**The text that follows is a PREPRINT.**

Please cite as:

Barbosa, R.I. and P.M. Fearnside. 2004. Wood density of trees in open savannas of the Brazilian Amazon**.** Forest Ecology and Management 199(1): 115-123.

ISSN: 0378-1127



The original publication is available at: http://www.elsevier.com.nl

# Wood density of trees in open savannas of the Brazilian Amazon

Reinaldo Imbrozio Barbosa
INPA/CPEC
Caixa Postal 96
69301-970 Boa Vista, Roraima
Brazil
tel: +55-95-623 9433
imbrozio@technet.com.br

Philip Martin Fearnside
INPA/CPEC
Caixa Postal 478
69011-970 Manaus, Amazonas
Brazil
tel: +55-92-643 1822
pmfearn@inpa.gov.br

28 January 2004; revised: 23 April 2004; corrections 30 April 2004

[**send proofs to:** Philip M. Fearnside, INPA, Caixa Postal 478, 69011-970 Manaus, Amazonas, Brazil; Fax: +55 (92) 642-8909, e-mail: pmfearn@inpa.gov.br]

**In press:** ***Forest Ecology and Management***

Abstract

Studies on basic density of woody species in Amazonian savannas are needed to convert data on woody volume to biomass. These ecosystems, which have large carbon stocks, emit greenhouse gases annually due to frequent burnings. Basic density (g $cm^{-3}$: oven-dry weight/wet volume), measured from complete sample disks (bark, sapwood and heartwood), was calculated for the most abundant woody species in three types of open savannas (Sg: grassy-woody savanna; Sp: savanna parkland; Tp: steppe-like parkland) in Roraima, a state in the northern part of Brazil's Amazon region. The species selected represent 90-95% of the woody biomass estimated in these ecosystem types. Seven additional species were lumped in an "others" group. In total, we sampled 107 trees: 40 in Sg, 37 in Sp and 30 in Tp. *Bowdichia virgilioides* (0.516 ± 0.021 (SE) g $cm^{-3}$) was the species with the highest basic density, followed by the "others" group (0.485 ± 0.057 g $cm^{-3}$), *Curatella americana* (0.413 ± 0.028 g $cm^{-3}$), *Byrsonima crassifolia* + *B. coccolobifolia* (0.394 ± 0.019 g $cm^{-3}$), *Himatanthus articulatus* (0.375 ± 0.020 g $cm^{-3}$) and *B. verbascifolia* (0.332 ± 0.020 g $cm^{-3}$). Basic density of the species with the greatest woody biomass in Roraima's open savannas (*C. americana* and *B. crassifolia* + *B. coccolobifolia*) did not differ significantly at the 5% level (ANOVA) among the three ecosystem types studied. Wood basic density in these savannas (weighted mean = 0.404 ± 0.025 g $cm^{-3}$) is lower than that in Amazonian forests (weighted mean = 0.680 g $cm^{-3}$). These results reduce uncertainty in calculations of carbon stocks and of greenhouse gas emissions from clearing and burning tropical savanna.

Keywords: Amazonia, cerrado, Roraima, savanna, wood density

## 1. Introduction

Wood density is of fundamental importance for estimating biomass in terrestrial ecosystems (Brown, 1997; Woodcock, 2000). "Basic density," or the ratio between the dry weight and the saturated volume of the wood (Trugilho et al., 1989), is used to convert volumetric data to biomass because it uses the wet volume as the base. Biomass calculation in Amazonia is an intensely debated subject because this parameter is directly linked to quantifying the emission of greenhouse gases to the atmosphere (Brown and Lugo, 1992; Fearnside, 1992; Achard et al., 2003; Eva et al., 2003; Fearnside and Laurance, 2003, 2004).

In spite of several studies in the Amazon region having reported wood density of different species (*e.g.*, Loureiro and Silva, 1968; Loureiro et al., 1979; Paula, 1981; Brazil, IBDF, 1983), interest has centered on the quality and suitability of raw materials for the commercial timber sector. Only recently have these commercial results been adapted for ecological purposes, indicating differences among the various ecosystems in the region (see Fearnside, 1997). Studies available to date for Amazonia are restricted to forest ecosystems. This is due to interest in evaluating the potential global emission of carbon stocks from tropical forests. Little attention has been given to savanna ecosystems, although they occupy between 13% (694,000 $km^2$) and 17% (850,000 $km^2$) of Brazil's $5 \times 10^6$-$km^2$ Legal Amazon region as a whole, based on the values of Fearnside and Ferraz (1995) and Skole and Tucker (1993), respectively.

Greenhouse gases are emitted when these ecosystems are cleared and burned for conversion to agriculture (Ward et al., 1992; Nepstad et al., 1997). The agricultural landscapes generally have lower biomass (and biomass carbon pools) than the natural savannas they replace. Although no reliable estimate exists of the total area of Amazonian savannas that have been altered by agriculture, in Central Brazil about 60-70% of the savannas have already been disturbed (Mantovani and Pereira, 1998; Klink and Moreira, 2000), with an annual rate of 20,000 $km^2.y^{-1}$ (Klink et al., 1994).

In addition to emissions from clearing, gases are emitted when biomass is burned in the repeated fires that occurf in uncleared savannas. Although arboreal biomass in savannas is less affected by fire frequency than is non-arboreal biomass, quantification of arboreal biomass is important because this compartment can support significant amounts of carbon, for instance, in systems without the presence fire (San José et al., 1998; Tilman et al., 2000).

The present study seeks to evaluate the basic density of the most common woody species in three types of open savannas located in Roraima. This area is the largest assemblage of savannas in Amazonia. These data help reduce the uncertainties surrounding carbon stocks and emission of greenhouse gases by burning and decomposition of the woody biomass in savannas.

## 2. Materials and methods

### *2.1. Description of the study area*

The study area is located in the northern and northeastern portions of the state of Roraima, approximately between 2° 30' N and 5 ° 00' N / 59 ° 30' W and 61° 30' W (Fig. 1). This area is a part of the "Rio Branco-Rupununi" complex, which occurs in both Brazil and Guyana (Eden, 1970; Sarmiento and Monasterio, 1975). The open areas -- "clean fields" (*campos limpos*) and parklands of this complex are known as "*lavrado*" in Roraima (Vanzolini and Carvalho, 1991). The other types of savannas are represented by closed forms (woodlands and forests) or high-altitude relicts with different structural and floristic compositions, and do not represent the "open" savanna group that is the subject of the present study.

[* * * Figure 1 here* * * ]

### *2.2. Ecoystem types studied*

Three ecosystem types in the region were selected (Table 1). The ecosystem types were defined using the criteria of the vegetation map of Amazonia (1:2,500,000) (Brazil, SUDAM and IBGE, 1989) and the Technical Manual of Brazilian Vegetation (Brazil, IBGE, 1992). The ecosystem types chosen represent the largest areas of savannas in Roraima and are subject to annual burning.

[***Table 1 here ***]

Grassy-woody savanna (Sg) has low relief (80-100 m) that allows the formation of lakes and marshy watercourses (*veredas*) where the presence of the buriti palm (*Mauritia flexuosa* L.) is characteristic. Savanna park (Sp) occurs in the Upper and

Middle Rio Surumu; although this ecosystem type has the diversity characteristics of "Sg," physically has denser clumping and trees with larger stature (Miranda and Absy, 2000). Steppe-like savanna parkland (Tp) is located on forested sandstones in the far north and northeast part of the state. This area is denominated as "steppe-like savanna parkland" (*savana-estépica parque*) by the RADAMBRASIL Project (Brazil, Projeto RADAMBRASIL, 1975), but by the IBGE classification (Brazil, IBGE, 1992) it corresponds to the class of steppe-like savannas. By the IBGE definition it would not fit well in the "parkland" subgroup.

### *2.3. Woody Species Sampled*

Considering only the areas that are typically open and those that border on small forest formations, the five principal species appraised in this study represent most of the individuals (> 92%) and biomass (> 97%) in the savannas of northern and northeastern Roraima (Barbosa, 2001). These species have wide distribution throughout this area of open vegetation (Takeuchi, 1960; Rodrigues, 1971; Dantas and Rodrigues, 1982; Sanaiotti, 1996; Miranda, 1998; Miranda et al., 2003). Together with the remaining species studied in the "others" group, they account for almost all of the woody biomass in these open ecosystem types.

*Curatella americana* L. (*caimbé*): This is an arboreal species in the family Dilleniaceae with high resistance to fire. It has the highest weighted mean arboreal biomass among the three ecosystem types: 95-3128 kg $ha^{-1}$ or 27.3-91.5% of all of the live woody biomass (seedlings, saplings and adults) with diameter of > 2 cm, measured at 2 cm above the ground (Barbosa, 2001). The very wide range of per-hectare biomass values for this and other species is the result of wide variation in the number of trees per hectare, as the savannas range from areas of grassland with a few scattered trees to "parkland" areas where trees are much more frequent, sometimes almost forming a closed canopy. The stature of individual trees also varies, being shorter in the more open areas. Biomass estimates were based on 378 quadrats (each 4 m × 20 m) distributed equally among the tree ecosytem types (126 plots in each type) (Barbosa, 2001). A total of 130 trees (of all species) were cut in the plots, from which allometric equations were developed to calculate the volume of the remaining trees (Barbosa, 2001).

*Byrsonima crassifolia* (L.) Kunth. in H.B.K. (*mirixi*) + *B. coccolobifolia* Kunth in H.B.K: These trees belong to the family Malpighiaceae. Together, these species have the second highest above-ground biomass per unit area (215-695 kg $ha^{-1}$ or 7.5-61.8%) (Barbosa, 2001).

*Byrsonima verbascifolia* (L.) Rich ex. A. Juss. (*mirixi-anão*): This species also belongs to the family Malpighiaceae. It has a bushy habit and has high frequency (76.4 individuals $ha^{-1}$), although it has low biomass (9.0 kg $ha^{-1}$) (Barbosa, 2001). It occurs from the sedimentary plains near Boa Vista to the stony plateaus of the Roraima Formation.

*Himatanthus articulatus* (Vahl) Woods. (*sucuba*): this species belongs to the family Apocynaceae and has higher frequency when close to forest ecosystems (forest islands, for example). In open areas it has an average of 3.5-6.2 individuals $ha^{-1}$.

*Bowdichia virgilioides* Kunth. (*paricarana*): this is an arboreal species in the family Fabaceae known for its very hard heartwood. In areas that are open and distant from forest formations this species has an average of 0.9-3.2 individuals $ha^{-1}$.

The "others" group: This group is composed of seven woody species (trees and/or bushes) with low abundance in open savanna locations. It includes *Antonia ovata* Pohl. (Loganiaceae), *Roupala montana* Aubl. (Proteaceae), *Xylopia aromatica* (Lam.) Mart. (Annonaceae), *Byrsonima* cf *intermedia* A. Juss. (Malpighiaceae), *Miconia rubiginosa* (Bonpl.) DC. (Melastomataceae), *Genipa americana* L. var *caruta* (H.B.K.) (Rubiaceae) and *Palicourea rigida* Kunth (Rubiaceae). Taken together, the species in the "others" group represented less than 5% of the total woody biomass.

Other woody species occur in the Sg, Sp and Tp savannas of Roraima (see Sanaiotti, 1996; Miranda and Absy, 2000; Miranda et al., 2003). However, these are very infrequent.

*2.4. Sampling methods*

We studied a total of 107 individuals distributed as follows: 28 of *C. americana* (Sg = 7; Sp = 13; Tp = 8), 39 of *B. crassifolia* + *B. coccolobifolia* (Sg = 17; Sp = 11; Tp = 11), 11 of *B. verbascifolia* (Sg = 7; Sp = 4; Tp = 0), 9 of *H. articulatus* (Sg = 5; Sp = 2; Tp = 2), 8 of *B. virgilioides* (Sg = 0; Sp = 3; Tp = 5) and 12 "others", or less-abundant species (Sg = 4; Sp = 4; Tp = 4).

Each individual was divided into three diameter classes, including saplings, as follows: (1) pieces with diameter (d) < 5 cm, (2) 5 cm < d <= 10 cm and (3) d > 10 cm, making a total of 209 samples or 67 pieces of *C. americana* (< 5 cm = 28; 5-10 cm = 24; > 10 cm = 15), 68 of *B. crassifolia* + *B. coccolobifolia* (37; 21; 10), 19 of *H. articulatus* (9; 4; 6), 14 of *B. verbascifolia* (10; 4; 0), 17 of *B. virgilioides* (0; 7; 10) and 24 in the "others" category (12; 7; 5). This was important for determining differences among the diameter classes and for inferring a weighted average for each species.

The sampling started with collection of 1 to 3 sample disks obtained using handsaws (so as not to damage or to contaminate the sample with the lubricating oil of a chainsaw). These disks were wood pieces (samples) where the bark, sapwood and heartwood were appraised jointly. This was done in order to avoid the bias inherent in analyses that only include the heartwood (ABNT, 1979, 2003). Analyses based only on heartwood are not appropriate for calculations of biomass and decomposition in these ecosystems.

All disks were collected in the centers of the classes in order to avoid contact with the other diameter classes. The remainder of the procedures for collection of the material was adapted from Trugilho et al. (1989, p. 165), Brazil, INPA (1991, p. 7) and Fearnside (1997, p. 61). Determining the basic density of wood samples requires the following steps:

a) Removal of contaminants such as soil particles;

b) Saturation of the samples by immersion in water for 4-5 days (enclosed in cloth sacks in order to prevent any loss of fine material) to approximate the conditions of natural saturation;

c) Drying (approximately 80°C) to constant weight and determination of the dry weight of the sample;

d) Determination of the volume by measuring the water (Archimedes principle) that the saturated piece displaces when immersed in a standard recipient (after deducting the volume of the cloth sack and of the wire that were immersed together with the piece);

e) Determination of the basic density by computing the ratio of the dry mass of the wood (g) to its respective saturated volume ($cm^3$).

Once the basic density (g $cm^{-3}$) for each of the 209 samples in the survey had been estimated, we proceeded to quantify the weighted average, by diameter class, for each species or group evaluated within each ecosystem. We then compared statistically the density of individuals of *C. americana* and *B. crassifolia* + *B. coccolobiflia* among the three environments in order to try to understand possible differences that affect the general calculation of the biomass of these most-abundant species in the area.

## 3. Results

The species with the highest basic density (bark + sapwood + heartwood), for the average of the three environments (± SE = standard error), weighted by the proportion of each diameter class, was *Bowdichia virgilioides* (0.516 ± 0.021 g $cm^{-3}$) (Table 2). This was followed by the "others" group (0.485 ± 0.057 g $cm^{-3}$), *Curatella americana* (0.413 ± 0.028 g $cm^{-3}$), *Byrsonima crassifolia* + *B. coccolobifolia* (0.394 ± 0.019 g $cm^{-3}$), *Himatanthus articulatus* (0.375 ± 0.020 g $cm^{-3}$) and *B. verbascifolia* (0.332 ± 0.020 g $cm^{-3}$). Individually, the lowest average by diameter class was found in *H. articulatus* (0.269 g $cm^{-3}$) in the < 5-cm class in the Tp ecosystem type. The highest was in the 5-10-cm class of *B. virgilioides* (0.593 g $cm^{-3}$) in Sp.

[* * * * Table 2 here* * * * ]

The weighted basic densities for the diameter classes of the two most common species in the savannas of Roraima were 0.441 g $cm^{-3}$ (Sg), 0.380 g $cm^{-3}$ (Sp) and 0.411 g $cm^{-3}$ (Tp) for *C. americana* and 0.373 g $cm^{-3}$ (Sg), 0.412 g $cm^{-3}$ (Sp) and 0.409 g $cm^{-3}$ (Tp) for *B. crassifolia* + *B. coccolobifolia* (Table 2). In both cases, the values did not differ at the 5% level (ANOVA) either among the three ecosystem types or between these two species. The individual results for each ecosystem type, weighted by area, species present and diameter-class distribution, were 0.392 ± 0.022 g $cm^{-3}$ (Sg), 0.394 ± 0.016 g $cm^{-3}$ (Sp) and 0.411 ± 0.040 g $cm^{-3}$ (Tp) (Table 3). The mean result for each diameter class, weighted by the area of each ecosystem type, increased as follows: 0.329 g $cm^{-3}$ (< 5 cm), 0.424 g $cm^{-3}$ (5-10 cm) and 0.449 g $cm^{-3}$ (> 10 cm). The weighted mean for all ecosystem types was 0.404 ± 0.025 g $cm^{-3}$ (Table 3).

[* * * * Table 3 here* * * * ]

## 4. Discussion

To our knowledge, the results presented here are the first available for basic density specific to the woody species in open savannas in Brazilian Amazonia. Most estimates of density for studies of wood technology and ecology in the region only report forest species. This is due to the great interest in characterizing wood for commercial uses (Souza et al., 1997) or in differentiating systems based on the intrinsic attributes of their arboreal components (Worbes, 1989; Parolin and Ferreira, 1998; Parolin and Worbes, 2000). However, wood density is an important component in calculations of total biomass in forest ecosystems and in savannas, and is therefore a key variable for calculating greenhouse gas emissions from land-use changes in Amazonia.

Comparison of our results with studies in forest environments indicates differences in the floristic composition of the two ecosystem types. The average basic density for Amazon forests is 0.690 g $cm^{-3}$ for heartwood, or 0.680 g $cm^{-3}$ if corrected for the volume and density of the sapwood and bark (Fearnside, 1997). This average is 1.7 times higher than 0.404 g $cm^{-3}$ estimated as the weighted average (by biomass and area) for the woody species present in open savannas (Sg, Sp, Tp) of Roraima. Our result is identical to the value for successional forests in the southern portion of the Peruvian Amazon (0.400 g $cm^{-3}$) reported by Woodcock (2000). However, it is in the lower part of the range of values observed in a forested savanna in Burkina Faso (Africa) by Nygard and Elfving (2000), who estimated values of 0.301-0.854 g $cm^{-3}$ for 57 woody species.

Although species with very dense wood exist in Brazilian savannas, as is the case for *B. virgilioides* (Paula and Alves, 1997 in Almeida et al., 1998) and *Sclerolobium paniculatum* (Pereira, 1990), the weighted average of all species tends to be dominated by the most abundant ones. In the case of Roraima, the average was heavily influenced by *C. americana* (0.413 g $cm^{-3}$) and *B. crassifolia* + *B. coccolobifolia* (0.394 g $cm^{-3}$), which dominate the open savannas of the "Rio Branco-Rupununi" complex. In addition, combining data from individuals of different ages or diameters might have influenced the average value. Basic density tends to be lower in very young trees (Vital et al., 1984), although diameter can fail to show a defined relationship with density (Castro et al., 1993). In the case of small-diameter individuals (< 5 cm) in the open savannas of Roraima, we observed that the general tendency was for these to have lower densities than the largest-diameter individuals. This would partly be explained by the greater proportion of bark in small-diameter pieces. The overall weighted average was 0.329 g $cm^{-3}$ for diameter < 5 cm, as compared to 0.424 g $cm^{-3}$ for diameter 5-10 cm and 0.449 g $cm^{-3}$ for diameter > 10 cm (see Table 3). With the use of the weighted average system, species with larger numbers of fine branches strongly influenced the individual average of the species, as in the case of *B. verbascifolia* and *B. crassifolia* + *B. coccolobifolia*.

Our method preserved all of the bark, which, in the case of the species studied, varied from 12% to 43% of the total volume of each sample determined from a scanned tracing of each sample disk (Barbosa, 2001). This is similar to the 9-53% range found by Nygard and Elfving (2000) in a forested savanna in Burkina Faso. In pure forest systems, this percentage can vary from 4 to 11%, with the basic density of bark representing 80% of the density of wood (Fearnside, 1997, p. 80). Therefore, using complete samples (bark, sapwood and heartwood) avoids an overestimation of biomass.

We tried to identify possible differences among the savannas studied by calculating the density of the main arboreal species (*C. americana* and *B. verbascifolia* + *B. coccolobifolia*). Latitudinal differences in relief or in structure can directly affect the density of the wood in forest trees (Williamson, 1984). Parolin and Worbes (2000) tentatively concluded that some identical species growing in different Amazon flooded forest environments (white water and black water) have different absolute densities. However, even with the three ecosystems that are the subject of the present study (Sg, Sp and Tp) having different relief gradients and soil types, this was not indicative of statistically significant differences (ANOVA) for the two most-common arboreal species.

## 5. Conclusions

The weighted mean (by biomass) for basic density of wood in open savannas (Sg, Sp, Tp) in Roraima is 0.404 g $cm^{-3}$. This is substantially lower than the weighted mean basic density in Amazonian forests (0.680 g $cm^{-3}$). The values found affect one of the most critical components in the calculation of total above-ground biomass in Amazonian savannas. Biomass is a critical part of recent discussions on estimates of greenhouse gas emissions and of carbon stocks in natural ecosystems in the Amazon.

## 6. Acknowledgments

The Government of the State of Roraima, through the 1st Addendum to the INPA/GERR Convention (1993) and the 2nd Addendum to the INPA/GERR Convention (1995), financed the initial expenses of this research, under the "Human Carrying Capacity in Amazon Agroecosystems - Roraima" project. The Nature and Society Program of the Worldwide Fund for Nature (WWF) financed the remainder of the study under the project "Savannas of the Amazon: emission of greenhouse gases ($CO_2$ and trace gases) by burning and decomposition of biomass in Roraima, Brazil" (CSR 131-99). Dr. Cid Ferreira, of the INPA herbarium in Manaus, identified the plant species. Two anonymous reviewers provided valuable comments.

## 7. Literature cited

ABNT, 1979. Densidade básica da madeira: Metodo de ensaio (NBR 1269).Associação Brasileira de Normas Técnicas (ABNT), Rio de Janeiro, RJ., Brazil

ABNT, 2003. Madeira - Determinação da densidade básica (NBR 11941). Associação Brasileira de Normas Técnicas (ABNT), Rio de Janeiro, RJ., Brazil. http://www.abnt.org.br/CB29/normas_madeira.asp..

Ab'Saber, A.N., 1997. O significado geomorfológico e geoecológico no contexto do relevo de Roraima. In: Barbosa, R.I., Ferreira, E., Castellón, E. (Eds.), Homem, Ambiente e Ecologia em Roraima. Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, Amazonas, Brazil, pp. 267-293.

Achard, F., Eva, H. D., Stibig, H.J., Mayaux, P., Gallego, J., Richards, T., Malingreau, J-P., 2002. Determination of deforestation rates of the world’s humid tropical forests. Science 297, 999-1002.

Almeida, S.P., Proença, C.E.B., Sano, S.M., Ribeiro, J.F., 1998. Cerrado: espécies vegetais úteis. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA/CPAC), Planaltina, DF, Brazil.

Barbosa, R.I., 2001. Savanas da Amazônia: Emissão de Gases do Efeito Estufa e Material Particulado pela Queima e Decomposição da Biomassa Acima do Solo, sem a Troca do Uso da Terra, em Roraima, Brasil. Ph.D. dissertation in ecology. Instituto Nacional de Pesquisas da Amazônia (INPA) and Universidade do Amazonas (UA), Manaus, Amazonas, Brazil.

Brazil, IBDF, 1983. Potencial madeireiro do Grande Carajás. Instituto Brasileiro de Desenvolvimento Florestal (IBDF), Brasília, DF, Brazil.

Brazil, IBGE, 1992. Manual Técnico da Vegetação Brasileira. Manuais Técnicos em Geociências no 1. Instituto Brasileiro de Geografia e Estatística (IBGE), Rio de Janeiro, Brazil.

Brazil, INPA, 1991. Catálogo de madeiras da Amazônia. CPPF, MCT / INPA / Coordenação de Pesquisas em Produtos Florestais, Manaus, Amazonas, Brazil.

Brazil, Projeto RADAMBRASIL, 1975. Levantamento de Recursos Naturais, Volume 8. Ministério das Minas e Energia. Rio de Janeiro, Brazil.

Brazil, SUDAM, IBGE, 1989. Mapa de Vegetação da Amazônia (Escala 1:2.500.000). Superintendência do Desenvolvimento para a Amazônia (SUDAM) and Instituto Brasileiro de Geografia e Estatística (IBGE), Belém, Pará, Brazil.

Brown, S., 1997. Estimating Biomass and Biomass Change of Tropical Forests. FAO, Rome (FAO Forestry Paper 134).

Castro, F., Williamson, G.B., Jesus, R.M., 1993. Radial variation in the wood specific gravity of *Joannesia princeps*: the roles of age and diameter. Biotropica 25, 176-182.

Coutinho, L.M., 1978. O conceito de cerrado. Rev. Brasileira de Botânica 1, 17-23.

Dantas, M., Rodrigues, I.A., 1982. Estudos fitoecológicos do Trópico Úmido Brasileiro: IV - Levantamentos botânicos em Campos do Rio Branco. Boletim de Pesquisa (EMBRAPA/CPATU), No. 40, Empresa Brasileira de Pesquisa Agropecuária/Centro de Pesquisa Agropecuária do Trópico Úmido (EMBRAPA/CPATU), Belém, Pará, Brazil.

Eden, M., 1970. Savanna vegetation in the northern Rupununi, Guyana. Jour. Trop, Geography 30, 17-28.

Eva, H.D., Achard, F., Stibig, H-J., Mayaux, P., 2003. Response to comment on "Determination of deforestation rates of the World's humid tropical forests." Science 299, 1015b.

Fearnside, P.M., 1992. Forest biomass in Brazilian Amazônia: comments on the estimate by Brown and Lugo. Interciencia 17, 19-27.

Fearnside, P.M., 1997. Wood density for estimating forest biomass in Brazilian Amazonia. Forest Ecol. Manage. 90, 59-87.

Fearnside, P.M., Ferraz, J., 1995. A conservation gap analysis of Brazil's Amazonian vegetation. Conserv. Biology 9(5), 1-14.

Fearnside, P.M., Laurance, W.F., 2003. Comment on "Determination of deforestation rates of the world's humid tropical forests". Science 299, 1015.

Fearnside, P.M., W.F. Laurance. 2004. Tropical deforestation and greenhouse gas emissions. Ecol. Appl. 14(4) (in press)

Klink, C.A., Macedo, R.H., Müeller, C.C., 1994. Cerrado: Processo de Ocupação e Implicações para a Conservação e Utilização Sustentável de sua Diversidade Ecológica. WWF-Brasil, Brasília, DF, Brazil.

Klink, C., Moreira, A., 2000. Valoração do potencial do cerrado em estocar carbono atmosférico, In: Moreira, A.G., Schwartzman, S. (Eds.), As Mudanças Climáticas Globais e os Ecossistemas Brasileiros. Instituto de Pesquisas da Amazônia (IPAM), Woods Hole Research Center (WHRC) and Environmental Defense (EDF), Brasília, DF, Brazil, pp. 82-88.

Loureiro, A.A., Silva, M.F., 1968. Catálogo das madeiras da Amazônia. Ministério do Interior / Superintendência do Desenvolvimento da Amazônia. Belém, Pará, Brazil.

Loureiro, A.A., Silva, M.F., Alencar, J.C., 1979. Essências madeireiras da Amazônia. CNPq / INPA / SUFRAMA. Manaus, Amazonas, Brazil.

Mantovani, J.E., Pereira, A., 1998. Estimativa da integridade da cobertura vegetal do cerrado através de dados TM / LANDSAT. Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, São Paulo, Brazil.

Miranda, I.S., 1998. Flora, fisionomia e estrutura das savanas de Roraima, Brasil. Ph.D. dissertation in botany. Instituto Nacional de Pesquisas da Amazonia (INPA) and Universidade do Amazonas (UA), Manaus, Amazonas, Brazil.

Miranda, I.S., Absy, M.L., 2000. Fisionomia das savanas de Roraima, Brasil. Acta Amazonica 30, 423-440.

Miranda, I.S., Absy, M.L., Rebêlo,G.H., 2003. Community structure of woody plants of Roraima Savannahs, Brazil. Plant Ecology 164: 109-123.

Nepstad, D., Klink, C, Uhl, C., Vieira, I.C., Lefebvre, P., Pedlowski, M., Matricardi, E., Negreiros, G., Brown, I.F, Amaral E., Homma, A., Walker, R., 1997. Land use in Amazonia and the Cerrado of Brazil. Ciência e Cultura 49, 73-86.

Nygard, R., Elfving, B., 2000. Stem basic density and bark proportion of 45 woody species in young savanna coppice forests in Burkina Faso. Ann. For. Sci. 57, 143-153.

Parolin, P., Ferreira, L.V., 1998. Are there differences in specific wood gravities between trees in várzea and igapó (Central Amazonia)? Ecotropica 4, 25-32.

Parolin, P., Worbes, M., 2000. Wood density of trees in black water floodplains of Rio Jaú National Park, Amazonia, Brazil. Acta Amazonica 30, 441-448.

Paula, J.E., 1981. Estudo das estruturas internas das madeiras de dezesseis espécies da flora brasileira, visando seu aproveitamento para produção de álcool, carvão, coque e papel. Brasil Florestal 11(47), 23-50.

Paula, J.E., Alves, J.L.H., 1997. Madeiras nativas: Anatomia, dendrologia, dendrometria, produção e uso. Fundação Mokita Okada, Brasília, DF, Brazil.

Pereira, B.A.S., 1990. Estudo morfo-anatômico da madeira, casca e folha de duas variedades vicariantes de Sclerolobium paniculatum (Leguminosae, Caesalpinoideae) de mata e cerrado. Master's thesis in forest sciences, Escola Superior de Agricultura "Luis de Queirroz" (ESALQ), Piracicaba, São Paulo, Brazil.

Rodrigues, W.A., 1971. Plantas dos campos do Rio Branco (Território de Roraima), In: Ferri, M.G. (Ed.), III Simpósio sobre o Cerrado, São Paulo, São Paulo, Brazil, pp. 180-193.

Sanaiotti, T., 1996. The Woody Flora and Soils of Seven Brazilian Dry Savanna Areas. Ph.D. dissertation in ecology, University of Stirling, Stirling, U.K.

San José, J.J., Monte, R.A., Fariñas, M.R., 1998. Carbon stocks and fluxes in a temporal scaling from a savanna to a semi-deciduous forest. Forest Ecol. Manage. 105, 251-262.

Sarmiento, G., Monasterio, M., 1975. A critical consideration of the environmental conditions associated with the occurrence of Savanna ecosystems in Tropical America. In: F. B. Golley and E. Medina (Eds.), Tropical Ecological Systems: Trends in Terrestrial and Aquatic Research. Springer-Verlag, New York, NY, pp. 223-250.

Skole, D., Tucker, C., 1993. Tropical deforestation and habitat fragmentation in the Amazon satellite data from 1978 to 1988. Science 260, 1905-1910.

Souza, M.H., Magliano, M.M., Camargos, J.A.A., Souza, M.R., 1997. Madeiras tropicais brasileiras. Ministério do Meio Ambiente / Instituto Brasileiro do Meio

Ambiente e dos Recursos Naturais Renováveis / Laboratório de Produtos Florestais. Brasília, DF, Brazil.

Takeuchi, M., 1960. A estrutura da vegetação da Amazônia II. As savanas do norte da Amazônia. Bol. Mus. Par. Emílio Goeldi 7 (Bot.), 1-14.

Tilman, D., Reich, P., Philips, H., Menton, M., Patel, A., Erin, V., Peterson, D., Knops, J., 2000. Fire suppression and ecosystem carbon storage. Ecology 81, 2680-2685.

Trugilho, P.F., Silva, D.A., Frazão, F.J.L., Matos, J.L.M., 1989. Comparação de métodos de determinação da densidade básica em madeira. In: III Encontro Brasileiro em Madeiras e Estruturas de Madeira. São Carlos, Universidade de São Paulo, Escola de Engenharia de São Carlos (26 a 28 de julho de 1989), Universidade de São Paulo, São Carlos, SP, Brazil, pp. 163-179.

Vanzolini, P.E., Carvalho, C.M., 1991. Two sibling and sympatric species of Gymnophtalmus in Roraima, Brasil (Sauria, Teiidae). Papéis Avulsos de Zoologia 37(12), 173-226.

Vital, B.R, Pereira, A.R., Lucia, R.M.D., Andrade, D.C. 1984. Efeito da idade da árvore na densidade da madeira de *Eucalyptus grandis* cultivado na região do cerrado de Minas Gerais. Boletim Técnico IBDF 8, 49-52.

Ward, D.E., Sussot, R.A., Kauffman, J.B., Babbitt, R.E., Cummings, D.L., Dias, B., Holben, B.N., Kaufman, Y.J., Rasmussen, R.A., Setzer, A.W., 1992. Smoke and fire characteristics for Cerrado and deforestation burns in Brazil: BASE-B Experiment. Journ. Geophys. Res. 97(D13), 14601-14619.

Williamson, G.B., 1984. Gradients in wood specific gravity of trees. Bulletin of the Torrey Botanical Club 3, 51-55.

Woodcock, D.W., 2000. Wood specific gravity of trees and forest types in the Southern Peruvian Amazon. Acta Amazonica 30, 589-599.

Worbes, M., 1989. Growth ring, increment and age of trees in inundation forests, savannas and mountain forest in the Neotropics. IAWA Bulletin n.s. 10, 109-122.

FIGURE CAPTION

Fig. 1 -- Study area and types of savannas.

Table 1
Savanna ecosystem types in Roraima

| Designation | Symbol[a] | Description | Geology | Equivalent in central Brazil[b] |
|---|---|---|---|---|
| Grassy-woody savanna | Sg | Grass with scattered bushes and trees | Boa Vista Formation [c] | "Clean field" (*campo limpo*) type, intermixed with "dirty field" (*campo sujo*) |
| Savanna park | Sp | Floristically similar to Sg, but denser clumping and trees with larger stature[d] | Surumu Formation and bordering areas of the Boa Vista Formation (< 250 m altitude) | Mosaic of "closed field" (*campo cerrado*), "dirty field" and "clean field" |
| Steppe-like savanna parkland | Tp | Trees not clumped except for effect of small rises in relief | Roraima Group (stony soils; > 600 m altitude) | Mixture of "closed field" and "*cerrado sensu stricto,*" but with a different soil type |

[a]IBGE map codes (Brazil, SUDAM and IBGE, 1989).

[b]Coutinho (1978).

[c]Ab'Saber (1997).

[d]Miranda and Absy (2000).

Table 2.
Wood density of five species in Sg, Sp and Tp savannas in Roraima.

| Species | Diameter class | Ecosystem type | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sg (grassy-woody) | | | | Sp (parkland) | | | | Tp (steppe-like parkland) | | | | All ecosystem types | | |
| | (cm) | (n) pieces | %[1] class | d (g cm$^{-3}$) | Standard error | (n) pieces | % class | d (g cm$^{-3}$) | Standard error | (n) pieces | % class | d (g cm$^{-3}$) | Standard error | (n) pieces | d[2] (g cm$^{-3}$) | Standard error |
| *Bowdichia virgilioides* | < 5 | | | | | 3 | 38 | 0.522 | 0.093 | 5 | 39 | 0.378 | 0.030 | 8 | | |
| (8 individuals) | 5-10 | | | | | 2 | 25 | 0.593 | 0.016 | 3 | 24 | 0.520 | 0.025 | 5 | | |
| | > 10 | | | | | 2 | 37 | 0.545 | 0.015 | 2 | 37 | 0.545 | 0.015 | 4 | | |
| | All classes | | | | | 7 | | **0.548** | 0.045 | 10 | | **0.474** | 0.023 | 17 | **0.516** | **0.021** |
| *Curatella americana* | < 5 | 7 | 26 | 0.349 | 0.028 | 13 | 24 | 0.283 | 0.014 | 8 | 27 | 0.320 | 0.012 | 28 | | |
| (28 individuals) | 5-10 | 6 | 29 | 0.479 | 0.051 | 11 | 29 | 0.392 | 0.015 | 7 | 30 | 0.428 | 0.024 | 24 | | |
| | > 10 | 5 | 45 | 0.469 | 0.045 | 5 | 47 | 0.423 | 0.011 | 5 | 43 | 0.456 | 0.032 | 15 | | |
| | All classes | 18 | | **0.441** | 0.042 | 29 | | **0.380** | 0.013 | 20 | | **0.411** | 0.024 | 67 | **0.413** | **0.028** |
| *Byrsonima crassifolia* | < 5 | 15 | 53 | 0.314 | 0.013 | 11 | 46 | 0.367 | 0.017 | 11 | 48 | 0.382 | 0.029 | 37 | | |
| + *B. coccolobifolia* | 5-10 | 8 | 34 | 0.429 | 0.014 | 6 | 33 | 0.444 | 0.011 | 7 | 33 | 0.416 | 0.017 | 21 | | |
| (39 individuals) | > 10 | 4 | 13 | 0.465 | 0.018 | 2 | 21 | 0.459 | 0.033 | 4 | 19 | 0.464 | 0.049 | 10 | | |
| | All classes | 27 | | **0.373** | 0.014 | 19 | | **0.412** | 0.018 | 22 | | **0.409** | 0.029 | 68 | **0.394** | **0.019** |
| *Himatanthus articulatus* | < 5 | 5 | 26 | 0.339 | 0.023 | 2 | 34 | 0.342 | 0.015 | 2 | 23 | 0.269 | 0.100 | 9 | | |
| (9 individuals) | 5-10 | 3 | 23 | 0.322 | 0.031 | 1 | 14 | 0.352 | - | 2 | 26 | 0.352 | 0.032 | 6 | | |
| | > 10 | 1 | 51 | 0.374 | 0.019 | 1 | 52 | 0.434 | - | 2 | 51 | 0.467 | 0.007 | 4 | | |
| | All classes | 9 | | **0.353** | 0.023 | 4 | | **0.391** | 0.005 | 6 | | **0.392** | 0.035 | 19 | **0.375** | **0.020** |
| *Byrsonima verbascifolia* | < 5 | 7 | 75 | 0.295 | 0.018 | 4 | 100 | 0.341 | 0.043 | | | | | 11 | | |
| (11 individuals) | 5-10 | 2 | 25 | 0.411 | 0.004 | | | | | | | | | 2 | | |
| | > 10 | 1 | 0.1 | 0.416 | - | | | | | | | | | 1 | | |

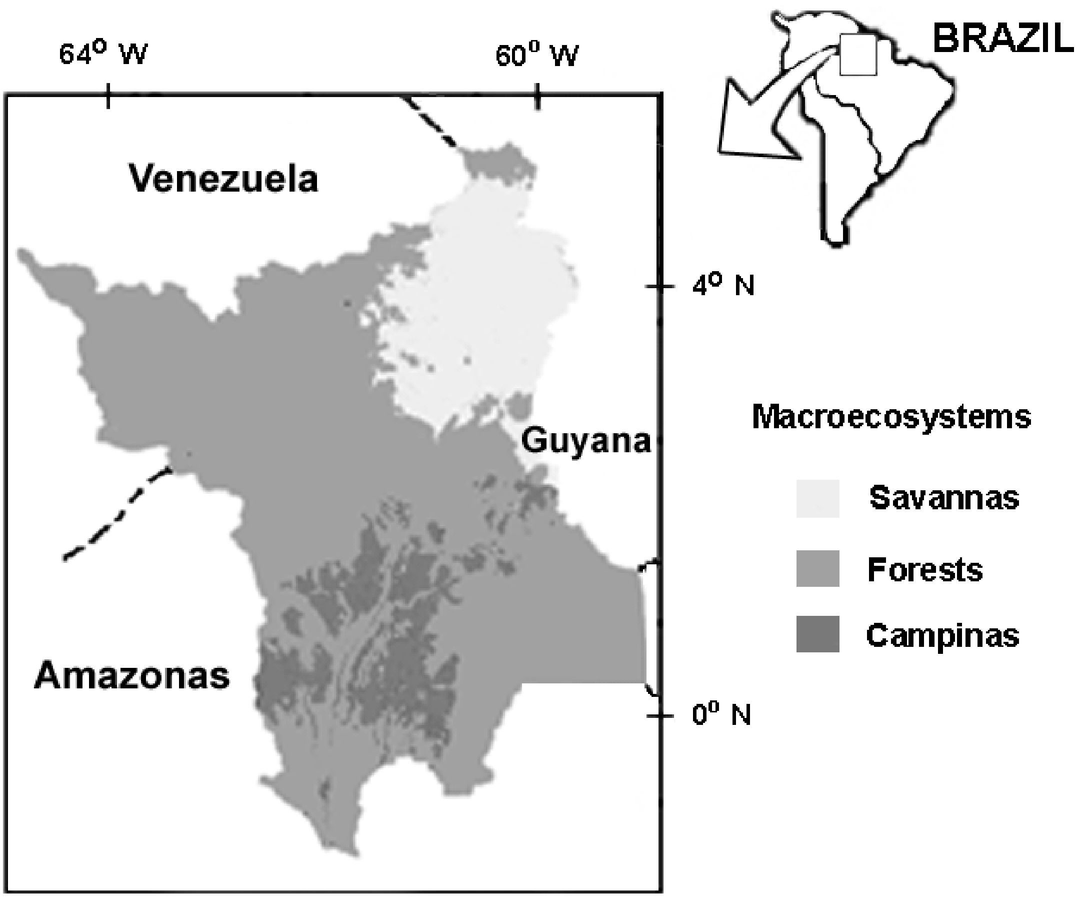
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All classes | 10 | | **0.324** | 0.014 | 4 | | **0.341** | 0.043 | | | | | 14 | **0.332** | **0.020** | |
| Others (various) | < 5 | 4 | 40 | 0.388 | 0.040 | 4 | 21 | 0.400 | 0.058 | 4 | 40 | 0.414 | 0.034 | 12 | | | |
| (16 individuals) | 5-10 | 3 | 24 | 0.568 | 0.015 | 2 | 16 | 0.537 | 0.084 | 2 | 34 | 0.563 | 0.051 | 7 | | | |
| | > 10 | 2 | 36 | 0.558 | 0.068 | 2 | 64 | 0.461 | 0.107 | 1 | 26 | 0.579 | 0.000 | 5 | | | |
| | Geral | 9 | | **0.492** | 0.044 | 8 | | **0.460** | 0.093 | 7 | | **0.507** | 0.031 | 24 | **0.485** | **0.057** | |
| | | | | | | | | | | | | | | | | | |

(1) "% class" is the mean percentage of dry biomass in each of the fractions defined by the diameter classes.

(2) the mean basic density of each species was determined by weighting each of the three ecosystem types studied by its respective area: Sg (42.4%), Sp (32.9%) e Tp (24.7%).

Table 3.
Basic density (g $cm^{-3}$) of diameter classes by ecosystem type

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Diameter class (cm) | | | | | |
| | Ecosystem type | | | | Mean | Standard error | |
| | | < 5 | 5-10 | > 10 | | | |
| | Sg | 0.322 | 0.443 | 0.467 | 0.392 | 0.022 | |
| | Sp | 0.331 | 0.415 | 0.432 | 0.394 | 0.016 | |
| | Tp | 0.329 | 0.427 | 0.456 | 0.411 | 0.040 | |
| | Mean | 0.329 | 0.424 | 0.449 | 0.404 | 0.025 | |


64° W
60° W
BRAZIL
Venezuela
4° N
Guyana
Amazonas
0° N
Macroecosystems
Savannas
Forests
Campinas