Wood and bark water content and monthly stem growth in Amazonian tree species

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ABSTRACT

The knowledge of how trees respond to microclimate variability is important in the face of climate changes. The objectives of this study were to examine the variation in wood water content (WWC) and bark water content (BWC) in Amazonian trees, as well as to assess the effect of microclimatic variability on monthly diameter growth rates (DGR). We extracted a core sample from each of 120 trees (28 species) and determined WWC and BWC on a fresh matter basis. DGR was measured monthly during the 12 months of 2007. The effect of microclimatic variability on DGR was analyzed by redundancy analysis. Average BWC and WWC were 53.4% and 34.7%, respectively, with a large variation in stem water content among species (BWC = 36.2−67.1%; WWC = 26.4−50.8%). There was no significant relationship between stem diameter and WWC or BWC, nor between DGR and wood density (p > 0.05). However, wood density was negatively correlated with WWC (r_s = −0.69, p < 0.001). The high BWC emphasizes the importance of the bark tissue in Amazonian trees. Contrary to expectations, variability of monthly irradiance, rainfall and temperature had no effect on DGR (p > 0.20). The unresponsiveness of DGR to microclimatic variability, even in an above-average rainy year such as 2007, indicates that other parts of the tree may have greater priority than the stem for carbon allocation during the dry season.

KEYWORDS: air temperature; rainfall; redundancy analysis; stem diameter; wood density

Conteúdo de água de madeira e casca e crescimento mensal do tronco em espécies arbóreas amazônicas

RESUMO

O conhecimento sobre a resposta das árvores à variação microclimatrica é importante em face das mudanças climáticas. Os objetivos deste estudo foram examinar a variação do conteúdo de água da madeira (WWC) e do conteúdo de água da casca (BWC) em árvores amazônicas, bem como avaliar o efeito da variabilidade microclimatrica sobre as taxas de crescimento diâtrico (DGR). Extraímos uma amostra do tronco de 120 árvores (28 espécies) e determinamos WWC e BWC na base da matéria fresca. As medições de DGR foram realizadas mensalmente durante os 12 meses de 2007. O efeito da variabilidade microclimatrica sobre o crescimento das árvores foi avaliado por meio de análise de redundância. Os valores médios de BWC e WWC foram 53,4% e 34,7%, respectivamente, com uma grande variação no conteúdo de água dos tecidos entre as espécies (BWC = 36,2−67,1%; WWC = 26,4−50,8%). Não houve relação significativa entre o diâmetro do tronco e WWC ou BWC, nem entre DGR e densidade da madeira (p > 0,05). Entretanto, a densidade da madeira foi negativamente correlacionada com WWC (r_s = −0,69, p < 0,001). O alto valor de BWC enfatiza a importância dos tecidos da casca em árvores da Amazônia. Contrariando as expectativas, a variabilidade mensal da irradiancia, precipitação e temperatura não afetou DGR (p > 0,20). A ausência de resposta da DGR à variabilidade microclimatrica, mesmo em um ano chuvoso acima da média como 2007, indica que outras partes da árvore podem ter maior prioridade do que o tronco para alocçação de carbono durante a época seca.

PALAVRAS-CHAVE: análise de redundância; densidade da madeira; diâmetro do tronco; precipitação; temperatura do ar

CITe AS: Dias, D.P; Marenco, R.A. 2021. Wood and bark water content and monthly stem growth in Amazonian tree species. Acta Amazonica 51: 363-369.
INTRODUCTION

The stem water content of trees is an important parameter in tree physiology, as it provides insights into the water relations along the soil-plant-atmosphere continuum (Zweifel et al. 2001; Ziemińska et al. 2020). Variations in stem water content may affect stem diameter (Stahl et al. 2010), which makes it difficult to accurately estimate tree growth. Water content within tree stems varies among species (Kenzo et al. 2017; Longuetaud et al. 2017), climatic seasons, and between wood and bark (Zweifel et al. 2001; Luo et al. 2020; Rosell et al. 2021). Increased precipitation can cause a rise in stem water content (Dias and Marenco 2016), which may lead to an increase in diameter either by sapwood or bark swelling (Stahl et al. 2010), while on the other hand, a decrease in stem water content may lead to stem shrinking and even to negative diameter measurements (Pastur et al. 2007). The amount of water stored in the stem can affect tree functioning in several ways. It can buffer fluctuations in water tension in xylem conduits, which decreases the risk of hydraulic failure (Chapotin et al. 2006). Stem water can also mitigate the impact of drought and enable leaf formation during the dry season (Borchert 1994; Chapotin et al. 2006). However, studies addressing the relationship between tree size and stem water content are scarce. Dias and Marenco (2006) and Kenzo et al. (2017) found no correlation between tree diameter and wood water content, but the variation of stem water content with tree size in a year of above-average rainfall had not yet been measured.

Many other factors contribute to tree growth, including site quality (e.g., soil fertility and topography), ontogeny (tree size), and environmental conditions (Bowman et al. 2013). Climatic variables such as irradiance, precipitation and air temperature can affect both photosynthesis and tree growth in tropical rainforests (Clark et al. 2003; Méndez 2018; Yang et al. 2018; Marenco and Antezana-Vera 2021). Air temperature is an important factor in the climate-forest interaction (Kitayama et al. 2021) and irradiance plays an essential role in plant functioning, as photosynthesis is highly responsive to changes in light intensity (Marenco et al. 2014). However, it is still under debate if in the rainiest part of the Amazon (north and central Amazon) tree growth responds to monthly variation in irradiance and precipitation – and hence to other environmental factors associated with changes in light conditions. Throughout the eastern and central Amazon, the Enhanced Vegetation Index (a surrogate of potential photosynthetic capacity) increased by 25% with increasing sunlight during the dry season (Huete et al. 2006), and in the central Amazon, tree growth increased during dry periods (Laurance et al. 2009). Likewise, Green et al. (2020) reported that, in the rainiest part of the Amazon, photosynthesis increases in the dry season, when solar radiation, temperature, and vapor pressure deficit (a direct function of temperature) are higher (Costa et al. 2010; Antezana-Vera and Marenco 2021). On the other hand, ecosystem photosynthesis over the entire Amazon can decline during prolonged droughts (Yang et al. 2018), and stem growth can decline during rather prolonged dry seasons (Antezana-Vera and Marenco 2021). Altogether, these results suggest that tree growth can increase in years when water availability is not a limiting factor for photosynthesis.

In this study, we aimed to evaluate the variation in wood and bark water content in Amazonian tree species in an above-average rainy year, as well as to assess the effect of microclimatic variability on stem growth in a terra-firme forest in the central Amazon. Considering that photosynthesis can increase during the mild dry season of the central Amazon (Green et al. 2020), we hypothesized (a) that stem growth (an estimator of tree growth) increases with a decrease in monthly precipitation in a rainy year, as decreased precipitation is associated with an increase in photosynthetically active radiation and air temperature, and (b) that stem water content is not correlated with stem size, as wood water content tends to remain constant irrespective of tree size when soil water is available to trees (Dias and Marenco 2016; Kenzo et al. 2017).

MATERIAL AND METHODS

Study area and microclimatic variables

This study was carried out at the Estação Experimental de Silvicultura Tropical (ZF2 reserve) (02°36’21”S, 60°08’11”W), a forest reserve of the Instituto Nacional de Pesquisas da Amazônia (INPA) located in the state of Amazonas, Brazil, in the central Amazon region. The climate in the region is tropical humid, with mean annual rainfall of 2,420 mm and a mild dry season from June through October, and, within this period, July, August and September are the driest months (< 100 mm per month, INMET 2021). The mean annual temperature is about 26°C (Dias and Marenco 2016; Antezana-Vera and Marenco 2021). The vegetation is classified as dense terra-firme rainforest, and the soil is an Oxisol with low fertility, clay texture, and pH of 4.2 to 4.5 (Magalhães et al. 2014).

Precipitation, air temperature and photosynthetically active radiation (PAR) were recorded daily in 2007 above the forest canopy, at the top of a 40-m tall observatory tower located near the study site (02°35’21”S, 60°06’53”W). A light sensor (LI-190SA, Li-Cor, Lincoln, NE, USA) connected to a datalogger (LI-1400, Li-Cor) was used to record PAR at 15-minute intervals (Dias and Marenco 2016), while air temperature (T) was collected (at 15-minute intervals) using a TR52 temperature sensor (Thermo recorded TR-52; T&D Co, Nagano, Japan). Mean monthly PAR (mol m⁻² day⁻¹) was obtained by integrating the instantaneous PAR values over the whole daylight period, i.e., 05:30–18:30. A standard rain gauge located at the same observation tower was used for collecting rainfall data.
Diameter growth rate and wood and bark water content

The study area in the terra-firme forest was located on a plateau. Tree species were selected along trails existing in the area based on the availability of at least two trees of the same species and stem diameter at breast height (DBH, 1.3 m from the ground) of at least 10 cm. Overall, we selected 120 mid-upper canopy trees from 28 species, 19 genera and 15 families, which were about 25 cm in diameter and 24 m tall (Table 1; Supplementary Material, Table S1). The increase in stem circumference, or girth increment (at breast height) was measured at monthly intervals, from January to December 2007 (12 measurements per tree) using dendrometer tapes and digital calipers. The tapes had been installed on the trees at least two years before data collection. DBH was obtained by computing the relationship between circumference and diameter: circumference = π × diameter, where π = 3.1416. The diameter growth rate (DGR, hereafter referred to as stem growth), an estimator of tree growth, was calculated as: (DBH - DBH)/t, where DBH and DBH represent the DBH at the end and beginning of the measurement period, respectively, and t, the time elapsed between two consecutive measurements.

To determine wood water content (WWC), bark water content (BWC) and wood density (WD), a core sample was extracted from each tree (3 to 5 cm in length and 5.15 mm in diameter) with an increment borer (Haglof, Sweden) at about 1.4 m from the ground. The sampling was carried out in April 2007, one of the rainiest months of the year, with the aim to obtain the highest possible water content in the samples.

After extraction, each fresh core sample (comprised of bark and wood) was placed into a small capped test tube. The tubes were tightly sealed to avoid loss of moisture and stored in a thermally insulated box with ice for transport to the laboratory, where the bark and wood portions of each sample were separated and weighed on an analytical balance (0.1 mg precision) for determination of bark and wood fresh water content (on a fresh matter basis); BWC = bark water content (on a fresh matter basis); WD = wood density. Values are the mean ± standard deviation. WWC and BWC expressed on a dry matter basis are shown in the Supplementary Material, Table S1.

Table 1. Species used in the study. Acronyms: n = number of individuals per species; DGR = diameter growth rate; DBH = diameter at breast height; WWC = wood water content (on a fresh matter basis); BWC = bark water content (on a fresh matter basis); WD = wood density. Values are the mean ± standard deviation. WWC and BWC expressed on a dry matter basis are shown in the Supplementary Material, Table S1.

| Family          | Species                                                                 | n  | DGR (mm month⁻¹) | DBH (cm) | WWC (%) | BWC (%) | WD (g cm⁻³) |
|-----------------|--------------------------------------------------------------------------|----|------------------|----------|----------|----------|-------------|
| Apocynaceae     | Geissospermum argenteum Woodson                                            | 2  | 0.05 ± 0.04      | 24.27 ± 9.74 | 29.62 ± 3.93 | 47.94 ± 9.40 | 0.84 ± 0.03  |
| Bureraceae      | Protonium apiculatum Swart                                                 | 8  | 0.11 ± 0.14      | 18.28 ± 8.48 | 31.78 ± 3.02 | 49.63 ± 3.64 | 0.63 ± 0.03  |
| Chrysobalanaceae| Licania cananensis Bomento                                                 | 3  | 0.26 ± 0.21      | 36.89 ± 2.76 | 26.38 ± 1.57 | 37.71 ± 1.41 | 0.88 ± 0.07  |
| Chrysobalanaceae| Licania micrantha Miq.                                                     | 5  | 0.16 ± 0.13      | 24.52 ± 10.18| 29.47 ± 3.23 | 36.19 ± 3.15 | 0.87 ± 0.02  |
| Euphorbiaceae   | Micrandropsis scleroxylon (WA Rodrigues)                                   | 3  | 0.08 ± 0.05      | 37.28 ± 6.07 | 31.56 ± 2.53 | 41.38 ± 3.79 | 0.89 ± 0.02  |
| Fabaceae        | Swartzia tomentifera (Ducke) Duche                                        | 4  | 0.08 ± 0.04      | 26.41 ± 12.82| 27.72 ± 2.70 | 45.71 ± 1.68 | 0.82 ± 0.04  |
| Fabaceae        | Tachigalia venusta Dwyer                                                   | 4  | 0.41 ± 0.32      | 26.84 ± 11.94| 35.95 ± 5.44 | 53.74 ± 23.52| 0.55 ± 0.06  |
| Fabaceae        | Inga laurina (Sw.) Willd.                                                  | 4  | 0.33 ± 0.39      | 28.45 ± 11.19| 32.74 ± 0.44 | 66.56 ± 8.73 | 0.79 ± 0.05  |
| Fabaceae        | Lacistema aggregatum (P.J.Bengius) Rusby                                  | 3  | 0.16 ± 0.11      | 20.10 ± 1.38 | 42.81 ± 3.88 | 63.91 ± 11.34| 0.60 ± 0.06  |
| Lauraceae       | Monolaurus ita-uba (Meisn.) Taub. ex Mez                                   | 5  | 0.03 ± 0.03      | 18.27 ± 4.31 | 34.04 ± 1.26 | 50.96 ± 9.75 | 0.75 ± 0.05  |
| Malpighiaceae   | Byrsonima duclosiana W.R. Anderson                                         | 4  | 0.16 ± 0.11      | 39.62 ± 9.79 | 40.24 ± 2.59 | 51.36 ± 4.84 | 0.61 ± 0.07  |
| Malpighiaceae   | Scironema micranthum (Ducke) Duche                                        | 4  | 0.24 ± 0.24      | 43.94 ± 11.06| 41.38 ± 6.69 | 51.05 ± 5.25 | 0.65 ± 0.06  |
| Malpighiaceae   | Theobroma sylvestre Aubl. ex Mart. in Buchner                             | 5  | 0.05 ± 0.05      | 13.49 ± 2.01 | 35.91 ± 4.32 | 64.93 ± 14.61| 0.71 ± 0.04  |
| Ollaceae        | Minquartia guanensis Aubl.                                                 | 3  | 0.03 ± 0.05      | 32.39 ± 16.88| 32.80 ± 1.62 | 61.70 ± 5.50 | 0.81 ± 0.05  |
| Sapotaceae      | Pouteria macrophylla (Lam.) Eyma                                         | 3  | 0.30 ± 0.10      | 42.87 ± 26.96| 31.16 ± 5.26 | 67.10 ± 20.64| 0.66 ± 0.09  |
| Urticaceae      | Porousa tomentosa subsp. apiculata (Spruce ex Benoist) C.C. Berg & Heusden | 4  | 0.21 ± 0.24      | 30.22 ± 8.06 | 50.84 ± 11.99| 57.61 ± 3.80 | 0.43 ± 0.03  |
| Urticaceae      | Erisma bicolor Duche                                                      | 3  | 0.05 ± 0.02      | 17.34 ± 2.19 | 44.17 ± 0.86 | 50.31 ± 5.20 | 0.57 ± 0.02  |

Mean across species

Diameters (mm); mean ± standard deviation; n = number of individuals per species; DGR = diameter growth rate; DBH = diameter at breast height; WWC = wood water content (on a fresh matter basis); BWC = bark water content (on a fresh matter basis); WD = wood density. Values are the mean ± standard deviation. WWC and BWC expressed on a dry matter basis are shown in the Supplementary Material, Table S1.
mass. The volume of the fresh wood and bark was calculated from the length and diameter of the samples (measured with digital calipers with 0.01 mm precision).

The dry mass of the wood and bark samples was determined by oven-drying at 102 °C until constant mass (about 72 h), and weighing on an analytical balance (precision of 0.1 mg). WWC and BWC were calculated as the water content to fresh mass ratio (i.e., fresh mass minus dry mass, divided by fresh mass, Osunkoya et al. 2007). WWC and BWC were expressed on a fresh matter basis, except when otherwise stated, to enable comparison with other studies. WWC and BWC on a dry matter basis (WWC Dry and BWC Dry) were calculated as the fresh mass minus dry mass, divided by dry mass). WD was determined as the ratio of dry mass to fresh mass volume (Suzuki 1999).

Data analysis

To assess the difference in growth rates among species, we used Kruskal-Wallis one way analysis of variance on ranks, as the data did not fulfill the normality assumption (Shapiro-Wilk test, p < 0.05) for parametric analysis. The Spearman correlation (r) was used to determine the association between DBH and WWC and BWC, between WD and mean monthly DGR, and between WD and WWC. The effect of the microclimatic variables [PAR, rainfall, mean temperature (Tmin), minimum temperature (Tmax), and maximum temperature (Tmax)] on monthly DGR was analyzed with redundancy analysis (RDA), which combines multiple regression analysis (MRA) and principal component analysis (PCA). MRA allows the modeling of the effect of explanatory variables on a response variable, while PCA allows the computation of orthogonal vectors, which can be used to reduce data dimensionality. Before performing the redundancy analysis, DGR data were centered (observed value minus the mean), and microclimatic data were standardized (observed value minus the mean, divided by the standard deviation). Standardization of data is required to analyze data expressed in different physical units. In MRA, the addition of explanatory variables to the model inflates the R2 value (explained variance divided by total variance), thus we used the predictive power of the RDA model:

\[ R_{adj}^2 = 1 - \frac{n - 1}{n - m - 1} (1 - R^2) \]

where n represents the number of months and m the number of explanatory variables in the model.

The analyses were performed using R v.3.5.1 (R Core Team, 2018). The RDA was computed using the Vegan 2.5-7 package (Oksanen et al. 2020). The adopted significance level was p ≤ 0.05.

RESULTS

In 2007, the annual rainfall measured at the study area was 2,638 mm. February, October, and September were the driest months, with precipitation of 100–110 mm month–1. Mean monthly PAR was 25.4 mol m–2 day–1, and mean monthly Tmax, Tmin, and Tmax were 25.4 °C, 22.4 °C, and 31.9 °C, respectively.

Wood and bark water content

Mean WWC across species was 34.7%, ranging from 26.4% in Licania canescens to 50.8% in Pourouma tomentosa subsp. apiculata, while mean BWC was 53.4%, ranging from 36.2% in Licania micrantha to 67.1% in Pouteria guianensis (Table 1). WWC, varied from 41.3 to 76.5% and BWC, from 76.9 to 321.6% (Supplementary Material, Table S1).

Both WWC and BWC varied significantly among species (H = 61.8, p < 0.001 for WWC; H = 57.0, p < 0.001 for BWC) and BWC was higher than WWC in all species (Table 1). There was no significant correlation between WD and DGR, nor between DBH and WWC (p > 0.20, Figure 1a,b) or BWC (p = 0.002, Figure 1d). WD was negatively correlated with WWC (r = −0.69, p < 0.001; Figure 1c). The correlation between WWC and BWC was also nonsignificant (r = 0.29, p = 0.14).

Across species, mean annual DGR was 1.56 mm (0.13 mm month–1), with significant differences among species (H = 41.1, p = 0.02). Mean DGR ranged from 0.03 mm month–1 (Eschweilera sp., Mezilaurus ita-uba, Gustavia augusta, and Minquartia guianensis) to 0.41 mm month–1 in Tachigali venusta (Table 1).

Effect of microclimate on tree growth

The RDA showed that the constrained variance (i.e., the proportion of variance explained by microclimatic variability) accounted for 43.8% of the total variance in DGR, thus the residual variance (unconstrained variance) represented 56.2% of total variability (Supplementary Material, Table S2). The R2 value (0.438), however, was inflated as it does not take into account the number of explanatory variables in the model. When it was adjusted, it became apparent that very little of the total variance was associated with the explanatory variables (R2 adj = 0.00), so that none of the five microclimatic variables evaluated had a significant effect on DGR (p > 0.20; Supplementary Material, Table S3), including monthly precipitation (Figure 2).

DISCUSSION

The significant variation in WWC and BWC across species and the lack of correlation with DBH in our study is consistent with the results reported by Dias and Marencó (2016) for the same study area and by Rosell et al. (2014) for tropical and temperate vegetation types. Our mean values of stem water content (34.7% for WWC and 53.4% for BWC) are within...
Phylogenetic factors affect the water content within tree tissues (Hietz et al. 2017), which likely contributed to the wide variation in WWC and BWC observed among the 28 species, which agrees with the results reported by Rosell et al. (2014) and Dias and Marenco (2016). Our values for BWC were higher than those of WWC across species because wood tends to contain less water than the bark, as the xylem conduits do not alter their dimensions, while the parenchymal tissue in the bark can expand (De Schepper et al. 2012). Moreover, the bark has almost twice the amount of soluble sugars (osmotically active compounds) than the sapwood, which can greatly affect the bark water content (Rosell et al. 2021). Although a positive correlation between the water content of living bark and wood has been reported across several vegetation types (Rosell et al. 2014), we found no significant correlation between WWC and BWC, possibly because our study included only rainforest trees.

The negative correlation between wood density and wood water content in our study agrees with Kenzo et al. (2017), who found a similar relationship in a tropical dry forest in Indochina. This result is generally expected, as denser woods have thicker xylem-cell walls, which reduces water storage capacity (McCulloh et al. 2011). Contrary to our expectation of a negative relationship between precipitation and girth growth, stem growth did not increase in the dry season. It has been reported that in the wettest parts of the Amazon rainforest (north and central Amazon), photosynthesis or tree growth tends to increase in the dry season (Huete et al. 2006; Laurance et al. 2009; Green et al. 2020), as precipitation events during the rainy season can reduce photosynthesis due to cloud cover. Earlier studies carried out at the same ZF2 reserve also failed to detect a significant correlation between precipitation and stem growth (Silva et al. 2003; Dias and Marenco 2016). Decreased stem growth or reduced ecosystem photosynthesis can be found in years when the dry season is more prolonged.
produced a negative correlation between stem growth and mean and minimum temperature over a period of 16 years, while, at the same time, no effect of maximum temperature and irradiance variability on the diameter increment of trees was found. In the central Amazon, variation in mean and minimum temperature did not affect stem growth over the 2013–2017 period, while stem growth decreased with increasing irradiance and maximum temperature across a large number of species (Marenco and Antezana-Vera 2021), which highlights the need for further research on this topic.

Production of new leaves (leaf flushing) tends to increase in the dry season (Marenco et al. 2019; Jansen et al. 2021), therefore the absence of an effect of temperature, irradiance and precipitation on DGR does not necessarily mean that canopy photosynthesis did not increase in the dry season, as assimilated carbon may have been diverted to leaf production. Wood production has relatively lower priority in comparison with production of new leaves, buds, and fine roots (Pretzsch 2009). Although many factors that affect tree growth remain to be investigated, we provided evidence that in an above-average rainy year there is no effect of precipitation, irradiance and air temperature on stem growth, even considering that photosynthesis can increase in the dry season.

CONCLUSIONS

We assessed the variation in wood water content and bark water content of trees on a terra-firme forest plateau in the central Amazon and evaluated the effect of monthly precipitation, irradiance, and air temperature on stem growth in a year of above-average rainfall. We found a high bark water content, which highlights the importance of the bark as an active tissue in Amazonian trees, although wood and bark water content did not correlate with stem diameter at breast height among species. In a year with rainfall intensity above the historical mean, monthly stem growth was unresponsive to variation in rainfall, temperature and irradiance, suggesting that, when water availability is not a limiting factor, a higher proportion of assimilated carbon may be diverted to higher priority organs in the dry season.

ACKNOWLEDGMENTS

This research was supported by Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM). We thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Code 001) for funding the study as part of the first author’s doctoral thesis; and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (proc. # 303907/2018-5). We also thank the editor and two anonymous reviewers for their valuable comments and suggestions, which greatly contributed to improve the quality of the manuscript.

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SUPPLEMENTARY MATERIAL (only available in the electronic version)

Dias & Marenco. Wood and bark water content and monthly stem growth in Amazonian tree species

Table S1. Wood water content (WWC) and bark water content (BWC) expressed on a dry matter basis for 28 tree species in a terra-firme forest in the central Amazon. The range of the diameter at breast height (DBH) and tree height of the sampled individuals of each species are also shown. Tree height was computed after Nogueira et al. (2008).

| Species                      | WWC (%) | BWC (%) | DBH (cm) | Height (m) |
|------------------------------|---------|---------|----------|------------|
| Byrsonia duckena             | 54.2 ± 0.09 | 96.4 ± 0.20 | 25.9 − 48.6 | 26.2 − 32.6 |
| Erisma bicolor               | 52.5 ± 0.20 | 96.7 ± 0.42 | 15.3 − 19.5 | 19.2 − 26.0 |
| Eschweilera bracteosa        | 56.9 ± 0.32 | 179.2 ± 1.26 | 13.7 − 27.0 | 19.2 − 26.0 |
| Eschweilera collina          | 50.4 ± 0.08 | 96.6 ± 0.16  | 12.1 − 29.8 | 18.2 − 28.1 |
| Eschweilera grandiflora      | 68.8 ± 0.18 | 102.1 ± 0.39 | 19.7 − 49.5 | 23.0 − 28.1 |
| Eschweilera pedicellata      | 44.8 ± 0.03 | 110.9 ± 0.34 | 13.1 − 50.0 | 17.3 − 25.7 |
| Geissospermum aggregatum     | 41.3 ± 0.08 | 89.0 ± 0.39  | 13.6 − 37.2 | 18.4 − 29.0 |
| Gustavia agusta              | 70.2 ± 0.31 | 153.2 ± 0.39 | 13.6 − 21.1 | 17.7 − 23.1 |
| Inga laurina                 | 63.8 ± 0.21 | 294.6 ± 1.82 | 18.4 − 34.0 | 22.7 − 31.1 |
| Lacistema aggregatum         | 47.6 ± 0.20 | 81.3 ± 0.49  | 15.7 − 19.9 | 22.3 − 23.3 |
| Licania canescens            | 47.7 ± 0.05 | 321.6 ± 2.62 | 14.9 − 38.3 | 20.6 − 30.4 |
| Licania micrantha            | 41.7 ± 0.14 | 107.3 ± 0.54 | 13.1 − 38.7 | 27.9 − 29.6 |
| Mezilaurus ita–uba           | 51.2 ± 0.20 | 90.2 ± 0.26  | 19.6 − 43.7 | 22.9 − 31.7 |
| Micropholis guyanensis       | 51.4 ± 0.20 | 90.2 ± 0.26  | 19.6 − 43.7 | 22.9 − 31.7 |
| Minquartia guianensis        | 51.9 ± 0.08 | 157.1 ± 0.29 | 16.8 − 52.1 | 20.4 − 33.2 |
| Pouteria macrophylla         | 49.8 ± 0.08 | 97.1 ± 0.32  | 17.7 − 36.2 | 22.2 − 29.9 |
| Pouteria cladantha           | 50.7 ± 0.04 | 135.2 ± 0.47 | 11.9 − 20.4 | 15.5 − 23.0 |
| Pouteria guianensis          | 56.9 ± 0.29 | 115.7 ± 0.15 | 22.5 − 66.2 | 23.7 − 37.8 |
| Pouteria microphylla         | 63.0 ± 0.20 | 184.1 ± 1.11 | 15.3 − 47.7 | 25.5 − 33.1 |
| Pouteria sp.                 | 46.2 ± 0.04 | 76.9 ± 0.10  | 14.2 − 23.0 | 18.2 − 24.4 |
| Protium apiculatum           | 52.7 ± 0.14 | 90.7 ± 0.28  | 10.5 − 31.1 | 15.5 − 23.7 |
| Protium hebetatum            | 56.2 ± 0.02 | 198.6 ± 2.45 | 12.0 − 15.5 | 17.1 − 20.0 |
| Scleronema micranthum        | 55.8 ± 0.22 | 88.7 ± 0.27  | 28.1 − 52.4 | 26.1 − 33.7 |
| Swartzia tomentosa           | 53.3 ± 0.18 | 83.8 ± 0.19  | 11.4 − 36.6 | 15.8 − 29.2 |
| Tachigali venusta            | 51.9 ± 0.07 | 117.8 ± 1.80 | 10.6 − 30.6 | 16.3 − 29.3 |
| Theobroma sylvestre          | 49.7 ± 0.10 | 187.6 ± 2.65 | 11.7 − 15.8 | 15.7 − 20.4 |

Table S2. Proportion of constrained variance of the effect of microclimatic variables on monthly diametric growth of 28 tree species in the central Amazon as explained by RDA–axes. The p, R² and R² adj values and the unconstrained (residual) variance are also shown.

| RDA-axis | Variance | Proportion of variance | p value |
|----------|----------|------------------------|---------|
| RDA1     | 0.11765  | 0.594492               | 0.384   |
| RDA2     | 0.03675  | 0.185700               | 0.990   |
| RDA3     | 0.01945  | 0.098282               | 1.000   |
| RDA4     | 0.01868  | 0.094391               | 0.990   |
| RDA5     | 0.00540  | 0.027287               | 0.999   |

R² = 0.4378 (0.1979/0.452)
R² adj = –0.03 (~0.00)

Table S3. Effect of microclimatic variables on monthly diametric growth of 28 central Amazonian tree species assessed by redundancy analysis and p values determined by the ordistep function of the Vegan package of the R program. Because none of the variables had a significant effect on tree growth, only the full model is shown. Tmin = minimum temperature; Tmax = maximum temperature; Tmean = mean temperature; PAR = photosynthetically active radiation; DF = degrees of freedom; F = ratio between explained and residual variance; p value = probability value.

| Variable                      | DF | F    | p value |
|-------------------------------|----|------|---------|
| Rainfall                      | 1  | 0.6959 | 0.660   |
| Tmin                          | 1  | 0.7042 | 0.630   |
| Tmax                          | 1  | 0.8658 | 0.540   |
| Tmean                        | 1  | 0.9344 | 0.395   |
| PAR                           | 1  | 1.4909 | 0.205   |