). The maximum absolute temperatures can reach 40 °C from October to January, while the minimum can go down to almost 0 °C in June and July (Embrapa, 1997). The region can present an annual water deficit of over 300 mm, mainly between August and October (Soriano, 1999).

2.2. Studied species

The five most abundant species in the woodland savanna of Rio Negro Farm were selected from a phytosociological study (Salis, 2004) and individual equations were developed for each one, as recommended by Anderson and Ingram (1993). The five species and their main characteristics, according to Prance (1972), Lorenzi (1992), Pott and Pott (1994) and Missouri Botanical Garden (2003) are given below.

2.2.1. *D. aurantiaca* Tul. (carvão-vermelho)—Leguminosae

Tree varying in height from 5–20 m, a straight stem, 20–40 cm diameter, with thick reddish bark. Deciduous during winter. Composite even-pinnate leaves, with 3–6 pairs of glabrous leaflets, coriaceous (3–6 cm long and 1.5–3.0 cm broad). The wood is moderately heavy, hard, resistant and durable even when exposed to weather. It is used in the Pantanal for fence poles and is appropriate for construction, lathing and rails. It occurs in woodland savannas, in transitional semideciduous forest in Brazil's states of Goiás, Mato Grosso do Sul, Minas Gerais and São Paulo and also in Bolivia.

2.2.2. *L. minutiflora* (Sagot) Fritsch (cedro-d'água)—Chrysobalanaceae

Basionym and synonyms: *Moquilea minutiflora* Sagot, *Licania rondonii* Pilg., *Moquilea riparia* Gleason, *Licania riparia* (Gleason) Standl. tree 6–16 m in height, rough trunk with a 20–40 cm diameter. Simple, coriaceous (length: 5–11 cm, width: 2–6 cm), glabrous leaves sparsely pubescent when young. Light wood, not used in the Pantanal. This tree occurs in woodland savannas ('cerradão') in Mato Grosso do Sul state, and in nonfloodable forests in Amazonia and the Guyanas.

2.2.3. *M. pubescens* A. St.-Hil. (timbó)—Sapindaceae

Synonyms: *Magonia glabrata* A. St.-Hil. Wide-crowned, thick-branched tree 6–16 m tall, the bark of its 20–45 cm diameter trunk has the appearance and texture of a hammered copper bowl. Deciduous. Composite odd-pinnate leaves, with 3–5 pairs of glabrous or pubescent leaflets (6–12 cm long and 3–5 cm wide). Heavy hardwood, termite-resistant, used for construction, fences and electricity poles. It occurs in woodland savannas and savannas in Brazil's mid-western to northeastern regions, in Paraguay and Bolivia.

2.2.4. *P. heptaphyllum* (Aubl.) Marchand (almécega)—Burseraceae

Synonyms: *Icica heptaphylla* Aubl. Tree, sometimes having more than one trunk, 5–18 m tall, smooth-barked trunk, 20–40 cm diameter. Evergreen. Composite odd-pinnate leaves, usually with seven glabrous leaflets (7–10 cm long, 4–5 cm wide). Wood of medium weight, hard and elastic, durable indoors, used for lathwork, carpentry and electricity poles. This tree occurs in forests and woodland savannas throughout Brazil and South America, from the Guyanas and Colombia to Argentina.

2.2.5. *T. argentea* Mart. and Zucc. (capitão)—Combretaceae

Tree 5–16 m in height, trunk with dark bark, 20–40 cm diameter. Deciduous. Simple leaves (6–14 cm long), pubescent when young. Hard wood of medium weight used in construction, in lathwork and as fence and electricity poles. This tree occurs in semideciduous forests and woodland savanna in the Brazilian states of Minas Gerais, Maranhão, Goiás, Mato Grosso do Sul, São Paulo and Paraná, and in Bolivia.

The other trees species from the community are represented by a group of 11 less abundant species selected randomly: *Agonandra brasiliensis* Miers ex Benth. and Hook f., *Alibertia sessilis* (Vell.) K. Schum., *Astronium fraxinifolium* Schott ex Spreng., *Hymenaea stigonocarpa* Mart. ex Hayne, *Pouteria* sp., *Rhamnidium elaeocarpum* Reissek, *Couepia grandiflora* (Mart. and Zucc.) Benth. ex Hook f., *Sapium haematospermum* Müll. Arg., *Simarouba versicolor* A. St.-Hil., *Swartzia jorori* Harms and *Vatairea macrocarpa* (Benth.) Ducke.

2.3. Biomass

Ten trees of each of the five species selected were randomly sampled, felled and weighed, following the methodology described by Anderson and Ingram (1993). These tree species were classified by size, according to the diameters found in the sampling site and reported in a phytosociological study (Salis, 2004). Of the remaining community, 11 trees from different species were randomly sampled and analyzed as one category (or equation) representing the species that contributed less to the biomass.

Measurements were taken of the diameter of each standing tree at breast height (BHD) and the crown area (represented by the area of the crown projection on the ground, estimated by eight measurements distributed equidistantly around the trunk), and of its trunk height and total height after it was felled. The individual trees were cut down at a height of approximately 10 cm from the ground and their branches and leaves lopped off the trunk and weighed immediately with field scales. The trunks were sectioned into 1 m long logs and their diameter measured to estimate their volume. A 5–10 cm-wide slices were cut transversally from each log as subsamples to estimate the dry weight of trunks and branches. The leaf samples, with a total fresh weight of 15–25%, were taken from various positions of the crown.

The slices of wood were dried at ambient temperature for six months, while the leaf samples were oven-dried at 60 °C. The weight of the whole trunk, branches and leaves was estimated from these samples.

The wood volume of the trunk with bark (V) was calculated using the formula:

$$V = \frac{\pi H}{3(R^2 + r^2 + Rr)},$$

where H = height, R = largest radius and r = smallest radius.

The regression analyses were calculated using Systat software (Wilkinson, 1998). The measurements (diameter, volume, and weight of trunk, branches and leaves) were used to determine a and b constants from the allometric equation $Y = aX^b$, where Y = dry weight or volume and X = BHD diameter. This equation describes the specific constant, or the plant's relative size to shape growth ratio (Niklas, 1994). The allometric equation was linearized by applying the logarithm $\ln Y = \ln a + b \ln X$, also known as a log–log regression (Grove and Malajczuck, 1985). Log transformation tends to equalize the variance throughout the data of the samples, although it introduces a systematic error, thus requiring a correction factor to neutralize the error (Baskerville, 1972; Lee, 1982; Sprugel, 1983). The correction factor proposed by Sprugel (1983) was used for some species (*D. aurantiaca*, *P. heptaphyllum* and *T. argentea*), when biomass was found to have been underestimated. Sprugel's (1983) correction factor (CF) presents the following formula:

$$\mathrm{CF} = \exp\left(\frac{E^2}{2}\right),$$

where E is the standard estimated error of the analysis.

To ascertain the normality of residues from the linear regressions presenting outlier values, as defined by Wilkinson (1990), symmetry and kurtosis tests were carried out (g_1 and b_2), based on Zar (1999) and D'Agostino and Tietjen (1971).

Whenever the linear regression analysis presented a determination coefficient (R^2) of less than 0.8, other models were tested (Anderson and Ingram, 1993), including tree diameter, height ($\ln D^2H$) and crown area. The studentized residues of each tested model were plotted versus the estimated value, ensuring that the data was congruent with the assumptions of the analysis. The selection of the best equation for each case was based on the highest R^2 within the lowest standard error (E) and by observation of the residues (Schacht et al., 1988). Tausch and Tueller (1988) stated that log–log regression, which is widely used to estimate biomass, is less precise and accurate than nonlinear regression. Therefore, our calculations for all the species were done by nonlinear regression. Whenever the allometric curves generated by linear and nonlinear regression were similar, linear regression prevailed since it is the simpler one. Nonlinear regression was used for species whose linear regression presented $R^2 < 0.8$ and whose allometric curves differed.

3. Results

All the regression analyses showed a level of significance of $P < 0.05$ and R^2 values close to or above 0.8 (Table 1). Most species showed a good dry weight to wood volume ratio at breast height diameter. The linear regression of most of the species presented a biomass curve predictably similar to the one obtained by nonlinear regression, except for *L. minutiflora* and the group of 11 species. *L. minutiflora* showed an architecture (shape) strongly affected by shading, with variations in tree height and development of an irregular crown eccentric in relation to the stem. Linear regressions were tested for *L. minutiflora* and the group of 11 species, including tree height and crown area. The height contributed slightly to improve the linear regression model. The inclusion of the crown area contributed somewhat to improve the linear regression model for estimating the biomass of branches and leaves of the group of 11 species. However, the curve obtained by nonlinear regression was more precise than the one provided by linear regression to improve calculations of the height and crown area.

Table 1
Wood volume, total, trunk, branch and leaf biomass of trees from the Pantanal estimated by linear (L) and nonlinear (NL) regression

Species	Part	Equation	ln a(a)	b	R^2	E	CF
Diptychandra aurantiaca, $D = 5–35$ cm; $n = 10$	Total biomass	L	−2.119	2.380	0.986	0.167	1.0140
	Volume[a]	L	−9.810	2.573	0.990	0.153	–
	Trunk	L	−2.781	2.382	0.988	0.151	1.0115
	Branches	L	−3.314	2.508	0.952	0.329	1.0556
	Leaves	L	−3.289	1.575	0.795	0.469	1.1101
Protium heptaphyllum, $D = 8–36$ cm; $n = 10$	Total biomass	L	−2.083	2.536	0.971	0.250	–
	Volume	L	−8.914	2.266	0.974	0.212	1.0227
	Trunk	L	−2.065	2.150	0.976	0.191	1.0184
	Branches	L	−3.554	2.868	0.911	0.510	–
	Leaves	L	−4.319	2.076	0.912	0.367	1.0697
Magonia pubescens, $D = 7$ to 35 cm; $n = 10$	Total biomass	L	−2.888	2.795	0.994	0.123	–
	Volume	L	−8.730	2.269	0.994	0.100	–
	Trunk	L	−2.525	2.411	0.984	0.172	–
	Branches[a,b]	L	−3.972	2.937	0.987	0.163	–
	Leaves	L	−4.998	2.342	0.881	0.490	–
Terminalia argentea, $D = 6–31$ cm; $n = 10$	Total biomass	L	−1.915	2.409	0.987	0.172	1.0149
	Volume	L	−8.285	2.113	0.949	0.300	1.0460
	Trunk	L	−1.380	1.984	0.950	0.281	–
	Branches	L	−5.161	3.195	0.920	0.581	1.1839
	Leaves	L	−4.074	1.967	0.807	0.592	1.1915
Licania minutiflora, $D = 10–36$ cm; $n = 10$	Total biomass	L	−2.265	2.386	0.912	0.322	–
	Volume[a,b]	L	−9.376	2.439	0.975	0.176	–
	Trunk	NL	(0.031)	2.556	0.926	–	–
	Branches	NL	(0.140)	2.076	0.948	–	–
	Leaves	NL	(0.030)	1.532	0.898	–	–
Group of 11 species, D = 6–27 cm; $n = 11$	Total biomass	L	−2.566	2.533	0.906	0.451	–
	Volume	NL	(0.0005)	1.899	0.973	–	–
	Trunk	NL	(0.339)	1.836	0.950	–	–
	Branches	NL	(0.011)	2.905	0.868	–	–
	Leaves	NL	(0.0001)	3.756	0.903	–	–

Constants (a and b) calculated by linear ($\ln Y = \ln a + b \ln D$) or nonlinear ($Y = aD^b$) regression, where Y = dry weight or wood volume, D = diameter at breast height, R^2 = square of the correlation coefficient, E = estimated standard error, and CF = correction factor.

[a] Regression with an outlier value.

[b] Regression with $n = 9$.

Crown eccentricity was also observed in *M. pubescens*, *T. argentea* and *D. aurantiaca*, but to a lesser degree than in *L. minutiflora*. *P. heptaphyllum* presented a well developed and regularly distributed crown around the trunk, even in conditions of deep shade.

Three of the linear regressions produced outlier values (Table 1). For *D. aurantiaca* the outlier value was kept in the analyses, since it was considered a normal variation of the species and did not affect the normality of the residue or the slope of the regression line. *M. pubescens* and *L. minutiflora* outlier values were excluded from the linear regression to increase the curve's predictability. Although variations can occur in nature without interfering in the normality of residues, the outlier values interfered strongly in the inclination of the curve. When these values were excluded from the linear regression, the resulting curve was similar to the one generated by nonlinear regression. The curves generated by linear and nonlinear regression are not presented in this paper.

Fig. 1 illustrates the linear regression and the confidence interval. The regressions for the leaves presented the lowest confidence interval and R^2, with a greater number of dispersed points.

The slope of the regression line for the tree trunk volume was similar for all the species (Fig. 2).

The regression curves that show the allometric correlation between breast height diameter and total biomass (trunk + branches + leaves) of the studied species (Fig. 3) were calculated using the values listed in Table 1 with the equation $Y = aX^b$. *M. pubescens*, which presented the greatest biomass, is a big tree with a large crown of thick branches and heavy wood. The wood of the other trees is also heavy, except for *L. minutiflora* and some of the species of the group of 11 trees, but no other trees except *P. heptaphyllum*, the second species in biomass, have such a well-developed crown.

The percentage of trunk and leaf biomass was found to be greater in trees with smaller diameters (Table 2), while trees with larger diameters presented a higher percentage of branch biomass than those with smaller diameters.

4. Discussion

The allometric equation $Y = aX^b$ obtained by linear or nonlinear regression represented well the correlation between breast height diameter and biomass, as reported by Clough and

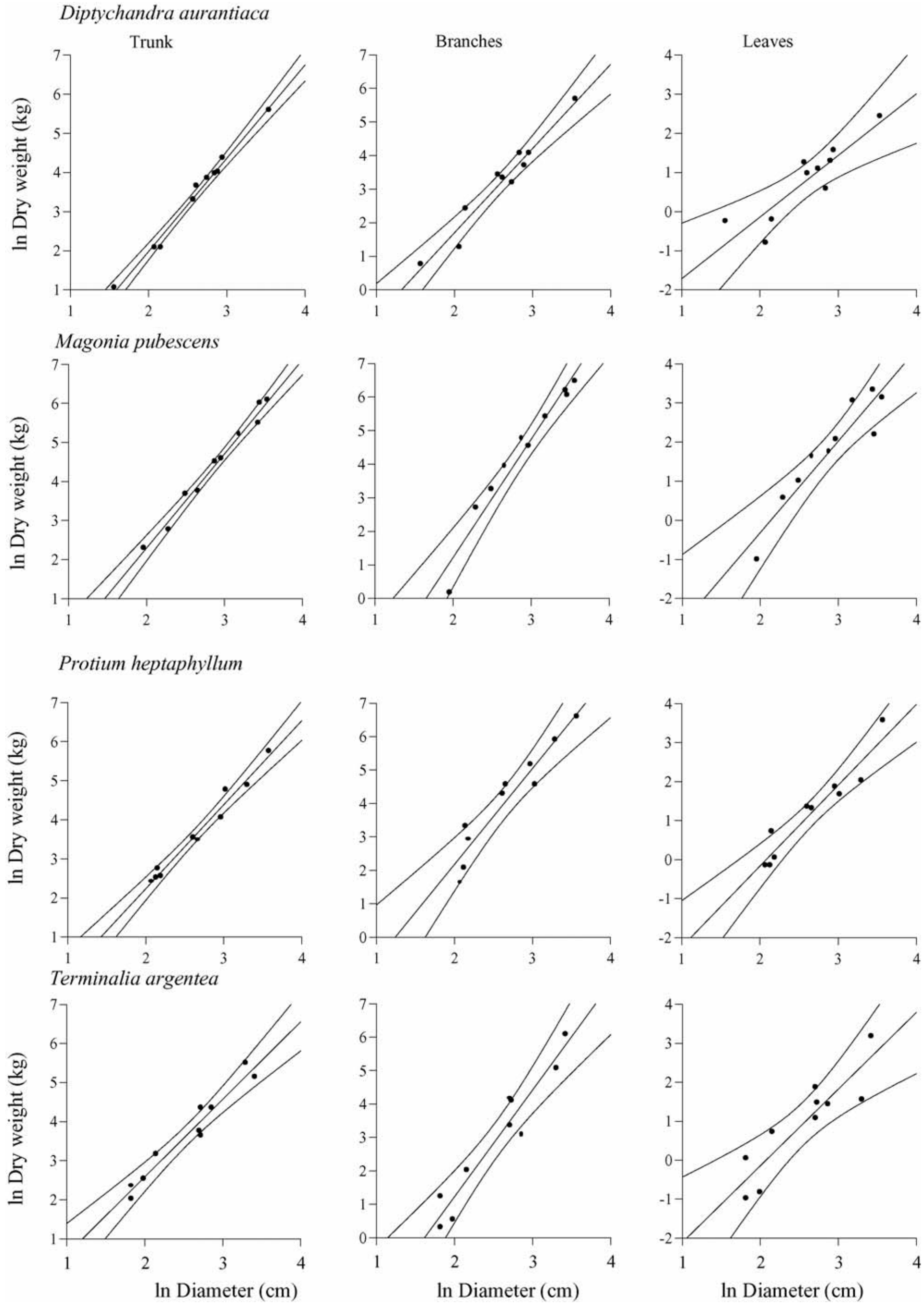

Fig. 1. Linear regressions (log–log) with 95% confidence interval for the five species studied.

Scott (1989) and Niklas (1994). However, Tausch and Tueller (1988) stated that the log-log regressions normally used to estimate biomass are less precise and accurate than nonlinear regression. The curves obtained by linear and nonlinear regression for most of the studied species were similar, sometimes coincident, mainly in terms of total biomass, trunk and wood volume.

The curves used for estimating leaf and branch biomass presented a greater natural variation, with lower R^2 and confidence intervals. This can be explained by the differences in crown development due to shading and to the different stages of leaf expansion or maturation. *P. heptaphyllum* presented a well developed crown distributed regularly around the trunk, even under deep shade, contradicting the species' classification as a heliophyte (Lorenzi, 1992).

Most of the species were tested by linear regression using other estimation models that included more variables such as height and canopy area. However, this led to only a slight improvement of R^2 and residues, so the inclusion of those models was not justified. The choice therefore fell on linear equations using the simplest model and taking only diameter as the variable.

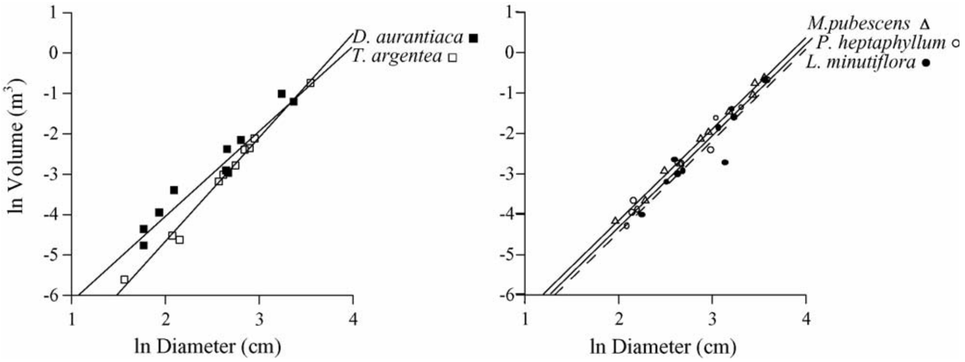

Fig. 2. Linear regression (log–log) to estimate wood volume of the trunks of the five species studied.

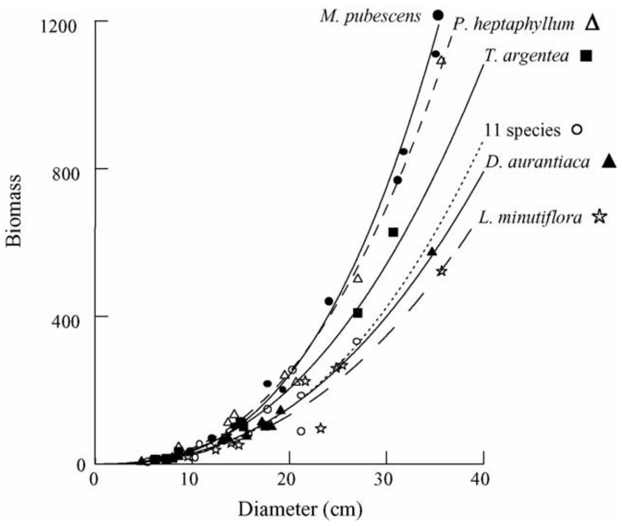

Fig. 3. Total biomass (dry weight) by allometric equation ($Y = aX^b$) calculated for all the species studied.

However, when a wider dispersion of the points occurred, the nonlinear model proved superior to the linear one, particularly for the group of 11 species and for *L. minutiflora*. In those cases, the height contributed little to improve the linear regression model, although some authors have suggested that the height increases the predictability of biomass (Schacht et al., 1988; Gillespie and Cunia, 1989). The nonlinear regression curve provided a better estimate of the biomass of tree with larger diameters (BHD > 20 cm). It was noticed that in this curve that for trees with diameters of less than 20 cm the leaf biomass may be underestimated or the biomass of the trunks overestimated.

Rather than correcting an underestimate, the use of Sprugel's (1983) correction factor may overestimate the biomass, mainly in the case of trees with a diameter of more than 30 cm (Westmann and Rogers, 1977; Tausch and Tueller, 1988). This effect was very evident in all the curves generated for *M. pubescens*. Some authors use no correction at all, since the difference in biomass estimates is considered negligible

Table 2
Biomass percentage of the trees' components classified by trunk diameter

Species	*D* (cm)	Trunk (%)	Branches (%)	Leaves (%)
Diptychandra aurantiaca	5–15	51.18 ± 10.24	42.67 ± 10.33	6.15 ± 4.20
	15–25	55.35 ± 6.63	41.49 ± 7.53	3.16 ± 1.07
	25–35	47.53	50.46	2.01
Licania minutiflora	5–15	59.17 ± 12.22	37.42 ± 10.43	3.41 ± 2.10
	15–25	41.36 ± 22.91	57.06 ± 23.31	1.58 ± 0.43
	25–35	48.96 ± 9.20	49.32 ± 8.63	1.72 ± 0.57
Magonia pubescens	5–15	59.26 ± 19.26	36.34 ± 18.29	4.40 ± 1.04
	15–25	44.84 ± 4.22	51.36 ± 4.61	3.80 ± 1.07
	25–35	39.87 ± 8.45	57.84 ± 7.15	2.29 ± 1.33
Protium heptaphyllum	5–15	42.34 ± 16.18	53.82 ± 16.78	3.84 ± 0.84
	15–25	39.18 ± 20.71	58.29 ± 20.53	2.53 ± 0.18
	25–35	27.56 ± 2.15	70.07 ± 3.33	2.37 ± 1.18
Terminalia argentea	5–15	68.54 ± 19.71	26.16 ± 18.44	5.30 ± 2.42
	15–25	61.07 ± 20.18	35.32 ± 19.74	3.61 ± 0.84
	25–35	43.95 ± 23.27	53.55 ± 21.35	2.50 ± 1.92
Group of 11 species	5–15	64.75 ± 20.82	28.18 ± 16.34	7.07 ± 6.24
	15–25	55.63 ± 8.93	40.92 ± 8.98	3.45 ± 1.07
	25–35	42.29	51.98	5.73

Values are shown in percentage with standard deviation. Values without standard deviation represent only one tree of its class.

(Malimbwi et al., 1994). However, it is advisable to analyze each case individually to ascertain the need to use the correction factor in biomass estimates.

The leaf biomass contributed the least to the tree's total biomass (usually not more than 5%), which is expected in arboreal species. Working with trees in swampy areas, semideciduous forests and woodland savannas, Clough and Scott (1989), Higuchi et al. (1994) and Haase and Haase (1995), respectively, observed a similar leaf biomass contribution of about 5%. However, Haase and Haase (1995) found that the leaves of *Vochysia divergens*, a common species in gallery forests, accounted for about 10% of the tree's total biomass.

5. Conclusions

Linear regression (log–log) proved to be the simplest and most accurate method to estimate the total biomass and volume of all the species studied here (*D. aurantiaca*, *L. minutiflora*, *M. pubescens*, *P. heptaphyllum* and *T. argentea*).

Nonlinear regression was more efficient than linear regression for estimating the trunk, branch and leaf biomass of *L. minutiflora* and of the group of 11 species that presented a greater dispersion of points.

The breast height diameter, a simple measurement used in forest studies, was confirmed as an excellent choice for estimating biomass and volume, with good results by both linear and nonlinear regressions.

Acknowledgements

The authors are indebted to Reinaldo Lourival, of Conservation International in Brazil, for his assistance. Sincere thanks are also due to the entire staff of the Rio Negro farm for their hospitality, to Sr. Baiano, a ''mateiro'', for his assistance in the fieldwork, to our colleagues Oslain, Admar, Maciel, Murilo, Airton and Haroldo at Embrapa Pantanal for their invaluable and willing help in collecting samples, and to Enede and Wibert for their assistance in the leaf weighing procedures.

References

Anderson, J.M., Ingram, J.S.I. (Eds.), 1993. Tropical Soil Biology and Fertility: A Handbook of Methods. 2nd ed. CAB International, Oxon, p. 221.

Baskerville, G., 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2, 49–53.

Brown, S., Gillespie, A.J.R., Lugo, A.E., 1989. Biomass estimation for tropical forests with applications to forest inventory data. For. Sci. 35 (4), 881–902.

Castro, E.A., Kauffman, J.B., 1998. Ecosystem structure in the Brazilian Cerrado: a vegetation gradient of aboveground biomass, root mass and consumption by fire. J. Tropical Ecol. 14, 263–283.

Clough, B.F., Scott, K., 1989. Allometric relationships for estimating above-ground biomass in six mangrove species. For. Ecol. Manage. 27, 117–127.

Cummings, D.L., Kauffman, J.B., Perry, D.A., Hughes, R.F., 2002. Above-ground biomass and structure of rainforests in the southwestern Brazilian Amazon. For. Ecol. Manage. 163, 293–307.

Dantas, M., 1989. Studies on Succession in Cleared Areas of Amazonian Rain Forest. PhD Thesis. Oxford University, Oxford, England, 397pp.

D'Agostino, R.B., Tietjen, G.L., 1971. Simulation probability points of b2 for small samples. Biometrika 58, 669–672.

Embrapa., 1997. Boletim Agrometeorológico: 1986–1996 (Fazenda Nhumirim). Boletim Agrometeorológico 3. Embrapa—Centro de Pesquisa Agropecuária do Pantanal, Corumbá, 81pp.

Figueiredo, E.O., Pereira, N.W.V., Wadt, L.H.O., 2000. Avaliação da composição estrutural e biomassa viva acima do solo, em florestas sob efeito da fragmentação na Amazônia Ocidental. Boletim de Pesquisa 26, Embrapa Acre, Rio Branco, 27pp.

Fittkau, E.J., Klinge, H., 1973. On biomass and trophic structure of the Central Amazonian Rain forest ecosystem. Biotropica 5, 2–14.

Gillespie, A.J.R., Cunia, T., 1989. Linear regression models for biomass table construction, using cluster samples. Can. J. For. Res. 19, 664–673.

Grove, T.S., Malajczuck, N., 1985. Biomass product by trees and understory shrubs in an age series of *Eucalyptus diversicolor* F. Muell. Stands. For. Ecol. Manage. 11, 59–74.

Haase, R., Haase, P., 1995. Above-ground biomass estimates for invasive trees and shrubs in the Pantanal of Mato Grosso, Brazil. For. Ecol. Manage. 73, 29–35.

Hase, H., Foelster, H., Lindheim, M., 1985. On the accuracy of estimating aboveground tree biomass in a evergreen forest near Manaus, Brazil. A simulation study. Biotropica 17, 191–195.

Hay, J.D., Henriques, R.P.B., Costa, S.R.A., 1982. Uma avaliação preliminar da possibilidade de usar equações de regressão para estimativas de biomassa na restinga. Rev. Brasil. Bot. 5, 33–36.

Higuchi, N., Santos, J.M., Imanaga, M., Yoshida, S., 1994. Aboveground biomass estimate for Amazonian dense tropical moist forests. Mem. Fac. Agric. Kagoshima Univ. 30, 43–54.

Imaña-Encinas, J., Paula, J.E., Kleinn, C., 1995. Wood biomass of one Gallery Forest. Pesquisa Agropec. Brasil. 30, 421–427.

Jordan, C.F., Uhl, C., 1978. Biomass of a ''tierra firme'' forest of the Amazon Basin, near San Carlos Del Rio Negro, Venezuela. Oecol. Plantarum 13, 387–400.

Lee, C.Y., 1982. Comparison of two correction methods for de bias due to the logarithmic transformation in the estimation of biomass. Can. J. For. Res. 12, 326–331.

Lorenzi, H., 1992. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Plantarum, Nova Odessa, pp 352.

Malimbwi, R.E., Solberg, B., Luoga, E., 1994. Estimation of biomass and volume in Miombo woodland at Kitulangalo Forest Reserve, Tanzania. J. Tropical For. Sci. 7, 230–242.

Missouri Botanical Garden, 2003. Missouri Botanical Garden W3 Tropicos. Vascular Tropicos Nomenclatural Database, Site created from 1995. Available in http://www.mobot.org/W3T/Search/vast.html. Visit at May 2003.

Moreira-Burger, D., Delitti, W.B.C., 1999. Fitomassa epígea da mata ciliar do rio Mogi-Guaçu, Itapira-SP. Rev. Brasil. Bot. 22, 429–435.

Niklas, K.J., 1994. Plant allometry: the scaling of form and process. The University of Chicago Press, Chicago/London, 395pp.

Prance, G.T., 1972. Flora Neotropica: Chrysobalanaceae, Monograph No. 9. Hafner Publishing Company, New York.

Pott, A., Pott, V.J., 1994. Plantas do Pantanal. Embrapa – CPAP e Embrapa – SPI, Brasília, 320p.

Ratter, J.A., Pott, A., Pott, V.J., Cunha, C.N., Haridassan, M., 1988. Observations on woody vegetation types in the Pantanal and around Corumbá. Notes Royal Bot. Garden Edinb. 45, 503–525.

Salis, S.M., 2004. Distribuição das espécies arbóreas e estimativa da biomassa aérea em savanas florestadas, Pantanal da Nhecolândia, Estado do Mato Grosso do Sul. PhD Thesis. Universidade Estadual Paulista, Instituto de Biociências, Rio Claro, São Paulo State, Brazil, 63pp.

Schacht, W.H., Long, J.N., Malechek, J.C., 1988. Above-ground production in cleared and thinned stands of Semiarid Tropical Woodland, Brazil. For. Ecol. Manage. 23, 201–214.

Soriano, B.M.A., 1999. Caracterização climática da sub-região da Nhecolândia, Pantanal, MS. In: Dantas, M., Catto, J.B., Resende, E.K. (Coords.). Anais do II Simpósio sobre Recursos Naturais e Sócio-econômicos do Pantanal, Embrapa Pantanal, Corumbá, Brasil, pp. 151–158.

Soriano, B.M.A., 2002. Boletim Agrometeorológico: 1999 (Fazenda Nhumirim), Documentos 26. Embrapa Pantanal, Corumbá, 19pp.

Sprugel, D.G., 1983. Correcting for bias in log-transformed allometric equations. Ecology 64, 209–210.

Tausch, R.J., Tueller, P.T., 1988. Comparison of regression methods for predicting singleleaf pinyon phytomass. Great Basin Nat. 48, 39–45.

Westmann, W.E., Rogers, R.W., 1977. Biomass and structure of a subtropical eucalypt forest, north Stradbroke Island. Aust. J. Bot. 25, 171–191.

Wilkinson, L., 1990. Systat: System for Statistics. Evanston, IL.

Wilkinson, L., 1998. Systat—Systems for Statistics 9. Chicago.

Zar, J.H., 1999. Biostatistical Analysis, 4th ed. Prentice Hall, New Jersey.