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REVIEW ARTICLE

Dendrochronology and climate in the Brazilian Atlantic Forest: Which species, where and how

Dendrocronologia e clima na Floresta Atlântica brasileira: quais espécies, onde e como

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Abstract

As dendrochronology noticeably increased in tropical regions during the last three decades, some general patterns could emerge from comprehensive analyses of case studies. Here, we investigated the state of dendrochronology's contributions to the bioclimatology of wood species in the Brazilian Atlantic Forest (AF). We asked: Which species and sites had cross-datable growth-ring series suitable for bioclimatic inference? What were the sampling and analytical methods applied? What do these studies tell us about plant-growth sensitivity to climate conditions? Which knowledge gaps may be identified? For this, we searched for articles addressing climate-growth relationships by means of cross-dated growth-ring chronologies within the AF. We found 11 articles, covering 16 chronologies from 10 species. The average number of trees in chronologies was 16 individuals. 87% of chronologies suggested a positive precipitation signal, and some positive temperature signal was identified in all chronologies that were compared to monthly or seasonal temperature series. The findings are supported by the specialized literature, which points out the influence of precipitation in the tropics. However, making stronger conclusions about the role of climate on the growth of AF tree species will require greater efforts in surveying the diverse tree flora and developing rigorous cross-dated chronologies.

Keywords: climate-growth relationship, dendrochronological parameters, tropical forest, subtropical forest.

Resumo

A dendrocronologia aumentou notavelmente nas regiões tropicais durante as últimas décadas e alguns padrões gerais podem emergir de análises abrangentes de estudos de caso. Aqui, investigamos as contribuições da dendrocronologia para a bioclimatologia de espécies arbóreas na Floresta Atlântica brasileira (FA). Perguntamos: Quais espécies e locais dispõem de séries de anéis de crescimento codatáveis adequadas para inferência bioclimática? Quais são os métodos de amostragem e análise aplicados? O que esses estudos dizem sobre a sensibilidade do crescimento das plantas às condições climáticas? Quais lacunas de conhecimento podem ser identificadas? Para isso, buscamos artigos abordando as relações clima-crescimento por meio de cronologias de anéis. Encontramos 11 artigos, cobrindo 16 cronologias de 10 espécies. O número médio de árvores nas cronologias foi de 16 indivíduos. Oitenta e sete por cento das cronologias sugeriram um sinal positivo de precipitação e algum sinal positivo de temperatura foi identificado em todas as cronologias comparadas às séries mensais ou sazonais de temperatura. Os resultados são apoiados pela literatura especializada, que aponta a influência da precipitação nos trópicos. Entretanto, tirar conclusões mais sólidas sobre o papel do clima no crescimento de espécies arbóreas da FA exigirá maiores esforços no levantamento da diversidade da arbórea e no desenvolvimento de rigorosas cronologias codatadas.

Palavras-chave: floresta subtropical, floresta tropical, parâmetros dendrocronológicos, relação clima-crescimento.

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Introduction

Dendrochronology through the rings of growth of the trees determines the age and studies its performance in relation to the factors that led it to growth, such as climatic factors. Dendroclimatic studies in tropical and subtropical regions remain one of the major gaps for dendrochronology, although such studies have increased in the last three decades (Zuidema *et al.*, 2012). The apparent absence of climatic seasonality (Brienen *et al.*, 2016; Fritts, 1976; Jacoby, 1989; Payette and Filion, 2010; Speer, 2010) and the complexity of growth rings in tropical species (Brienen *et al.*, 2016; Jacoby, 1989; Stahle, 1999) have left researchers pessimistic about the application of dendrochronology in these environments and hindered its development. Thus, recent studies have been concerned with describing species showing dendrochronological potential (e.g., Baker *et al.*, 2017; Fichtler *et al.*, 2003; Soliz-Gamboa *et al.*, 2011; Worbes and Junk, 1989; Zuidema *et al.*, 2012). These studies already form a dense theoretical body that demonstrates the feasibility of tropical dendroclimatology, but also provides information on both the natural dynamics of the climate and the relationship between climate and biological patterns. This knowledge is especially important to understand, predict, and mitigate the effect of global climatic changes of anthropogenic origin that is currently one of the greatest challenges for science.

Current climate change stands out for the magnitude, intensity, and speed with which it is occurring. The process has accelerated over the last 70 years as a result of emissions of atmospheric pollutants and greenhouse gases (GHGs: carbon dioxide, methane and nitrous oxide) through the production of energy and the conversion of natural ecosystems into agriculture/pasture areas and urban areas (IPCC, 2014). Changes in climate include increased global average temperature (oceanic and atmospheric), changes in the hydrological cycle, acidification and rising of the sea levels, reduced ice cover and increased occurrence of extreme events such as storms and cyclones (IPCC, 2014). Scientists from the most diverse areas of knowledge have mobilized to understand the impacts of these changes on the fauna and flora, human health and socioeconomic development.

Vegetation is an important component of climate regulation, which involves issues related to surface roughness, evapotranspiration and albedo (Anderson-Teixeira *et al.*, 2012; Cardoso and Justino, 2014; Shukla *et al.*, 1990). According to Bonan (2008, p. 1444), "the world's forests influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition". In this sense, tropical forest play a fundamental role in the terrestrial carbon cycle since they store approximately 54% of the total biomass carbon of global forests (Liu *et al.*, 2015; Wagner *et al.*, 2016).

The Atlantic Forest (AF) is the second largest tropical forest in South America and, because it is under high anthropogenic pressure and rich in species diversity and endemism, it was considered one of the seven priority hotspots for conservation in the region (Myers *et al.*, 2000; Oliveira-Filho and Fontes, 2000). In its original distribution, the forest extended from the south to the northeast of Brazil in lowlands and highlands of the Atlantic zone, spreading inland to the east of Paraguay and northwest of Argentina (Galindo-Leal and Câmara, 2003; Lima and Capobianco, 1997). However over 93% of the forest has been lost to economic purposes (Galindo-Leal and Câmara, 2003), with most remaining areas being small and isolated patches (<50 ha and distant more than 1000 m from other spots) (Ribeiro *et al.*, 2009). Less than 9% of its total remaining area is currently under protection, which comprises less than 1% of the original forest area (Ribeiro *et al.*, 2009).

Because of its remarkable range of latitude and altitude, the AF has high climatic variability (Oliveira-Filho and Fontes, 2000) and a broader vegetation scheme, including mangroves, coastal plain "restingas", seasonal forests, evergreen forests (mixed ombrophilous and dense ombrophilous), subtropical grasslands and wetlands (IBGE, 2012; Víncens *et al.*, 2003; Oliveira-Filho and Fontes, 2000). It comprises a temperature gradient that rises toward the tropics. In the south, the climate is marked by quite low winter temperatures and well-distributed rainfall throughout the year (Nimer, 1971). Northward, the intra-annual temperature variation becomes less pronounced, but dry seasons also occur. Average monthly rainfall below 60 mm occurs in the central portion of the AF from May to September (Sant'Anna-Neto, 2005), while in the northern portion even drier conditions prevail from September to January (Ferreira and Mello, 2005).

Here, we explore how tree-ring studies have contributed to current understanding of growth/climate relationships of tree species from the AF. More specifically, we asked: (i) Which species and sites had cross-datable growth-ring series suitable for bioclimatic inference? (ii) What were the sampling and analytical methods applied? (iii) What do these studies tell us about the sensitivity of tree growth to climatic conditions? In order to answer such questions and contribute to the development of tropical dendroclimatology, we have gathered information on dendroclimatic studies from the AF region from a literature review.

Material and methods

Literature review

As a strategy for constructing our information base, we searched articles indexed in three electronic databases (publications until December 2016): Scopus, SciELO and

Web of Science. We used the following keywords combined in different ways using Boolean operators: “dendro*”, “climat*”, “Atlantic Forest”, “tree ring”, “growth ring”, “Brazil*”. From the articles found, we considered those in which the abstract or the full text noted that the dendrochronological series had been crossdated and related to climatic series. We read these articles in full, to record the below information on climate chronologies and relationships.

Site, taxa, location and environmental data

We reviewed on the website Tropicos (2017) the botanical family and the scientific name of each species. For geographical coordinates of the site, if not explicitly stated, we derive them inferred by the given locational references (i.e., name of the municipality or Conservation Unit). We did the same for site elevation, using it based on the Google Earth (2017) in the respective geographic location. The vegetation type (according to IBGE, 2012) was assigned inferring it based on the description of the vegetation on the vegetation map of Brazil (IBGE, 2004).

Chronologies and climatic signals

We classified the information on the sampling and development of the chronologies by analyzing: the method of sampling wood (destructive or non-destructive), number of trees and cores extracted per tree, the total number of trees and series that composed the chronology, period and extension of the mean chronology.

We also analyzed the applied analytical methods and the chronology descriptions, evaluating: Details of the cross-dating techniques, standardization and integration methods, series descriptions and their degree of synchronization (intercorrelation – *r*int, mean correlation between series – *r*bar, Gleichlaufigkeit – GLK, Expressed Population Signal – EPS, Mean Sensitivity Index – MSI). In a dendroclimatic context, standardization involves a modeling and removal of non-climatic trends in the growth rings (Cook, 1985; Fritts, 1976). The autocorrelation is “the correlation between growth in one time interval with that in a subsequent interval calculated over all individuals of populations” (Brienen *et al.*, 2006).

The *r*int presents the correlation coefficient of each tree series compared against the master dating series (Grissino-Mayer, 2001). *R*bar indicates the mean correlation coefficient applied for all possible pairings of ring width series over a common time (Cook and Holmes, 1996). The GLK is a measurement of similarity (Speer, 2010). It calculates the sign of agreement of a sample series with a chronology or between two chronologies, presenting the sum of the equal slope intervals in percentage, generally being significant from 60% on ($p < 0.5$) (Rinn, 2011). Eps represents the expected correlation between the *t*-series average of a finite number of trees and a hypothetical population average, with a threshold of EPS ≥ 0.85 (Wigley *et al.*, 1984). MSI is a measurement that informs about variation in tree-ring year-to-year ranging from 0 to 1 (Speer, 2010).

Finally, we checked the results related to the relationships between dendrochronological and climatic series to infer patterns of dendroclimatic signals.

Results

Taxa and environmental characteristics of chronologies

Our search in the databases and with the selected terms resulted in 29 indexed articles. However, only 11 of these declared to be based on crossdated chronologies and related to climatic series, a condition for the inclusion in this study.

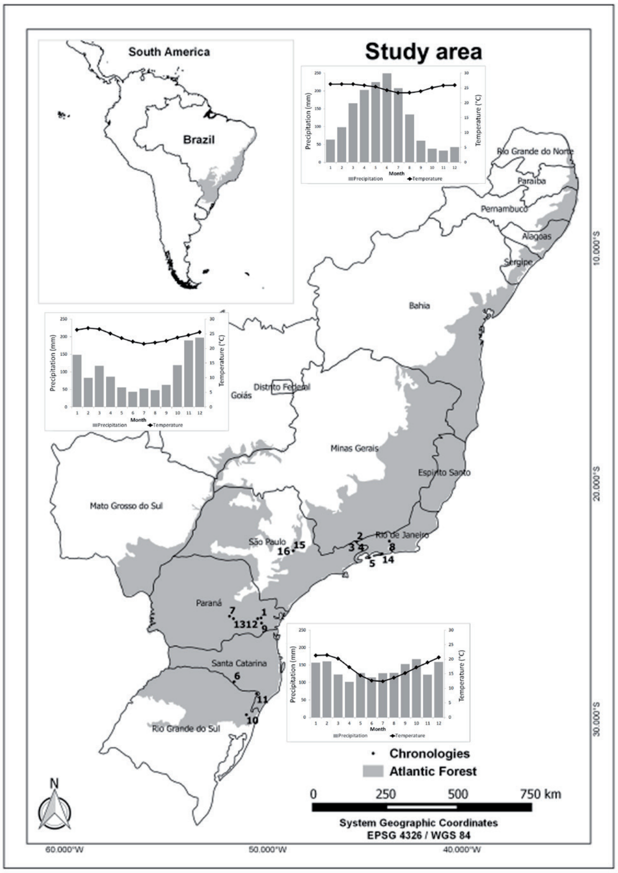


Figure 1. Location of growth-ring chronologies used in dendroclimatic studies within the Brazilian Atlantic Forest (numeric code). Climatic diagrams of the modeled historical series (1901-2014) of mean monthly temperature and mean monthly total precipitation for the southern, central and northern parts of the Atlantic Forest. Source: CRU TS3.23 (http://ckan.data.alpha.jisc.ac.uk/).

These publications totaled 16 chronologies, developed with ten different species (seven native, three exotic) and under various environmental conditions (Table 1, Figure 1).

The family with more taxa investigated was Fabaceae Lindl., with four species and three genera, while other families had only one species analyzed. The species with the highest number of chronologies was the conifer *Araucaria angustifolia* (Bertol.) Kunze (n=5), and the broadleaf trees *Cedrela fissilis* Vell. (n=2) and *Schizolobium parahyba* (Vell.) S.F. Blake (n=2). Three exotic species composed the sample, namely the conifers *Cryptomeria japonica* (Thunb. ex L. f.) D. Don and *Pinus caribaea* Morelet, and the broadleaf *Tectona grandis* L. f. One of the studies was developed with lianas, investigating three Fabaceae species (Table 1).

The chronologies were concentrated in the central-southern and eastern portions of the AF, with no study in the northern and western portions. As for altitude, 11 were in elevated areas (700-1265 m), three in medium elevations (200-700 m) and two in lowlands (<100 m). This spatial distribution of chronologies comprised four types of climate and three types of vegetation. The great majority of the chronologies (n=14) represented temperate climate conditions, according to the classification of Köppen (Alvares *et al.*, 2013) (*i.e.*, with temperatures above 10ºC in the hottest month, and between 0 and 18ºC in the coldest month), especially in regions with no dry season and warm summers (Cfb, 11 chronologies) or hot summers (Cfa, 2 chronologies). Only two chronologies represented sites of tropical climate (*i.e.*, with an average temperature of the hottest month above 18ºC). Among the phytophysiognomies included in the biome AF, the chronologies included sites of mixed ombrophilous (n=7), dense ombrophilous (n=6) and seasonal (n=2) forests, in addition to one in a commercial plantation (Table 1; Figure 1).

Table 1. Growth-ring chronologies used for dendroclimatic studies within the Brazilian Atlantic Forest, according to taxa, leaf phenology, environmental setting, code number (this study) and reference.

Taxa	Leaf phenology	Altitude (m asl)	Climate type (Koppen)	Forest type (IBGE)	Code	Reference
Araucariaceae						
Araucaria angustifolia (Bertol.) Kuntze	Evergreen	910	Cfb	Mixed ombrophilous	9	Lorensi and Prestes (2016)
		866	Cfb	Mixed ombrophilous	10	Oliveira *et al.* (2010)
		1265	Cfb	Mixed ombrophilous	11	Oliveira *et al.* (2010)
		940	Cfb	Mixed ombrophilous	12	Perone *et al.* (2016)
		800	Cfb	Mixed ombrophilous	13	Perone *et al.* (2016)
Cupressaceae						
Cryptomeria japonica (L.f.) D.Don	Evergreen	970	Cfb	Commercial plantation	6	Dobner-Jr *et al.* (2014)
Fabaceae						
Dalbergia frutescens (Vell.) Britton	No data	700-1100	Cfb	Dense ombrophilous	4	Brandes *et al.* (2011)
Piptadenia adiantoides (Spreng.) J.F.Macbr.	No data	700-1100	Cfb	Dense ombrophilous	2	Brandes *et al.* (2011)
Piptadenia micracantha Benth.	No data	700-1100	Cfb	Dense ombrophilous	3	Brandes *et al.* (2011)
Schizolobium parahyba (Vell.) Blake	Deciduous	20-80	Aw	Dense ombrophilous	5	Callado and Guimarães (2010)
		500	Cwb	Dense ombrophilous	8	Latorraca *et al.* (2015)
Meliaceae						
Cedrela fissilis Vell.	Deciduous	945	Cfb	Dense ombrophilous	1	Andreacci and Botosso (2014)
		890-940	Cfb	Mixed ombrophilous	7	Dünisch (2005)
Pinaceae						
Pinus caribaea var. hondurensis Morelet	Evergreen	546	Cfa	Semideciduous	15	Venegas-González *et al.* (2016)
Rhizophoraceae						
Rhizophora mangle L.	Evergreen	<100	Aw	Dense ombrophilous	14	Souza *et al.* (2016)
Verbenaceae						
Tectona grandis Linn. F.	Deciduous	546	Cfa	Semideciduous	16	Venegas-González *et al.* (2016)

Sampling characteristic

The total number of trees sampling to build the chronologies was 326, of which 248 (76%) were used in the master chronologies. The mean number of trees in each chronology was 16 individuals, ranging from 5 to 44 individuals (SD = 12; median = 11). The number of radii evaluated varied from 2 to 5 per tree, being more frequent the analysis of 4 radii per individual (Table 2).

The most used method for the sampling was the non-destructive method by increment borer, used in 10 (63%) chronologies, while for 6 (37%) of the chronologies, the destructive method was used, with a section of wood discs. The destructive method allowed a better use of those wood samples collected, with an inclusion of 97% of the sampled trees. In contrast, chronologies based on samples collected with increment borer resulted in an inclusion of 72% of the trees (Table 2).

Regarding the chronological period, trees comprised the years between 1790 and 2011, with analyzed period ranging from 6 to 218 years and mean of 68 years (SD ± 61 years, median = 39 years). It should be noted that *A. angustifolia* has the longest chronologies, with a mean of 140 years (SD ± 46, median = 122), while the other species comprise chronologies with a mean extension of 35 years (SD ± 31, median = 24). Among the angiosperms, the longest extension period analyzed was for *C. fissilis*, with a chronology of 110 years (Table 2).

Numerical methods

The cubic smoothing spline with a 50% frequency-response cutoff was the most used detrending model (applied in 63% of chronologies), often preceded by an exponential or linear model. Most chronologies (54%) that detrended the raw series did not inform if trends were filtered by ratios or residuals. Autoregressive modeling was not applied in most chronologies (63%), but serial autocorrelation levels were not given for any of these chronologies (or the others). The expected value function used to integrate the detrended series in the master chronology was informed for 50% of the chronologies, of which half used the bi-weighted robust mean and half the arithmetic mean (Table 3).

In relation to synchronism and sensitivity, for all chronologies at least one measure of series association was informed. The most used statistic was *r*int (63%), followed by *r*bar (31%) and GLK (13%). The values of *r*int ranged between 0.28 up to 0.94, while the *r*bar were between 0.25 up to 0.69, and GLK agreement above 60% (significance level at 5%). Chronologies that informed about series' standard deviation showed mean values between 1.99 and 6.46 (mm). MSI ranged between 0.16 up to 0.57, with higher values to the north of the AF and lower to the south. However, 44% of the chronologies did not inform MSI values. EPS was only given in one study, with two chronologies, with values around 0.93 (Table 3).

Table 2. Sample and crossdate efforts of growth ring chronologies used in dendroclimatic studies within the Brazilian Atlantic Forest.

Chronology code	Species	Wood sample type	Sampled individuals	Sampled radii per individual	Crossdated individuals	Crossdated period	Crossdated length (yr)
9	*A. angustifolia*	Core	10	4	8 (80%)	1907-2009	102
10	*A. angustifolia*	Core	30	2-5	17 (57%)	1882-2003	122
11	*A. angustifolia*	Core	30	2-5	18 (60%)	1861-2003	142
12	*A. angustifolia*	Core	22	2	10 (45%)	1790-2008	218
13	*A. angustifolia*	Core	44	2	39 (89%)	1891-2008	117
15	*P. caribea*	Core	10	4	10 (100%)	1971-2011	36
6	*C. japonica*	Stump	30	4	29 (97%)	1987-2010	24
4	*D. frustescens*	Stump	15	4	15 (100%)	1970-2005	35
2	*P. adiantoides*	Stump	7	4	7 (100%)	1993-2005	12
3	*P. micracantha*	Stump	7	4	6 (86%)	1987-2005	18
5	*S. parahyba*	Stump	5	2-3	5 (100%)	1995-2001	6
8	*S. parahyba*	Core	30	4	16 (53%)	1939-2011	73
1	*C. fissilis*	Core	20	3-4	11 (55%)	1985-2009	22
7	*C. fissilis*	Core	51	2	42 (82%)	1890-2000	110
14	*R. mangle*	Stump	7	4	7 (100%)	2004-2011	7
16	*T. grandis*	Core	8	4	8 (100%)	1976-2011	41
Mean			20	4	16 (81%)		68
Standard deviation			14	1	12 (20%)		61
Median			18	4	11 (87%)		39
Minimum			5	2	5 (45%)		6
Maximum			51	4	42 (100%)		218

Table 3. Numerical methods applied to build and describe the growth ring chronologies used in dendroclimatic studies within the Brazilian Atlantic Forest. Models applied to depict and remove ontogenetic and disturbance variations in raw growth ring series, statistics describing the synchronicity among indexed growth ring series (*r*int, intercorrelation; *r*bar, mean correlation between series; GLK agreement, Gleichlaufigkeit; EPS, expressed population signal) and their time variation degree (MSI, mean sensitivity index), and the mean function used to integrate indexed growth ring series. Interrogation indicates that no information was given. CRN = Chronology code number in the study.

CRN	Trend model	Trend removal	Autoregressive model	Synchronism and sensitivity statistics	Expected value function
9	Polynomial linear model (1st to 3rd order)	Ratios	No	*r*int=0.28	?
10	Cubic spline 50% cutoff (50 yr)	Ratios	Yes	*r*int=0.49 *r*bar=0.25 MSI=0.24	Bi-weighted robust mean
11	Cubic spline 50% cutoff (50 yr)	Ratios	Yes	*r*int=0.57 *r*bar=0.34 MSI=0.16	Bi-weighted robust mean
12	Exponential or linear model (slope ≤ 0) and cubic spline 50% cutoff (22 yr)	?	No	GLK > 60%	Bi-weighted robust mean
13	Exponential or linear model (slope ≤ 0) and cubic spline 50% cutoff (15 yr)	?	No	GLK > 60%	Bi-weighted robust mean
15	Exponential or linear model (slope ≤ 0), Cubic spline 50% cutoff (67%)	Ratios	Yes	*r*bar=0.69 EPS=0.95	?
6	?	Ratios	?	*r*int=0.67	?
4	Cubic spline 50% cutoff (5 yr)	?	No	*r*int=0.5 MSI=0.51	Arithmetic mean
2	Cubic spline 50% cutoff (5 yr)	?	No	*r*int=0.69 MSI=0.57	Arithmetic mean
3	Cubic spline 50% cutoff (5 yr)	?	No	*r*int=0.48	Arithmetic mean
5	None	None	No	MSI=0.37	?
8	?	?	No	*r*int=0.71 MSI=0.42	?
1	Exponential model (slope ≤ 0) and cubic spline 50% cutoff (67%)	?	No	*r*int=0.57 MSI=0.49	?
7	Logarithmic model	Residual	No	*r*bar=0.31	Arithmetic mean
14	?	?	?	*r*int=0.94	?
16	Exponential or linear model, cubic spline 50% cutoff (67%)	Ratios	Yes	*r*bar=0.64 EPS=0.93	?

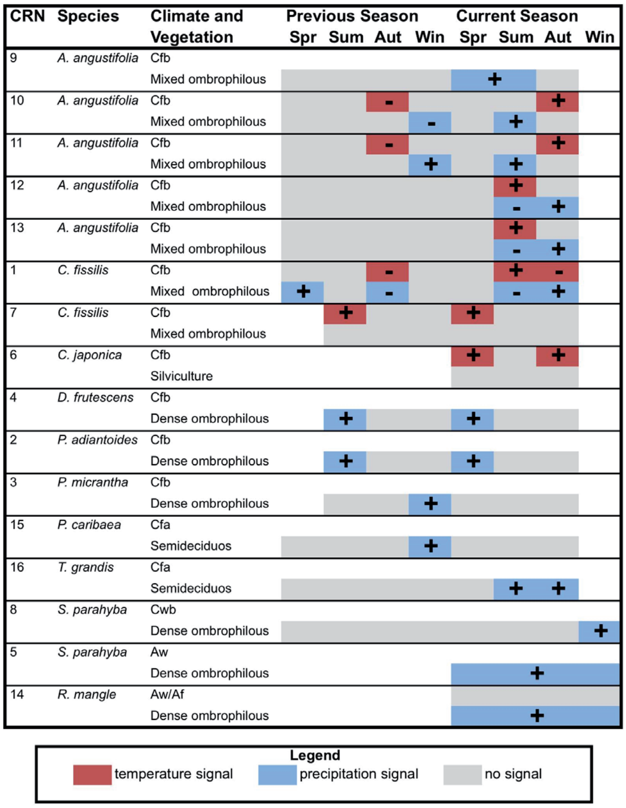
Climatic influence on the Atlantic Forest

Despite the differences on species and environmental conditions among the AF chronologies, some dendroclimatic patterns may be drawn. All but two chronologies (87%) evidenced some positive precipitation signal, and some positive thermal signal was identified in all chronologies that were compared to monthly or seasonal temperature series (n=8), *e.g.* mostly of *A. angustifolia* and *C. fissilis* in mixed ombrophilous forest under Cfb climate. Nevertheless, precipitation and/or temperature signals occurred in quite different seasons, even among chronologies under similar climate types and/or belonging to the same species, as for *A. angustifolia* and *C. fissilis* (Figure 2). Interestingly, climatic signals were more homogeneous in nature and schedule between pairs of chronologies reported in the same paper (chronologies: 10 and 11; 12 and 13; 4 and 2) (Figure 2; Table 1).

Discussion

Site, taxa, location and environmental data

We reviewed all available tree-ring studies from Brazilian AF focused on growth-climate relationships. Only 7 of the 491 tree species described for the AF were found to have cross-datable annual growth rings, despite 235 tree species having some form of anatomical growth differentiation in their wood (Alves and Angyalossy-Alfonso, 2000). For example, among Lauraceae from the southern AF region, ten potential species were pointed out for dendrochronology (Reis-Ávila and Oliveira, 2017), as well as Fabaceae



CRN	Species	Climate and Vegetation	Previous Season				Current Season			
			Spr	Sum	Aut	Win	Spr	Sum	Aut	Win
9	*A. angustifolia*	Cfb								
		Mixed ombrophilous	⬜	⬜	⬜	⬜	🟦 +	🟦	⬜	
10	*A. angustifolia*	Cfb	⬜	⬜	🟥 -	⬜	⬜	⬜	🟥 +	
		Mixed ombrophilous	⬜	⬜	⬜	🟦 -	⬜	🟦 +	⬜	
11	*A. angustifolia*	Cfb	⬜	⬜	🟥 -	⬜	⬜	⬜	🟥 +	
		Mixed ombrophilous	⬜	⬜	⬜	🟦 +	⬜	🟦 +	⬜	
12	*A. angustifolia*	Cfb	⬜	⬜	⬜	⬜	⬜	🟥 +	⬜	
		Mixed ombrophilous	⬜	⬜	⬜	⬜	⬜	🟦 -	🟦 +	
13	*A. angustifolia*	Cfb	⬜	⬜	⬜	⬜	⬜	🟥 +	⬜	
		Mixed ombrophilous	⬜	⬜	⬜	⬜	⬜	🟦 -	🟦 +	
1	*C. fissilis*	Cfb	⬜	⬜	🟥 -	⬜	⬜	🟥 +	🟥 -	
		Mixed ombrophilous	🟦 +	⬜	🟦 -	⬜	⬜	🟦 -	🟦 +	
7	*C. fissilis*	Cfb		🟥 +	⬜	⬜	🟥 +	⬜	⬜	
		Mixed ombrophilous		⬜	⬜	⬜	⬜	⬜	⬜	
6	*C. japonica*	Cfb					🟥 +	⬜	🟥 +	
		Silviculture					⬜	⬜	⬜	
4	*D. frutescens*	Cfb								
		Dense ombrophilous		🟦 +	⬜	⬜	🟦 +	⬜	⬜	
2	*P. adiantoides*	Cfb								
		Dense ombrophilous		🟦 +	⬜	⬜	🟦 +	⬜	⬜	
3	*P. micrantha*	Cfb								
		Dense ombrophilous		⬜	⬜	🟦 +	⬜	⬜	⬜	
15	*P. caribaea*	Cfa								
		Semideciduos	⬜	⬜	⬜	🟦 +	⬜	⬜	⬜	
16	*T. grandis*	Cfa								
		Semideciduos	⬜	⬜	⬜	⬜	⬜	🟦 +	🟦 +	
8	*S. parahyba*	Cwb								
		Dense ombrophilous	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟦 +
5	*S. parahyba*	Aw								
		Dense ombrophilous					🟦 +	🟦	🟦	🟦
14	*R. mangle*	Aw/Af					⬜	⬜	⬜	⬜
		Dense ombrophilous					🟦 +	🟦	🟦	🟦

Legend

🟥 temperature signal 🟦 precipitation signal ⬜ no signal

Figure 2. Seasonal dendroclimatic signals in growth-ring chronologies within the Brazilian Atlantic Forest. We considered evidence of seasonal climatic influence on plant growth if authors reported any meaningful association between the growth-ring chronology and temperature- or precipitation-related series, for any month of the season or for the entire season. Symbols identify positive or negative associations.

(and others) from the western AF region (Lisi *et al.*, 2008). Furthermore, cambial activity studies confirm the annual growth rings in many species (Callado *et al.*, 2014).

In addition, we did not find publications for the northern region of this biome, which presents important floristic and climatic differences. An area not yet investigated contains the "Tabuleiro" AF, considered globally as the area with the highest diversity of flora species per hectare (Thomas *et al.*, 2008), which adds importance to research on issues related to the temporal development of this forest. It is also noticed that there are more chronologies in the regions of high altitude, especially in regions of mixed ombrophilous forest, characterized by the floristic mixture of Australasian and Afro-Asian genera and by the low temperature in the winter (IBGE, 2012), and in mountainous regions of dense ombrophilous forest. It is possible that, during the choice of study sites, the greatest variation in the temperature presented in these areas is being considered. However, there is a strong theoretical framework demonstrating that the variation in precipitation, which impacts on droughts and floods, is the main variable involved in the formation of growth rings in tropical regions (Botosso and Vetter, 1991; Brienen *et al.*, 2016; Pagotto *et al.*, 2017; Schöngart *et al.*, 2005; Worbes, 1989). Thus, to contribute to the understanding of the influence of climate on AF, it is necessary to include more studies in coastal regions, as well as in the northern and inner areas of this biome, especially because the same species may have a very different growth response depending on where it occurs (Baker *et al.*, 2017).

This result is also inexpressive in comparison to the number of active research groups registered in the Directory of Research Groups in Brazil that includes a research line in dendrochronology (15 groups) (Conselho Nacional de Desenvolvimento Científico e Tecnológico, 2017). Another finding in our data search is that there is a large academic production in the form of theses and dissertations, but those were not yet published in scientific journals. The publications are important to give greater visibility to the study and its validation, as well as to contribute to a better understanding of the complex relationships involved in the growth of tropical trees. In this way, considering the great floristic diversity of the country (Forzza *et al.*, 2012) and the number of species for which the formation of annual rings has been proven to be of potential use for dendrochronology, as well as the number of existing research groups, it is necessary to unite researchers and groups and discuss mechanisms that help to expand this field in the AF and how to publish these studies.

Sampling characteristic

In general, the average number of trees (16 individuals) used in the chronologies is in agreement with that indicated in the literature (Briffa and Jones, 1990; Esper and Gärtner, 2001; Schweingruber *et al.*, 1990). However, some chronologies containing few individuals consisted of sampling by the destructive method, in which wood discs were evaluated. The difference between chronologies from stem discs and cores points to the presence of rings that are not complete around the circumference and it is better to identify them in discs. Thus, stem discs increases the use of the sampling in master chronology and allows greater accuracy in the dates since it facilitates the identification of false rings, missing rings and other anomalies of the wood. The chronologies with the greatest sampling, for the most part, consisted of cores (non-destructive method), probably due to the greater agility in the sampling and exemption of cut authorization. For Fichtler (2017), non-destructive sampling methods are not indicated for most tropical broad-leaf species, since the anatomical inspection of the wood and secure identification of the ring requires a larger surface than that possible by radius analysis. In this context, more samples by individuals would help to solve this problem.

The number of trees in the chronologies also depends on the research objectives and cannot be generically stipulated (Mérian *et al.*, 2013). Nevertheless, Briffa and Jones (1990) suggest at least 5 trees (1 radius per tree), but they emphasize that the more individuals, the better. Schweingruber *et al.* (1990) recommend at least 10 individuals. Esper and Gärtner (2001) also indicate 10 individuals and note that 20 trees can easily emphasize site signs. Speer (2010) indicates 20 trees, two radii each. Cook (1985) mentioned between 20-40 trees and Fritts and Swetnam (1989) at least 30 or 40 trees. For Fritts (1976), a large number of trees is important, since the variation in growth is related to variation in the climate, being this common to all trees, therefore retaining the climatic variation in the means. In this way, it is possible to reduce the large proportion of non-climatic factors involved in tree growth (Fritts, 1976). The author also points out that in sites subjected to extreme climatic variations, less trees are needed, while in a site where the climate is not highly limiting, other environmental and ecological factors can influence growth, causing rings with differing marks and sizes between trees. In these cases, a large number of trees (replicates) is needed to achieve dendrochronological objectives (Fritts, 1976). As for the number of radii, Fritts (1976) points out that the reduction of errors is more dependent on the number of trees in the sample than the number of radii per tree. However, the author ponders that is possible to reduce standard errors. For example, 17 trees with one radius per tree reduce the standard error to 0.05 or less, while for 12 trees it is necessary to take 4 radii per tree to obtain the same result (Fritts, 1976). In a nutshell, it is preferable to have more trees than number of radii per tree, but if there are few trees in the field, it is advisable to sampling more radii per tree. This information is relevant, considering that in the tropical forest regions most species are rare (Hubbell, 2013). Studies have shown that most of the tree species of AF are somehow rare (Caiafa and Martins, 2010; Fontana *et al.*, 2014, 2016). This forest feature demands more financial resources and time in the field, requiring sampling efforts in a much larger and often difficult to access area when compared to the characteristics of temperate forests, for example. Thus, for dendrochronological studies in tropical forests, besides the annual ring frequency and other principles of dendrochronology (Fritts, 1976), it is necessary to consider the abundance of the species in the site while building the sample design.

In addition, there is the intense deforestation process to which tropical forests are subjected, reducing the area of primary forests, where it would be more likely to find old trees. In particular, the AF underwent several cutting cycles that greatly reduced its coverage area (Ribeiro *et al.*, 2009). It is worth mentioning that A. *angustifolia*, a long-lived gymnosperm with potential for study of long-term changes in tropical forest dynamics, had the culmination of its suppression process in the 20th century (Carvalho, 2012). Precisely the trees with large diameters (> 40cm) were prioritized for cutting by the timber industry (Carvalho, 2012). Thus, it can be seen that even though some trees in this forest genetically can live for hundreds of years, the selective cutting cycles to which they were subjected reduce the possibility of finding old trees nowadays. For dendrochronology purposes, Briffa and Jones (1990) indicate an extension of analysis with at least 30 years, while Pilcher (1990) points to a minimum of 40 years and Stahle *et al.* (1999) indicate at least 50, and up to 100, years. In summary, it is desirable that the time-span period is long enough to include a few years with the climate able to limit plant growth (Fritts and Swetnam, 1989). Also, it should be taken into account that dendrochronological studies demonstrate that millenary trees are exceptions in tropical forests, and even those about 500 years old are rare, with an average age of about 200 years being the most common (Brienen *et al.*, 2016).

Numerical methods

The construction and interpretation of a chronology is an elaborate task since there are different statistical methods and decisions that are up to take (Esper and Gärtner, 2001). In this sense, a prerequisite for the interpretation of chronologies of tree-rings is to have access to information about the main techniques applied in the studies (Esper and Gärtner, 2001). In our review, we observed that important classical parameters in dendrochronology (Fritts, 1976) are often not mentioned. Data of trend model and correlation value are the most frequently reported in the AF chronologies, while data about MSI, trend removal, and expected value function appear in approximately half of the chronologies, but EPS and autocorrelation are among the parameters with less information available (Table 3). In the sequence, we discuss our main result groups and approach the relevance of key parameters.

Standardization (trend model, trend removal, Table 3): An important question involved in the choice of standardization methods is related to the characteristics of the sampling site. Cook (1985) deal with this issue in depth. For example, many of the standardization methods have been developed for the Arizona semi-arid, where the trees are spaced apart. According to Cook (1985, 1987), in such environments, simple mathematical models are enough to model tree growth, such as an exponential model, linear regression or polynomial detrending (deterministic methods). This is possible because trees growing in the open-canopy environment tend not to be under competition, so they grow well in youth and reduce growth over the years (negative growth curve) (Cook, 1985). Considering dendroclimatic studies, such a growth trend that is not related to climatic factors should be removed from the analysis through the application of standardization methods. Keeping this in mind, in mesic environments (as in tropical forests), the forest usually has a closed-canopy, on competition pressure and sporadic disturbances, which demands more elaborate mathematical models to remove noises from the chronology (Cook, 1985). In this sense, flexible empirical models (stochastics methods, such as low-pass digital filtering and cubic smoothing splines), rather than inflexible physical models (deterministic methods), appear to be better to express these complex changes (Cook, 1987, 1985; Cook and Peters, 1997; Fritts and Swetnam, 1989; Speer, 2010). The cubic spline standardization method was used in most of the studies in the AF. Nevertheless, sometimes, it was applied as a second detrending, after other deterministic methods, usually an exponential or linear model. For Speer (2010), two runs at detrending series are not necessary since the most cubic smoothing splines can remove noise such as a negative exponential curve. In this sense, this author recommends using an interactive detrending to visualize data and choose the best adjustment for each series. Another advantage of the cubic smoothing splines is that it takes into consideration the autocorrelation, i.e., “the effect of previous growth or climate on the current year’s growth” (Speer, 2010).

After fitting a growth curve to the ring-width series, it is used as the expected value of growth (Cook and Peters, 1997). Thus, giving the sequence to standardization, the non-stationary ring-widths are transformed into stationary tree-ring indices, whose average is defined as 1.0, maintaining the proportions of the ring and with the variance constant (homoscedastic) (Cook, 1987). It is used to stabilize the variance and allow to compare chronologies that previously had variance differences. There are many ways to standardization of series. Some of them are applied by dividing (ratio) each measured ring-width by the estimated curve, or by subtracting (residual) each measured ring-width by the expected value (Cook, 1987). The main issue in the use of ratio or residue is that in residues a previous transformation of data is necessary, *e.g.*, applying logarithms to the series. In the AF, the most used transformation method for variance stabilization was the ratio, and when residue was used, no information about transformation was given.

Many chronologies in the AF applied the autoregressive model but did not give any information about the autocorrelation. Summarizing, the correlation reflects how much of the growth attributed to previous years growth. This accumulated growth in the year, in general, is due to non-climatic factors. If the data shows a large autocorrelation, it is recommended to apply autoregressive models that satisfactorily remove autocorrelation in most cases, which allows emphasizing the climatic signal (Brienen *et al.*, 2006). For this reason, it is important to know what the autocorrelation in the chronology is.

Synchronism degree: The most frequent information in the studies is the value of the correlation (*r*int, *r*bar or *GLK*). In the crossdating, a *t*-value above 3.5 suggests a possible match, but for conclusions higher values are desirable, *e.g.*, *t*-value > 6.0 (Grissino-Mayer, 2001). For average interseries, correlation is indicated as a value above *r*int = 0.5, although it implies considerations such as species, geographic location, and regional climate (Grissino-Mayer, 2001). Since rainforests are less susceptible to variations in climate, e.g., in relation to temperate and tree-line forests, this value may be considered high for these forests. It is dependent on the sample depth and considered a good measure of percent common variance (Cook *et al.*, 2000; Speer, 2010). It compares the ratio of increase and decrease in growth at the same time between two consecutive years (Esper and Gärtner, 2001; Speer, 2010). In synthesis, information about series correlation significance is fundamental to validate the chronologies, as it demonstrates how well a set of data is related.

Sensitivity statistics: EPS is commonly lacking in the searched articles. EPS is variable in the different parts of the chronology, being directly influenced by the number of replications, with a value that increases rapidly from one to 10 trees and gradually stabilizes from this point on (Cook and Kairiukstis, 1990). Mérian *et al.* (2013) agree that the increase in the number of trees increases the value of EPS, but this author points out that increasing the number of sites is more important than increasing the number of trees per site. On the other hand, two trees per site are preferable than one, as it reduces the noise and allows estimating the signals both inside and between sites (Mérian *et al.*, 2013). However, increase in sample size affects differently the EPS and the climate-growth relationships, so EPS should not be applied as a linear estimator of the climate-growth relationship since the common signal does not necessarily reflect this relationship (Cook and Kairiukstis, 1990; Mérian *et al.*, 2013).

Almost half of the reviewed articles did not present mean values for MSI (the values presented were below 0.57), while the SD is a parameter that is rarely addressed in the studies. It is desirable that both parameters present high values since in this way they indicate a greater adjustment to the variability in the environmental changes (Grissino-Mayer, 2001). For MSI considerations, it is necessary to use the filtered series, and for SD one must use the unfiltered series (Grissino-Mayer, 2001). The MSI is considered low when it is between 0.10–0.19, intermediate between 0.20–0.29, and presents the most evident climate sensitivity with values above 0.30 (Grissino-Mayer, 2001). MSI above 0.4 is so sensitive that it greatly increases the difficulty in dating because of the frequency of micro or missing rings next to very wide rings (Speer, 2010).

Autocorrelation value does not prove to be a parameter considered in the surveys in the AF since no study provided this information (data not shown). It is strongly influenced by the relationship between size and rate of growth, *e.g.*: small trees grow more slowly than large trees; juvenile trees have higher growth rate (Brienen *et al.*, 2006). The closer to zero, the smaller is the autocorrelation between the years, indicating that the series is random in time (Grissino-Mayer, 2001). In this way, a series with low autocorrelation tends to put more emphasis on the climatic signal. Autocorrelation can be removed from the data by standardization techniques, especially applying autoregressive models.

Expected value function: Almost half of the chronologies did not explain the expected value function. However, among the studies that presented this parameter, half applied arithmetic mean and another half used bi-weighted robust mean. The arithmetic mean is a widely used central trend measure. It represents the expected value of a variable when calculated for the population (Callegari-Jacques, 2003). It is indicated when the individuals in the sample have the same variance (Bi, 2006). Therefore, the main issue of arithmetic mean is when there are many outliers in the data. The outlier is a rare data and its discrepant value affects the mean and may cover some general phenomena expressed from the sample (Volpato and Barreto, 2016). In dendrochronology, in general, a ring can be considered an outlier if it is greater than +3.0 SD or -4.5 SD of the mean of the other series for that year (Cook and Holmes, 1996; Grissino-Mayer, 2001). If there are many outliers in the series, the bi-weighted robust mean is the most appropriate choice (Bi, 2006). In weighted robust mean, low weights are attributed to observations with great variation (Bi, 2006), and this minimizes the bias caused by outliers. Bi-weight mean is strongly recommended to remove endogenous effects and to emphasize the common signal contained in the data (Cook and Holmes, 1996).

Climatic influence on the Atlantic Forest

In the tropics, the main factor that acts on the annual growth is the variation in precipitation that is involved in annual droughts or floods depending on the region (Brienen *et al.*, 2016; Worbes, 2002, 1989). In subtropical regions, the temperature happens to be a regulating factor of the biological processes in the plants (Evert, 2013; Fritts, 1976). In part, our data supports these points, but add that the precipitation in subtropical AF also affects plant growth, even though precipitation is well distributed throughout the year in this region. Observing the distribution of the sites considered in this research, one can notice that the set of sites with chronologies generated in the central part of AF (codes 2, 3, 4, 5, 8, 14, 15 and 16) show positive associations with precipitation (climatic signal), while the set of sites with chronologies generated in the south (codes 1, 6, 7, 9, 10, 11, 12 and 13), under subtropical climate, indicate positive and negative associations with temperature and precipitation. In general, both sets of data match the findings of Wagner *et al.* (2016), who classify the central portion of AF as “water-limited sites” and the southern one as “light-limited sites”. According to the authors, the first one is characterized by the relationship between photosynthetic capacity and precipitation, and the second one by the relationship between photosynthetic capacity and maximal temperature. However, regardless of climate limitations, wood productivity is driven by seasonal variation in precipitation (Wagner *et al.*, 2016).

Considering *A. angustifolia*, the most studied species, one can notice that the previous growth season influences the current growth in the region of southern distribution of the species, whereas in the centermost region of the distribution there is influence only of the current season (Figure 2). One of the principles of dendrochronology is precisely about the greater climatic sensibility of the species the closer they are to the natural distribution limit (Fritts, 1976). This situation is possibly the case of *A. angustifolia*, when presenting climatic signs also for the previous growing season. Besides that, this species presents an opposite signal for precipitation even in the closer sites, as the case of the site located near Curitiba and two sites in Rio Grande do Sul (codes 9 and 12; 10 and 11, respectively). For the latter case, the authors suggest that the occurrence of annual anthropogenic fires (exogenous disturbance) may interfere with the growth for up to two years and, consequently, correlations with precipitation were negative (Oliveira *et al.*, 2010). In addition to exogenous and endogenous disturbances that may affect the climatic signal in the trees, issues related to plant age and random site events should also be considered (Cook, 1987; Fritts, 1976; Speer, 2010). In this sense, a more precise characterization of the sampling, with the focus on parameters that matter for dendrochronology, may be important for future comparisons and predictions.

Finally, modeling climate scenarios indicates a change in precipitation patterns and an increase in temperature in the AF region (IPCC, 2014). In our research, the deficiency in water supply clearly affects negatively most of the analyzed species. It may mean that this forest will retain less carbon in the future.

Final remarks and conclusions

In general, there is a large number of missing information in the descriptions of the chronologies developed in the AF, especially regarding methods of trend removal. It was also noticed that many authors chose not to apply autoregressive models, but did not even inform the autocorrelation level of the series. This information is important for conclusions about chronology, because if the chronology has a moderate or strong autocorrelation level, this may affect the power of the significance test of the climatic signals.

Regarding the climatic signals in the AF, to make stronger conclusions about the evidence of climate influence on the growth of AF species, it is necessary to intensify efforts on building chronologies. The increase in replication is fundamental to contribute to understand the climatic past and to infer about the future development of this forest in relation to climatic changes.

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References

ALVARES, C.A.; STAPE, J.L.; SENTELHAS P.C.; GONÇALVES, J.L.M.; SPAROVEK, G. 2013. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, **22**(6):711-728. https://doi.org/10.1127/0941-2948/2013/0507

ALVES, E.S.; ANGYALOSSY-ALFONSO, V. 2000. Ecological trends in the wood anatomy of some Brazilian species. 1. Growth rings and vessels. *IAWA Journal*, **21**(1):3-30. https://doi.org/10.1163/22941932-90000233

ANDERSON-TEIXEIRA, K.J.; SNYDER, P.K.; TWINE, T.E.; CUADRA, S.V.; COSTA, M.H.; DELUCIA, E.H. 2012. Climate-regulation services of natural and agricultural ecoregions of the Americas. *Nature Climate Change*, **2**(3):177-181. https://doi.org/10.1038/nclimate1346

ANDREACCI, F.; BOTOSSO, P. 2014. Sinais climáticos em anéis de crescimento de Cedrela fissilis em diferentes tipologias de florestas ombrófilas do sul do Brasil. *Floresta,* **44**(2):323-332.

BAKER, J.C.A.; SANTOS, G.M.; GLOOR, M.; BRIENEN, R.J.W. 2017. Does Cedrela always form annual rings? Testing ring periodicity across South America using radiocarbon dating. *Trees*, **31**(6):1999-2009. https://doi.org/10.1007/s00468-017-1604-9

BI, J. 2006. *Sensory discrimination tests and measurements: Statistical principles, procedures, and tables*. Virginia, Blackwell Pub, 298 p.

BONAN, G.B. 2008. Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science,* **320**(80):1444-1449. https://doi.org/10.1126/science.1155121

BOTOSSO, P.C.; VETTER, R.E. 1991. Alguns aspectos sobre a periodicidade e taxa de crescimento em 8 espécies arbóreas tropicais de floresta de terra firme (Amazônia). *Revista do Instituto Florestal*, **3**(2):163-180.

BRANDES, A.F.N. ; LISI, C.S.; BARROS, C.F. 2011. Dendrochronology of lianas of the Leguminosae family from the Atlantic Forest, Brazil. *Trees - Structure and Function*, **25**(1):133-144. https://doi.org/10.1007/s00468-010-0529-3

BRIENEN, R.J.W.; SCHÖNGART, J.; ZUIDEMA, A. 2016. Tree rings in the tropics: Insights into the ecology and climate sensitivity of tropical trees, in: *Tropical Tree Physiology: Adaptations and Responses in a Changing Environment*. Cham, Springer, p. 439-461. https://doi.org/10.1007/978-3-319-27422-5_20

BRIENEN, R.J.W.; ZUIDEMA, P.A.; DURING, H.J. 2006. Autocorrelated growth of tropical forest trees: Unraveling patterns and quantifying consequences. *Forest Ecology and Management*, **237**(1-3):179-190. https://doi.org/10.1016/j.foreco.2006.09.042

BRIFFA, K.; JONES, P.D. 1990. Basic chronology statistics and assessment. *In:* E. COOK; L. KAIRIUKSTIS (ed.), *Methods of Dendrochronology: Applications in the Environmental Sciences.* Dordrecht, Springer-Science, Business Media, B.V., p. 137-152.

CAIAFA, A.N.; MARTINS, F.R. 2010. Forms of rarity of tree species in the southern Brazilian Atlantic rainforest. *Biodiversity Conservation*, **19**(9):2597-2618. https://doi.org/10.1007/s10531-010-9861-6

CALLADO, C.H.; DE VASCONCELLOS, T.J.; COSTA, M.S.; BARROS, C.F.; ROIG, F.A.; TOMAZELLO-FILHO, M. 2014. Studies on cambial activity: Advances and challenges in the knowledge of growth dynamics of Brazilian woody species. *Anais da Academia Brasileira de Ciências*, **86**(1):277-283. https://doi.org/10.1590/0001-3765201320130033

CALLEGARI-JACQUES, S.M. 2003. *Bioestatística: princípios e aplicações*. Porto Alegre, Artmed, 255 p.

CARDOSO, G.M.; JUSTINO, F. 2014. Simulação dos componentes da evapotranspiração sob condições climáticas atuais e de cenários climáticos futuros de aquecimento global com o uso de modelos de clima-vegetação. *Revista Brasileira de Meteorologia*, **29**(1):85-95. https://doi.org/10.1590/S0102-77862014000100009

CARVALHO, M.M.X. 2012. Os fatores do desmatamento da Floresta com Araucária: agropecuária, lenha e indústria madeireira. *Esboços*, **18**(25):32-52.

CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLÓGICO. 2017. Diretório dos Grupos de Pesquisa no Brasil. Disponível em: http://dgp.cnpq.br/dgp/faces/consulta/consulta_parametrizada.jsf. Acesso em: 03/09/2017.

COOK, E.R. 1985. A time series analyses approach to tree ring standardization. (These). University of Arizona. Disponível em: https://ltrr.arizona.edu/content/time-series-analysis-approach-tree-ring-standardization. Acesso em: 30/10/2018.

COOK, E.R. 1987. The decomposition of tree-ring series for environmental studies. *Tree-Ring Bulletin,* **47**(1):37-59. Disponível em: https://repository.arizona.edu/handle/10150/261788. Acesso em: 30/10/2018.

COOK, E.R.; BUCKLEY, B.M.; D'ARRIGO, R.D.; PETERSON, M.J. 2000. Warm-season temperatures since 1600 BC reconstructed from Tasmanian tree rings and their relationship to large-scale sea surface temperature anomalies. *Climate Dynamics*, **16**(1-3):79-91. https://doi.org/10.1007/s003820050006

COOK, E.R.; HOLMES, R.L. 1996. Guide for computer program ARSTAN. *In:* H.D. GRISSINO-MAYER; R.L. HOLMES; H.C. FRITTS (eds.), *The International Tree-Ring Data Bank Program Library Version 2.0 User's manual*. Tuscson, University of Arizona, Laboratory of Tree-Ring Research, p. 75-87.

COOK, E.R.; KAIRIUKSTIS, L. 1990. *Methods of dendrochronology — Applications in the environmental sciences.* Dordrecht/Boston/London, Kluwer Academic Publishers, 120 p.

COOK, E.R.; PETERS, K. 1997. Calculating unbiased tree-ring indices for the study of climatic and environmental change. *The Holocene,* **7**(3):361-370. https://doi.org/10.1177/095968369700700314

DOBNER-JR, M.; TRAZZI, P.A.; HIGA, A.R. 2014. Dendroecologia de um povoamento de Cryptomeria japonica (L. F.) Don. com 25 anos de idade no sul do Brasil. *Ciência Florestal,* **24**(2):413-420.

DÜNISCH, O. 2005. Influence of the El-niño southern oscillation on cambial growth of Cedrela fissilis Vell. in tropical and subtropical Brazil. *Journal of Applied Botany and Food Quality*, **79**:5-11.

ESPER, J.; GÄRTNER, H. 2001. Interpretation of tree-ring chronologies. *Erdkunde*, **55**(3):277-288. https://doi.org/10.3112/erdkunde.2001.03.05

EVERT, R.F. 2013. *Anatomia das Plantas de ESAU*: *meristemas, células e tecidos do corpo da planta: sua estrutura, função e desenvolvimento*. São Paulo, Blucher, 728 p.

FERREIRA, A.G.; MELLO, N.G. DA S. 2005. Principais sistemas atmosféricos atuantes sobre a região nordeste do Brasil e a influência dos oceanos. *Revista Brasileira de Climatologia*, **1**(1):15-28. https://doi.org/10.5380/abclima.v1i1.25215

FICHTLER, E. 2017. Dendroclimatology using tropical broad-leaved tree species – A review. *Erdkunde*, **71**(1):5-22.
https://doi.org/10.3112/erdkunde.2017.01.01

FICHTLER, E.; GOETTINGEN, U.; CLARK, D.A. 2003. Age and long-term growth of trees in an old-growth Tropical Rain Forest, based on analyses of tree rings and $^{14}C^1$. *Biotropica*, **35**(3):306-317.
https://doi.org/10.1111/j.1744-7429.2003.tb00585.x

FONTANA, C.; GASPER, A.L.; SEVEGNANI, L. 2014. Espécies raras e comuns de Myrtaceae da Floresta Estacional Decidual de Santa Catarina, Brasil. *Rodriguésia*, **65**(3):767-776.
https://doi.org/10.1590/2175-7860201465314

FONTANA, C.; GASPER, A.L.; SEVEGNANI, L. 2016. A raridade das espécies arbóreas de Lauraceae no planalto do Estado de Santa Catarina, Brasil. *Hoehnea*, **43**(3):361-369.
https://doi.org/10.1590/2236-8906-95/2015

FORZZA, R.C.; BAUMGRATZ, J.F.A.; BICUDO, C.E.M.; CANHOS, D.A.L.; CARVALHO, A.A.; COELHO, M.A.N.; COSTA, A.F.; COSTA, D.P.; HOPKINS, M.G.; LEITMAN, P.M.; LOHMANN, L.G.; LUGHADHA, E.N.; MAIA, L.C.; MARTINELLI, G.; MENEZES, M.; MORIM, M.P.; PEIXOTO, A.L.; PIRANI, J.R.; PRADO, J.; QUEIROZ, L.P.; SOUZA, S.; SOUZA, V.C.; STEHMANN, J.R.; SYLVESTRE, L.S.; WALTER, B.M.T.; ZAPPI, D.C. 2012. New Brazilian Floristic List Highlights Conservation Challenges. *Bioscience* **62**(1):39-45.
https://doi.org/10.1525/bio.2012.62.1.8

FRITTS, H.C. 1976. *Tree rings and climate change*. New York, Academic Press Inc. Ltd., 567 p.

FRITTS, H.C.; SWETNAM, T.W. 1989. Dendroecology: A tool for evaluating variations in past and present forest environments. *Advances in Ecological Research*, **19**(C):111-188.
https://doi.org/10.1016/S0065-2504(08)60158-0

GALINDO-LEAL, C.; CÂMARA, I.G. 2003. *The Atlantic Forest of South America*: *Biodiversity Status, Threats and Outlook*. São Paulo/Belo Horizonte, Fundação SOS Mata Atlântica/Conservação Internacional, 472 p.

GOOGLE EARTH. 2017. Google. Disponível em: https://earth.google.com/web/. Acesso em: 03/01/2017.

GRISSINO-MAYER, H.D. 2001. Evaluating crossdating accuracy: a manual and tutorial for the computer program Cofecha. *Tree-Ring Research*, **57**(2):205-221.

HUBBELL, S.P. 2013. Tropical rain forest conservation and the twin challenges of diversity and rarity. *Ecology and Evolution*, **3**(10):3263-3274. https://doi.org/10.1002/ece3.705

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). 2004. Mapa de Vegetação do Brasil. Disponível em: http://geoftp.ibge.gov.br/informacoes_ambientais/vegetacao/mapas/brasil/vegetacao.pdf. Acesso em: 01/02/2018.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). 2012. *Manual técnico da vegetação brasileira*. 2nd ed., Rio de Janeiro, Coordenação de Recursos Naturais e Estudos Ambientais (Série manuais técnicos de geociências), 274 p.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). 2014. *Climate Change 2014*: *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPPC Panel, Geneva, Switzerland, 151 p.

JACOBY, G.C. 1989. Overview of tree-ring analysis in tropical regions. *International Association of Wood Anatomists Bulletins,* **10**(2):99-108.
https://doi.org/10.1163/22941932-90000478

LATORRACA, J.V.F.; SOUZA, M.T.; SILVA, L.D.S.A.B.; RAMOS, L. M. A. 2015. Dendrocronologia de árvores de Schizolobium parahyba (Vell.) S. F. Blake de ocorrência na REBIO de Tinguá-RJ. *Revista Árvore,* **39**(2):385-394. https://doi.org/10.1590/0100-67622015000200018

LIMA, A.R.; CAPOBIANCO, P.R. 1997. *Mata Atlântica: avanços legais e institucionais para sua conservação*. Documentos ISA. São Paulo, Instituto Socioambiental, n. 4, 118 p.

LISI, C.S.; TOMAZELLO-FO, M.; BOTOSSO, P.C.; ROIG, F.A.; MARIA, V.R.B.; FERREIRA-FEDELE, L.; VOIGT, A.R.A. 2008. Tree-ring formation, radial increment periodicity, and phenology of tree species from a Seasonal Semi-deciduous Forest in Southeast Brazil. *IAWA Journal*, **29**(2):189-207. https://doi.org/10.1163/22941932-90000179

LIU, Y.Y.; VAN DIJK, A.I.J.M.; DE JEU, R.A.M.; CANADELL, J.G.; MCCABE, M.F.; EVANS, J.P.; WANG, G. 2015. Recent reversal in loss of global terrestrial biomass. *Nature Climate Change*, **5**(5):470-474. https://doi.org/10.1038/nclimate2581

LORENSI, C.; PRESTES, A. 2016. Dendroclimatological reconstruction of spring-summer precipitation for Fazenda Rio Grande, PR, with samples of Araucaria angustifolia (Bertol.) Kuntze. *Revista Árvore,* **40**(2):347-354. https://doi.org/10.1590/0100-67622016000200017

MÉRIAN, P.; PIERRAT, J.C.; LEBOURGEOIS, F. 2013. Effect of sampling effort on the regional chronology statistics and climate-growth relationships estimation. *Dendrochronologia,* **31**(1):58-67.
https://doi.org/10.1016/j.dendro.2012.07.001

MYERS, N.; MITTERMEIER, R.; MITTERMEIER, C.; DAFONESCA, G.; KENT, J. 2000. Biodiversity hotspots for conservation priorities. *Conservation Biology*, **403**(6772):853-858.

NIMER, E. 1971. Climatologia da Região Sul do Brasil. *In*: INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (ed.), *Introdução a Climatologia Dinâmica*. Rio de Janeiro, IBGE, p. 3-65.

OLIVEIRA, J.M.; ROIG, F.A.; PILLAR, V.D. 2010. Climatic signals in tree-rings of Araucaria angustifolia in the southern Brazilian highlands. *Austral Ecology*, **35**(2):134-147.
https://doi.org/10.1111/j.1442-9993.2009.02018.x

OLIVEIRA-FILHO, A.A.T.; FONTES, M.A.L. 2000. Patterns of floristic differentiation among Atlantic Forests in Southeastern Brazil and the influence of climate patterns of floristic differentiation among Atlantic Forests in Southeastern Brazil and the influence of climate. *Biotropica,* **32**(4):793-810.
https://doi.org/10.1646/0006-3606(2000)032[0793:POFDAA]2.0.CO;2

PAGOTTO, M.A.; DESOTO, L.; CARVALHO, A.; NABAIS, C.; TOMAZELLO FILHO, M.; RIBEIRO, A.; LISI, C.S. 2017. Evaluation of X-ray densitometry to identify tree-ring boundaries of two deciduous species from semi-arid forests in Brazil. *Dendrochronologia*, **42**(March):94-103.
https://doi.org/10.1016/j.dendro.2017.01.007

PAYETTE, S.; FILION, L. 2010. *La dendroécologie: principes, méthodes et applications*. Québec, Presses de l'Université Laval, 772 p.

PERONE, A.; LOMBARDI, F.; MARCHETTI, M.; TOGNETTI, R.; LASSERRE, B. 2016. Evidence of solar activity and El Nino signals in tree rings of Araucaria araucana and A. angustifolia in South America. *Global and Planetary Change* **145**:1-10.
https://doi.org/10.1016/j.gloplacha.2016.08.004

PILCHER, J.R. 1990. Primary data. *In:* E.R. COOK; L. KAIRIŪKŠTIS (eds.), *Methods of Dendrochronology: Applications in the Environmental Sciences*. Dordrecht, Kluwer Academic Publishers, p. 23-96.

REIS-ÁVILA, G.; OLIVEIRA, J.M. 2017. Lauraceae: A promising family for the advance of neotropical dendrochronology. *Dendrochronologia*, **44**(June):103-116. https://doi.org/10.1016/j.dendro.2017.04.002

RIBEIRO, M.C.; METZGER, J.P.; MARTENSEN, A.C.; PONZONI, F.J.; HIROTA, M.M. 2009. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation*, **142**(6):1141-1153.
https://doi.org/10.1016/j.biocon.2009.02.021

RINN, F. 2011. *TSAP-Win User Reference Manual*. Heidelberg, Rinntech, 110 p.

SANT'ANNA -NETO, J.L. 2005. Decálogo da climatologia do sudeste brasileiro. *Revista Brasileira de Climatologia,* **1**(1):43-60.
https://doi.org/10.5380/abclima.v1i1.25232

SCHÖNGART, J.; PIEDADE, M.T.F.; WITTMANN, F.; JUNK, W.J.; WORBES, M. 2005. Wood growth patterns of *Macrolobium acaciifolium* (Benth.) Benth. (Fabaceae) in Amazonian black-water and white-water floodplain forests. *Oecologia*, **145**(3):454-461.
https://doi.org/10.1007/s00442-005-0147-8

SCHWEINGRUBER, F.H.; KAIRIUKSTIS, L.; SHIYATOV, S. 1990. Sample selection. *In*: E.R. COOK; L. KAIRIUKSTIS (eds.), *Methods of Dendrochronology: Applications in the Environmental Sciences*. Dordrecht, Springer-Science, Business Media, B.V., p. 23-35.

SHUKLA, J.; NOBRE, C.; SELLERS, P. 1990. Amazon deforestation and climate change. *Science,* **247**(4948):1322-1325. https://doi.org/10.1126/science.247.4948.1322

SOLIZ-GAMBOA, C.C.; ROZENDAAL, D.M.A.; CECCANTINI, G.; ANGYALOSSY, V.; BORG, K.V.; ZUIDEMA, P.A. 2011. Evaluating the annual nature of juvenile rings in Bolivian tropical rainforest trees. *Trees*, **25**(1):17-27. https://doi.org/10.1007/s00468-010-0468-z

SOUZA, B.T.; ESTRADA, G.C.D.; SOARES, M.L.G.; CALLADO, C.H. 2016. Occurrence of annual growth rings in Rhizophora mangle in a region with low climate seasonality. *Anais da Academia Brasileira de Ciencias,* **88**(March):517-525. https://doi.org/10.1590/0001-3765201620150009

SPEER, J.H. 2010. *Fundamentals of tree-ring research*. Tucson, University of Arizona Press, 368 p.

STAHLE, D.W. 1999. Usefull strategies for the development of tropical tree-ring chronologies. *IAWA Journal*, **20**(3):249-253. https://doi.org/10.1163/22941932-90000688

STAHLE, D.W.; MUSHOVE, P.T.; CLEAVELAND, M.K.; ROIG, F.; HAYNES, G.A. 1999. Management implications of annual growth rings in Pterocarpus angolensis from Zimbabwe. *Forest Ecology and Management,* **124**(2-3):217-229. https://doi.org/10.1016/S0378-1127(99)00075-4

THOMAS, W.W.; CARVALHO, A.M.V.; AMORIM, A.M.; HANKS, J.G.; SANTOS, T.S. 2008. Diversity of woody plants in the Atlantic coastal forest of Southern Bahia, Brazil. *In:* W.W. THOMAS; E.G. BRITTON (eds.), *The Atlantic Coastal Forest of Northeastern Brazil*. New York, The New York Botanical Garden Press, p. 21-66.

TROPICOS. 2017. Tropicos.org. Missouri Botanical Garden. Disponível em: http://www.tropicos.org/. Acesso em: 08/07/2017.

VENEGAS-GONZÁLEZ, A.; CHAGAS, M.P.; ANHOLETTO JÚNIOR, C.R.; ALVARES, C.A.; ROIG, F.A.; TOMAZELLO FILHO, M. 2016. Sensitivity of tree ring growth to local and large-scale climate variability in a region of Southeastern Brazil. *Theoretical and Applied Climatology,* **123**(1-2):233-245. https://doi.org/10.1007/s00704-014-1351-4

VÍNCENS, R.S.; AGAREZ, F.V.; GARAY, I. 2003. A região da REBIO Sooretama e da Reserva de Linhares e seu entorno: das características físico-geográficas ao uso da terra. *In*: I. GARAY; C.M. RIZZINI (ed.), *A Floresta Atlântica de Tabuleiros: diversidade funcional da cobertura arbórea*. Vozes, Petrópolis, p. 7-15.

VOLPATO, G.; BARRETO, R. 2016. *Estatística sem dor*. 2nd ed., Botucatu, Best Writing, 157 p.

WAGNER, F.H.; HÉRAULT, B.; BONAL, D.; STAHL, C.; ANDERSON, L.O.; BAKER, T.R.; BECKER, G.S.; BEECKMAN, H.; SOUZA, D.B.; BOTOSSO, P.C.; DAVID, M.J.; BOWMAN, S.; BRÄUNING, A.; BREDE, B.; BROWN, F.I.; CAMARERO, J.J.; CHAGAS, K.; CHAVE, J.; CHIDUMAYO, E.N.; CLARK, D.A.; REGINA, F.; COSTA, C.; COURALET, C.; HENRIQUE, P.; DALITZ, H.; DE, V.R.; ELOISA, J.; MILANI, D.F.; OLIVEIRA, E.C. DE; ARRUDA, L.D.S. 2016. Climate seasonality limits leaf carbon assimilation and wood productivity in tropical forests. *Biogeosciences*, **13**(8):2537-2562. https://doi.org/10.5194/bg-13-2537-2016

WIGLEY, T.M.L.; BRIFFA, K.R.; JONES, P.D. 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Applied Meteorology and Climatology*, **23**(Feb.):201-213. https://doi.org/10.1175/1520-0450(1984)023<0201:OTAVOC>2.0.CO;2

WORBES, M. 1989. Growth rings, increment and age of trees in inundation forests, savannas and a mountain forest in the neotropics. *IAWA Bulletins*, **10**(2):109-122. https://doi.org/10.1163/22941932-90000479

WORBES, M. 2002. One hundred years of tree-ring research in the tropics – a brief history and an outlook to future challenges. *Dendrochronologia*, **20**(1-2):217-231. https://doi.org/10.1078/1125-7865-00018

WORBES, M.; JUNK, W.J. 1989. Dating tropical trees by means of 14c from bomb tests. *Ecology*, **70**(2):503-507. https://doi.org/10.2307/1937554

ZUIDEMA, P.A.; BRIENEN, R.J.W.; SCHÖNGART, J. 2012. Tropical forest warming: Looking backwards for more insights. *Trends in Ecology & Evolution*, **27**(4):193-194. https://doi.org/10.1016/j.tree.2011.12.007

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