



Diametric Growth of Tree Species in the Atlantic Forest, Paraná, Brazil

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Abstract: Management of remnants in Atlantic Forest is an alternative for their conservation, however, information on the growth and ecology of those species is lacking. This study aimed to describe diametric growth of *Balfourodendron riedelianum*, *Cordia trichotoma* and *Ocotea diospyrifolia* based on its growth rings and to verify the relationship between this growth with the environmental characteristics in different altitude levels and forest types. Diametric growth was higher for the largest tree diameters of the three species. Based on the fitted growth model, the age in which mean annual increment in diameter becomes greater than the current annual increment was 55 years for *B. riedelianum* (DBH = 18.27 cm), 45 years for *C. trichotoma* (DBH = 26.56 cm) and 44 years for *O. diospyrifolia* (DBH = 26.05 cm). Environmental conditions and forest types affected diametric growth of these species. *B. riedelianum* and *O. diospyrifolia* showed higher diametric growth in plain regions with higher fertility soil and few frosts. *C. trichotoma* was negatively affected by low water availability in winter at lower altitudes and showed higher diametric growth at higher altitudes, where soil fertility is low but there is well-drainage, high rainfall and high relative humidity during the dry season.

Key words: Dendrochronology, altitude levels, forest types, forest management, forest ecology, Iguaçu National Park.

INTRODUCTION

The Atlantic Forest is one of the most diverse biomes and is the home of many endemic species (Guedes-Bruni et al. 2009). The agricultural expansion followed by industrialization and urban development resulted in a significant degradation and fragmentation of this biome to small areas with less than 12.6% remaining of its original forest area (Ribeiro et al. 2009).

In order to guarantee the conservation of the remnants, the Atlantic Forest Law was

established and, among other rules, it prohibits the commercialization of native species. This rule has been established due to the lack of technical information on growth of native species and the technical and economic feasibility of small area management (Brasil 2006). The lack of information on native species and their potential for economic use also contributed to the abandonment of forest remnants by the rural producers, as they consider these sites unproductive. In this context, efforts seeking to reveal how the growth of native species occurs are necessary for the Atlantic Forest.

Growth of forest species has been studied worldwide by the measurement of growth rings

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(Mattos et al. 2011, De Ridder et al. 2013, Vlam et al. 2014, Latorraca et al. 2015, Brandes et al. 2016, Kanieski et al. 2017). Climate-growth relationships are also extensively known (Costa et al. 2015, Rohner et al. 2016, Granato-Souza et al. 2018), contributing to identify the environmental preferences of a given species, for the restoration of degraded areas and to analyze the effects of climate changes.

The measurement of growth rings is an efficient technique that allows to obtain information on past diameter growth both quickly and at a low cost. For a growth ring reading to be reliable it must be performed annually or with known periodicity and distinguished by some anatomical feature of the wood (Botosso and Mattos 2002); techniques such as cross-dating are still required to minimize errors in reading (Worbes 1995). Information about tree growth is used in forest management to determine the Biological Rotation Age (BRA) and the Minimum Logging Diameter (MLD) of each species (Schöngart et al. 2007, 2008, De Ridder et al. 2013, López et al. 2013). Toledo et al. (2011) also pointed out that knowing environmental conditions and your effect in tree growth rates contribute to forest management.

Balfourodendron riedelianum (known as Pau-Marfim), *Cordia trichotoma* (known as Louro-Pardo) and *Ocotea diospyrifolia* (known as Canela-Loura) are native species of the Atlantic Forest (Lorenzi 1998, Carvalho 2002, 2004). As these species have distinct rings formed annually (Boninsegna et al. 1989, Maria 2002, Mattos et al. 2003, Lisi et al. 2008, Caum 2013), as well as a great value for the furniture industry, they were selected for this study, which consisted of the following objectives: (1) to describe growth patterns from growth rings diameter and; (2) to identify the effect of environmental characteristics (soil, temperature and rainfall) at different altitudes and forest types on the diametric increase.

MATERIALS AND METHODS

STUDY AREA

Iguaçu National Park (INP) is located in the western region of the state of Paraná, southern Brazil, and has a total area of 185,262 hectares (ha) (Figure 1). Köppen's climate classification type is Cfa (Alvares et al. 2013) with transition to Cfb in the northern region of the park. In the southern region, the historical average air temperature (1983-1997) ranges from 16°C (June) to 25.7°C (January) with an absolute minimum of -1.2°C (July), while the rainfall varies from 99.7 mm (July) to 227.6 mm (October). In the northern region, the historical average air temperature (1973-1998) ranges from 15.1°C (June) to 23.1°C (January) with an absolute minimum of -4.2°C (July), while the rainfall ranges from 108.7 mm (July) to 227.5 mm (October) (IAPAR 2017).

The Iguaçu National Park is located in the Atlantic Forest Biome, with the Semideciduous Seasonal Forest (SSF) as the predominant vegetation (Souza et al. 2017). In the southern region (<600 m), SSF Typical Submontane occurs in the plains, with deep soil of slow drainage and high fertility (Eutrophic Red Nitosol) (Souza et al. 2017). The SSF Humid Submontane occurs in this same altitude range, located on the slopes and base of the drainage ramps, with varying soil types (Eutrophic Red Nitosol, Eutrophic Melanic Tb Gleisol and Eutrophic Regolitic Neosol) and high humidity associated with the surrounding rivers (Souza et al. 2017).

In the northern region of the INP there are montane environments (≥ 600 m), with a predominance of well-drained soils with low fertility (Distrophic Red Latosol). The vegetation is classified as SSF Montane (600-700 m) and Ecotone between SSF Montane and Mixed Ombrophilous Forest (MOF) (>700 m) (Souza et al. 2017).

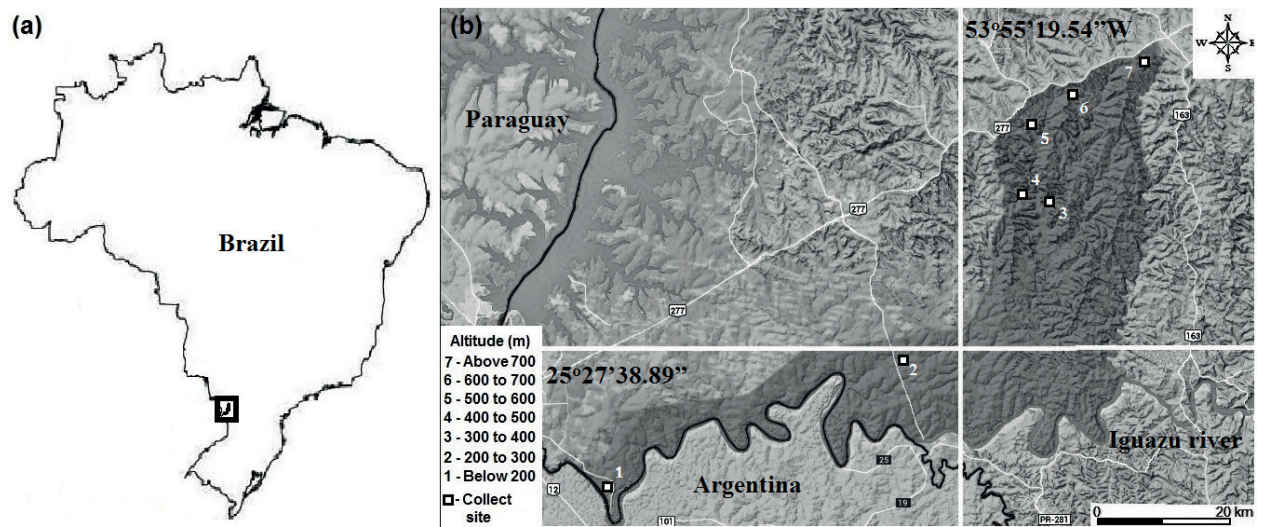


Figure 1 - (a) Study area in the Brazil. (b) Iguazu National Park in the Western of Paraná State.

DATABASE

The field work was carried out at the end of the vegetative growth period in July 2015. Twenty-two trees of *B. riedelianum* with diameter at breast height (DBH) of 40.51 ± 8.99 cm, 27 trees of *C. trichotoma* with DBH of 36.55 ± 7.06 cm and 30 trees of *O. diospyrifolia* with DBH of 39.62 ± 7.13 cm were sampled, with all measurements taken outside the bark. Around the permanent plots allocated in the study area described by Souza et al. (2017), the trees are distributed in the INP altitude and forest types according to Table I. The sampled trees were in the forest canopy, healthy and with tall and even stem. *B. riedelianum* presented height of the morphological inversion point of 13.94 ± 2.98 m and total height of 19.51 ± 4.17 m, *C. trichotoma* presented morphological inversion point of 14.29 ± 2.92 m and total height of 20.00 ± 4.09 m and *O. diospyrifolia* presented morphological inversion point of 10.67 ± 2.83 m and total height of 14.94 ± 3.96 m.

In each sampled tree, two increment cores (90° angle) were collected with an increment borer (length 40 cm, diameter 5.15 mm) at DBH. Wood cores were glued on a wooden support, dried outdoors and polished consecutively with

sandpaper from 100 to 600 grit (Orvis and Grissino-Mayer 2002). Tree rings structure was analyzed by wood anatomical pattern using Leica DMS 300 stereomicroscopic (Figure 2). Maria (2002) and Lisi et al. (2008) delimited annual rings in *B. riedelianum* and described semiporous rings that differed by the combination of thick-walled fibers of late wood and marginal parenchyma, while emphasizing that fake rings are rare. Boninsegna et al. (1989) and Caum (2013) found rings formed annually in *C. trichotoma*, as well as semiporous rings distinct by late woods formed by small and medium sized vessels, thick-walled fibers and axial parenchyma. Finally, Mattos et al. (2003) described the formation of annual rings in *O. diospyrifolia* and rings marked by a darker tangential line with thick-walled radial fibers.

Wood cores were scanned with a HP Deskjet Ink Advantage 3636 at 600 dpi and ring widths were measured to the nearest 0.04 mm by *ImageJ* software (NIH 2016) in the bark-pith direction. Cross-dating with COFECHA software (Holmes 1983) and graphical analysis between wood cores of the same tree were used to minimize labeling error in the false rings.

TABLE I
Trees sampled at altitude levels and forest types with respective environmental characteristics in the Iguaçú National Park

Environmental Gradient	Soil Class*	Temp** (°C)	Rainfall** (mm)	Trees Sampled			
				<i>Balfourodendron riedelianum</i>	<i>Cordia trichotoma</i>	<i>Ocotea diospyrifolia</i>	
Altitude level (m)	150	19.60	1831	2	7	2	
	250			Red Nito	3	1	4
				Gley Mel			
	350	Red Nito					
		Reg Neos			4	-	1
	450	Red Nito			21	3	13
	550	Red Nito			-	11	2
Reg Neos							
650	Eu Red Lato	21.40	1971	2	1	3	
750	Di Red Lato			-	4	5	
Forest type*	SSF Sub Humid	Red Nito					
		Gley Mel			4	2	1
	SSF Sub Typical	Reg Neos	19.60	1831			
		Red Nito					26
SSF Mont	Eu Red Lato	21.40	1971	2	1	3	
Ecotone SSF/MOF	Di Red Lato			-	4	5	

SSF Sub - Submontane Semideciduous Seasonal Forest; SSF Mont - Montane Semideciduous Seasonal Forest; MOF - Mixed Ombrophilous Forest; Red Nito - Eutrophic Red Nitosol; Gley Mel - Gleysol Melanic Tb Eutrophic; Reg Neos - Eutrophic Regolitic Neosol; Eu Red Lato - Eutrophic Red Latosol; Di Red Lato - Distrophic Red Latosol; *Classified by Souza et al. (2017); **Historical temperature (temp) and rainfall annual means (IAPAR 2017).

DIAMETRIC GROWTH PATTERN

The combined width of the two rings observed from two cores collected on the tree represent the annual diametric increment; the DBH in each year was obtained by the addition of these values from tree pith. For trees in which it was not possible to identify the tree pith location, the annual increments were subtracted from the DBH measured in the field disregarding the bark thickness, until the last ring observed.

In order to describe in details the diametric growth pattern of each species, the increment values were classified by DBH-classes of 5.0 cm from the

pith. A *t*-test was carried out to verify the effect of the size on the diametric growth by grouping the increments into two classes (DBH <20 and DBH ≥20 cm), as the largest classes had few measured rings.

Description of the species diametric growth using a well-defined model is useful for forest management and allow the estimation of the diametric growth, current annual increment in diameter (CAI_d) and mean annual increment in diameter (MAI_d) curves. These values are used to define the Biological Rotation Age (BRA), which is determined by using the basal area (López et al. 2013) or volume (Schöngart et al. 2007, 2008, De Ridder et al. 2013). The Chapman-Richards

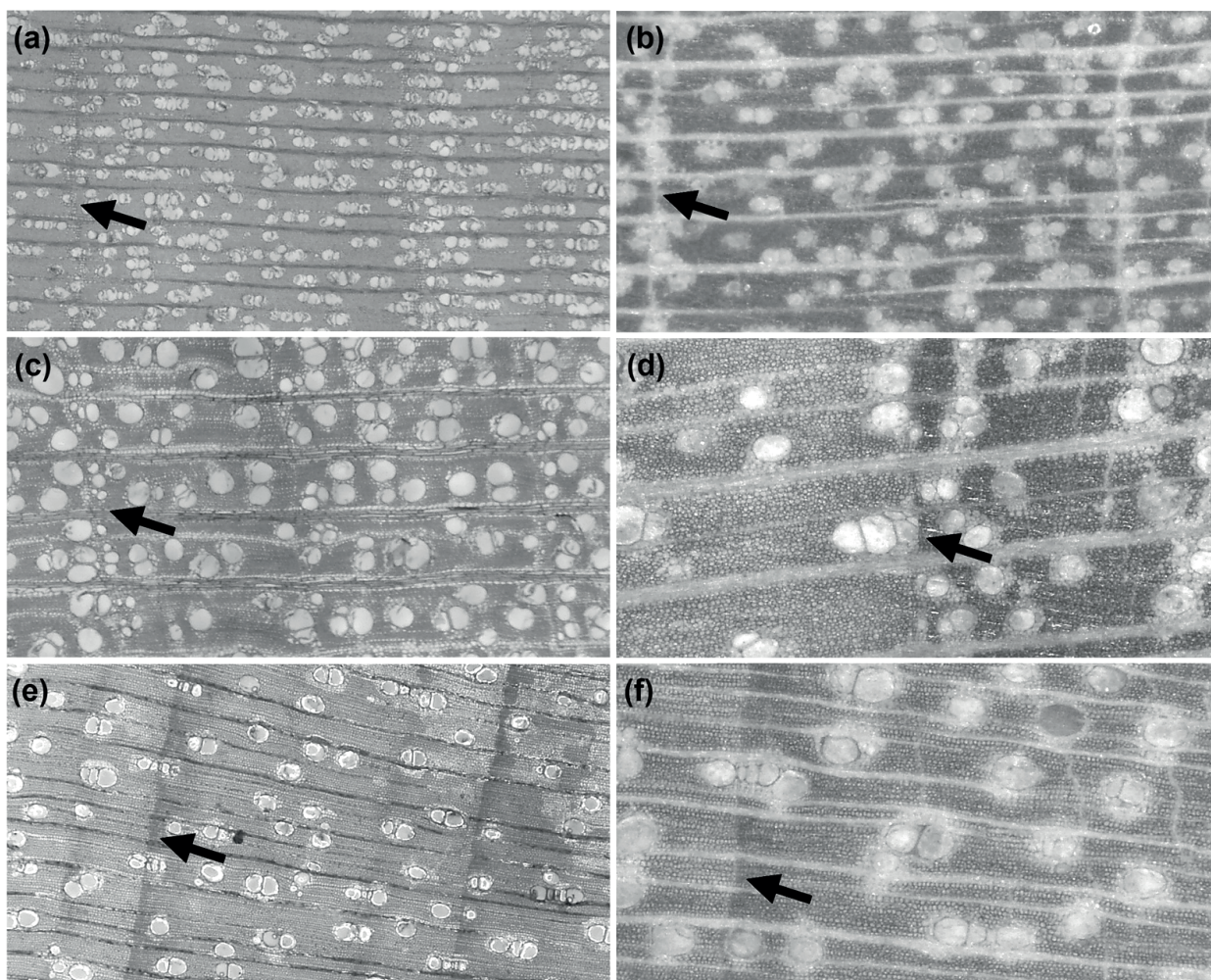


Figure 2 - Wood anatomy of the species. Tree rings characterized in *Balfourodendron riedelianum* by the combination of latewood thick-walled fibers and marginal parenchyma (a) and (b); *Cordia trichotoma* by latewood made up of small and medium-sized vessels, thick-walled fibers and axial parenchyma (c) and (d); *Ocotea diospyrifolia* by a darker tangential line and radial thick-walled fibers (e) and (f). Arrows indicate the ring boundaries.

sigmoidal growth model (Richards 1959), was adjusted for each species dataset. This model was selected for efficiency and flexibility to express the growth and production of biological variables (Zhao-gang and Feng-ri 2003, Cruz et al. 2008, Machado et al. 2015, Figueiredo Filho et al. 2017). In the growth model, Y is the estimated diameter outside the bark (cm); I is the age (years); and b_0 , b_1 and b_2 are the estimated coefficients.

DBH and age data were used to fit growth models. Accuracy was verified by the coefficient of determination (r^2), standard error (S_y) and distribution of residuals. The age of the trees in

which the pith was not identified was estimated in 2015 by dividing DBH minus the bark by the mean diametric growth (Worbes 1995, Botosso and Mattos 2002, Stepka et al. 2014). The age of the trees with visible pith was estimated using this method and thus, a t -test was carried out to validate the procedure.

EFFECT OF ENVIRONMENTAL CONDITIONS

The effects of soil, temperature and rainfall on the diametric growth of the species were analyzed following the distribution of trees in the altitudes and forest types (Table I). Altitudes and forest

types were defined as treatments in two completely randomized designs (CRD) and current increments in diameter were considered replications. The availability of light through canopy profiles affects the growth of trees in native forests (Hubbell et al. 1999) so that trees located in the understory have lower diametric growth (Hart et al. 2010). In order to minimize the effect of lack of light in the first stages of growth, only the annual increments with $DBH \geq 20$ cm were considered (minimum diameter of the forest canopy trees, which were considered subjectively) in the statistical analysis of the environmental effects on diametric growth (Vera et al. 2012). The nonparametric Kruskal-Wallis test was applied followed by multiple comparisons (Siegel and Castellan 1988), since there is no normal distribution and homogeneity of variances (Bartlett's test, $P < 0.05$).

RESULTS

READING AND MEASURING GROWTH RINGS

The process for verifying error of labeling in the false rings using cross-dating and graphical analysis allowed rings synchronization between wood cores. The mean intercorrelation between core pairs was 0.39 (critical point 0.33, $P > 0.01$) for *B. riedelianum*, with ages estimated from 54 to 138 years; 0.53 (critical point of 0.51, $P > 0.01$) for *C. trichotoma*, with ages estimated from 27 to 78 years; 0.57 (critical point of 0.42, $P > 0.01$) for *O. diospyrifolia*, with ages estimated from 29 to 79 years.

DIAMETRIC GROWTH PATTERN

Current annual increment in diameter for DBH-classes and the total of each species are presented in Table II. All three species presented growth rate increase with DBH increase and *C. trichotoma* had the maximum growth rate earlier than the other species ($0.67 \text{ cm year}^{-1}$, DBH-class 20-25 cm). The means of the three species for DBH-class ≥ 20 cm

was higher than for the DBH-class < 20 cm (t -test, $P < 0.01$). A single tree of *B. riedelianum* showed $DBH \geq 50$ cm ($DBH = 72.57$ cm) resulting in a CAI_d decrease for the highest DBH-class. The maximum CAI_d for *B. riedelianum* occurred in DBH-class of 30-35 cm ($1.52 \text{ cm year}^{-1}$), for *C. trichotoma* in DBH-class of 15-20 cm ($1.59 \text{ cm year}^{-1}$) and for *O. diospyrifolia* in DBH-class of 30-35 cm ($1.71 \text{ cm year}^{-1}$).

The tree pith was not identified in 24 out of 32 *B. riedelianum* trees, 25 out of 27 of *C. trichotoma* and 18 out of 30 of *O. diospyrifolia*, whose ages were estimated from the respective mean diametric increment (t -test, $P = 0.46$). With these estimates and the values observed for the trees in which it was possible to identify the tree pith, growth models were fitted for each species (Table III).

Using these fitted growth models, a mean diametric growth curve, CAI_d and MAI_d curves were obtained for each species (Figure 3). The asymptotic yield of DBH is estimated by the coefficient b_0 of the Chapman-Richards model (Richards 1959, Zhao-gang and Feng-ri 2003). The maximum CAI_d was estimated at ages 29 ($0.36 \text{ cm year}^{-1}$), 25 ($0.63 \text{ cm year}^{-1}$) and 24 years ($0.64 \text{ cm year}^{-1}$) for *B. riedelianum*, *C. trichotoma* and *O. diospyrifolia*, respectively. The maximum MAI_d occurs with 55 ($0.33 \text{ cm year}^{-1}$), 45 ($0.59 \text{ cm year}^{-1}$) and 44 ($0.59 \text{ cm year}^{-1}$) years for *B. riedelianum*, *C. trichotoma* and *O. diospyrifolia*, respectively. These latter ages represent the BRA of studied tree species as MAI_d was higher than CAI_d .

EFFECT OF ENVIRONMENTAL CONDITIONS

Significant differences were observed for mean CAI_d values among altitude levels and forest types for the three species (Figure 4) (Kruskal-Wallis, $P < 0.05$). The lowest altitudes are favorable to the current increment for *B. riedelianum*; the highest mean for current increment in diameter occurs at 250 m ($0.50 \text{ cm year}^{-1}$), which was statistically

TABLE II
Measured rings (n) and mean for current annual increment in diameter (CAI_d) grouped by DBH-class of 5 and 20 cm for three forest species in the Iguaçu National Park.

DBH-class (cm)	<i>Balfourodendron riedelianum</i>		<i>Cordia trichotoma</i>		<i>Ocotea diospyrifolia</i>	
	n	CAI _d (cm year ⁻¹)	n	CAI _d (cm year ⁻¹)	n	CAI _d (cm year ⁻¹)
0-5	316	0.26 ± 0.12	127	0.51 ± 0.18	151	0.46 ± 0.21
5-10	463	0.30 ± 0.13	222	0.52 ± 0.17	229	0.54 ± 0.17
10-15	515	0.31 ± 0.16	221	0.56 ± 0.20	226	0.59 ± 0.17
15-20	494	0.32 ± 0.16	202	0.64 ± 0.24	263	0.58 ± 0.18
20-25	443	0.36 ± 0.15	191	0.67 ± 0.23	235	0.63 ± 0.20
25-30	372	0.41 ± 0.19	156	0.67 ± 0.23	198	0.68 ± 0.22
30-35	282	0.42 ± 0.21	126	0.66 ± 0.24	132	0.71 ± 0.23
35-40	140	0.50 ± 0.22	79	0.57 ± 0.16	95	0.68 ± 0.20
40-45	69	0.57 ± 0.22	29	0.63 ± 0.16	68	0.64 ± 0.18
45-50	30	0.47 ± 0.12	5	0.51 ± 0.14	21	0.70 ± 0.18
50-55	10	0.49 ± 0.07			3	0.75 ± 0.18
55-60	9	0.56 ± 0.11				
60-65	9	0.53 ± 0.11				
65-70	16	0.33 ± 0.12				
70-75	5	0.15 ± 0.04				
<20 cm	1788	0.30 ± 0.20	772	0.56 ± 0.22	869	0.55 ± 0.21
≥20 cm	1385	0.41* ± 0.15	586	0.65* ± 0.21	752	0.67* ± 0.19
Total or Mean	3173	0.35 ± 0.18	1358	0.60 ± 0.22	1621	0.61 ± 0.21

Mean ± Standard deviation to CAI_d. * Highest mean (*t*-test for DBH ≥20 or DBH <20 cm, *P* < 0.01).

equal to 150 m (0.43 cm year⁻¹). The lowest mean for *B. riedelianum* was observed between 650 and 350 m (0.38 to 0.41 cm year⁻¹). Among the forest types, the highest mean CAI_d for *B. riedelianum* was observed in SSF Typical Submontane (0.42 cm year⁻¹), which was similar to SSF Montane (0.38 cm year⁻¹) (Kruskal-Wallis, *P*>0.05).

At high altitudes, higher growth of *C. trichotoma* was observed: 0.74 cm year⁻¹ at 750 m against 0.62 cm year⁻¹ at 150 m. The highest mean (0.74 cm year⁻¹) among forest types was in Ecotone SSF/MOF, SSF Montane and SSF Typical Submontane, which was higher than in SSF Humid Submontane (0.52 cm year⁻¹) (Kruskal-Wallis, *P*<0.05). In general, higher growth of *O.*

diospyrifolia occurred between 150 and 550 m (0.73 against 0.61 cm year⁻¹) (Kruskal-Wallis, *P*<0.05). The highest mean CAI_d was observed in SSF Typical Submontane (0.72 cm year⁻¹), varying between 0.58 and 0.64 cm year⁻¹ in the other forest types (Kruskal-Wallis, *P*>0.05).

DISCUSSION

Tree rings were used to describe the diametric growth pattern of *B. riedelianum*, *C. trichotoma* and *O. diospyrifolia* and to analyze the effect of environmental conditions on their diametric growth. Diametric growth was higher in the larger DBH-classes for the three species, as observed for

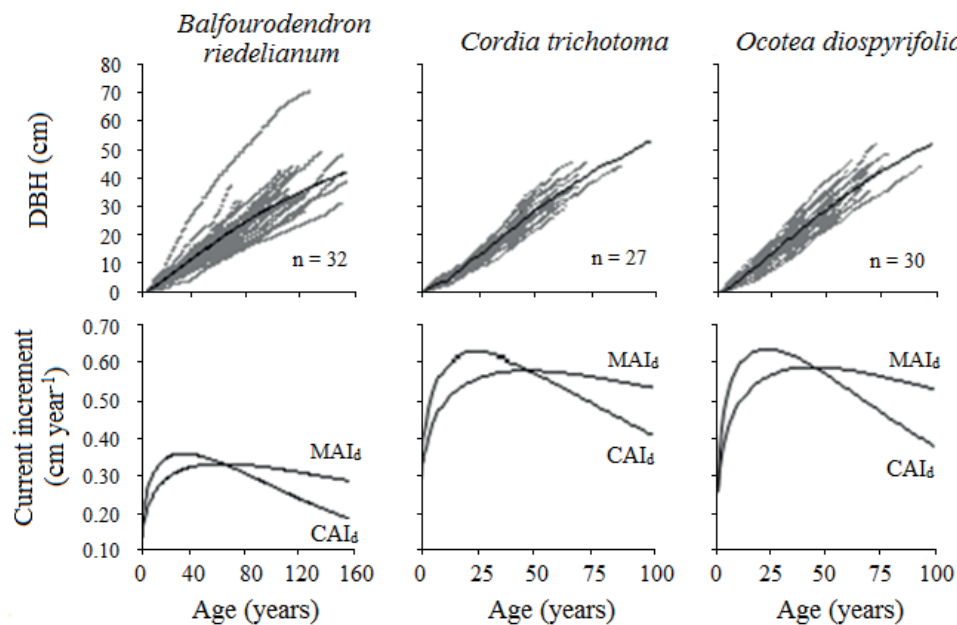


Figure 3 - Individual diametric growth curves and mean curves fitted by growth models (black line), current annual increment in diameter (CAId) and mean annual increment in diameter (MAId) to *Balfourodendron riedelianum*, *Cordia trichotoma* and *Ocotea diospyrifolia* in the Iguazu National Park.

other species in native forests (Clark and Clark 1999, Silva et al. 2002). Hubbell et al. (1999) and Silva et al. (2002) reported that trees with larger diameter occupying the forest canopy receive more light on the crown and have higher photosynthetic rates, causing increases in diametric growth.

Vera et al. (2012) found the same dependence between increment and size for adult trees of *O. diospyrifolia* in a secondary forest, describing higher periodic increments (five years) for larger trees (DBH ≥ 20 cm, $1.47 \text{ cm year}^{-1}$) than for smaller trees (DBH < 20 cm, $0.63 \text{ cm year}^{-1}$). Mattos (2007) also emphasized a positive correlation between the periodic increment in basal area ($\text{cm}^2 \text{ year}^{-1}$) and DBH-classes for *C. trichotoma*, *Cedrela fissilis* and *Cabralea canjerana*, attributing the result to lower competition of the trees that occupy the forest canopy.

For a sustainable management of native forests, it is necessary to define a MLD for each species, based on the respective BRA (Schöngart 2008, De Ridder et al. 2013, López et al. 2013). Using fitted

growth models and based on diameter, the BRA values were estimated in 55 years with MLD of 18.27 cm for *B. riedelianum*, 45 years with 26.56 cm for *C. trichotoma* and 44 years with 26.05 cm for *O. diospyrifolia*. López et al. (2013) determined higher biological rotation ages (≥ 80 years) and, consequently, higher DBH values (≥ 45 cm) for seven species in the Bolivian Savanna, which is justified by the use of the basal area (cm^2) instead of the diameter. Schöngart (2008) also described biological rotation ages in volume greater than 60 years for 9 of 12 species studied (DBH's ≥ 53 cm).

The lowest BRA values observed for *B. riedelianum*, *C. trichotoma* and *O. diospyrifolia* are associated with the use of diameter as a biological variable, commonly not used in the management of natural forests. However, the diameter is an alternative for the management of small forest remnants in South Brazil. In addition, the estimated DBH values for BRA were based on trees that grew without the application of silvicultural techniques, which might result in higher diametric growth rate, as observed by Venturoli et al. (2015) for other

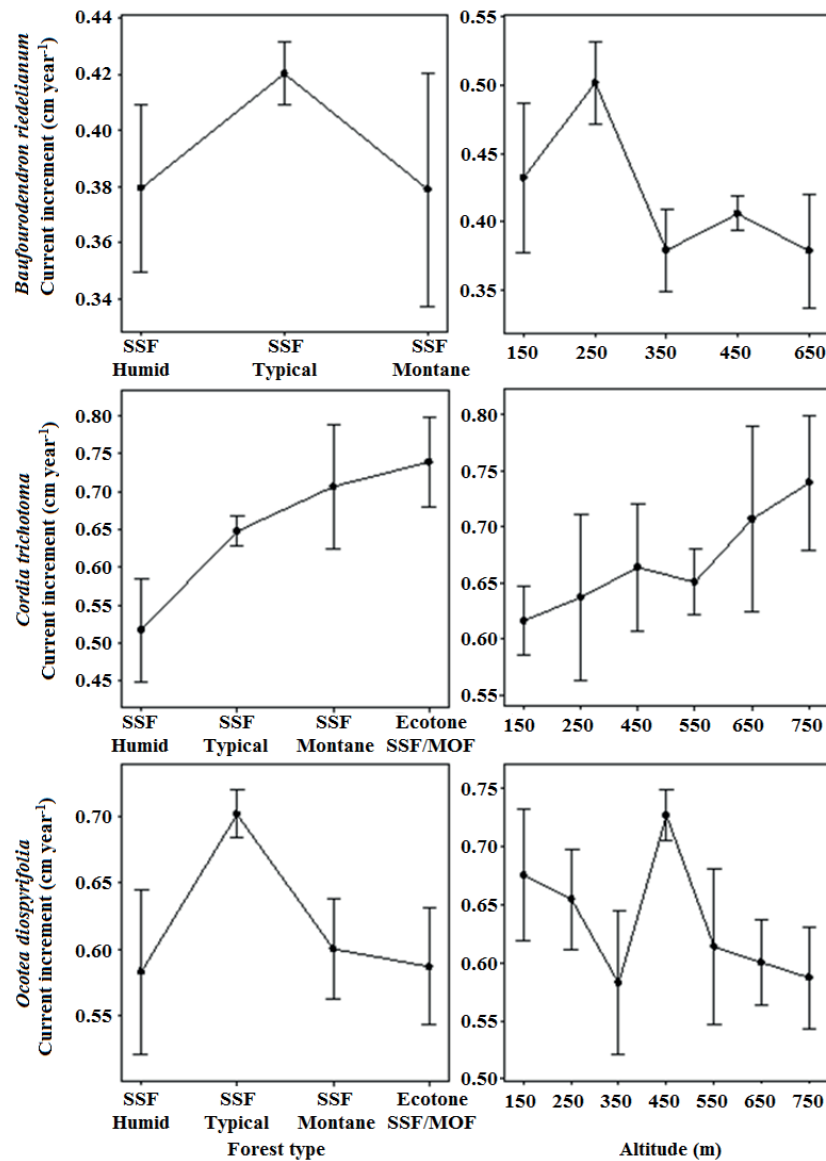


Figure 4 - Means for current increment in diameter (DBH ≥ 20 cm) of *Balfourodendron riedelianum*, *Cordia trichotoma* and *Ocotea diospyrifolia* at altitude levels and forest types in the Iguaçu National Park; SSF - Seasonal Semideciduous Forest, MOF - Mixed Ombrophilous Forest.

semideciduous species. Bulfe (2008) for example, described an increase of 0.25 cm year⁻¹ in periodic increment after application of selective harvesting (6 years) for *B. riedelianum*, 0.19 cm year⁻¹ for *O. diospyrifolia* and 0.15 cm year⁻¹ for *C. trichotoma* as compared to the control (no treatment).

Observed results for forest stands also indicate that these species may have high diametric growth when trees are exposed to light from the

early years. For *B. riedelianum*, Carvalho (2004) described MAI_d of 1.18 cm year⁻¹ (7 years), Kubota et al. (2015) reported MAI_d between 0.55 and 0.59 cm year⁻¹ (27 years) in the progeny test, and Mattos et al. (2004) found MAI_d of 1.0 and 1.15 cm year⁻¹ for 12 and 15 years, respectively. For *C. trichotoma*, Radomski et al. (2012) and Carvalho (2002) reported MAI_d values of 1.26 cm year⁻¹ (7 years) and 3.07 cm year⁻¹ (3 years), respectively.

TABLE III
Fitted growth models for three forest species in the Iguaçu National Park.

Species	Fitted Growth Model	r^2	S_y
<i>Balfourodendron riedelianum</i>	$Y = 63.1291(1 - e^{-0.0088(t)})^{1.2908}$	0.75	6.27
<i>Cordia trichotoma</i>	$Y = 99.3419(1 - e^{-0.0096(t)})^{1.2565}$	0.95	2.72
<i>Ocotea diospyrifolia</i>	$Y = 88.3181(1 - e^{-0.0112(t)})^{1.2954}$	0.92	3.83

Y - Estimated diameter outside bark (cm); t - Age (years); r^2 - Coefficient of determination; S_y - Standard error.

Environmental characteristics such as soil, water availability, temperature and rainfall affect the distribution of forest species (Oliveira-Filho and Fontes 2000, Botrel et al. 2002, Ferreira-Júnior et al. 2007), as well as the growth pattern (Toledo et al. 2011). With the reduction of altitude in the INP, where the winters are dry, with few days of rain and frost of low intensity, and the summers are hot and humid (IAPAR 2017), *B. riedelianum* and *O. diospyrifolia* grew up better (Table II). At low altitudes, the highest diametric growth of both species occurred in SSF Typical Submontane, in plains with deep soil of slow drainage and high fertility (Eutrophic Red Nitosol) and lower humidity when compared to the SSF Humid Submontane (Souza et al. 2017).

The environmental conditions that favored the growth of *B. riedelianum* in the INP were also described by Carvalho (2004), corroborating the results of the present study. For *O. diospyrifolia*, this is the first study about the effect of environmental conditions on its diametric growth. It is noteworthy that this species showed higher growth rate between 150 and 550 m, with the exception of 350 m. This can be explained by the high humidity and shallow soil from the site at 350 m, which is characterized by SSF Humid Submontane, located in the slope of the drainage ramp and close to a river. Despite this result, due to the wide geographic distribution of *O. diospyrifolia*, occurring from north to south of

Brazil (Quinet 2015), Paraguay (López 2002) and Argentina (Vera et al. 2012), further investigations are necessary to corroborate the results found in this study.

In fact, the environmental influence on growth rates of forest species must be carefully analyzed. For instance, *C. trichotoma* presented higher diametric growth at the highest altitude in Ecotone SSF/MOF (Figure 3) with well-drainage soil of low fertility (Distrophic Red Latosol), while Carvalho (2002) reported that this species grows up in sites with well-drainage higher fertility soil. Caum (2013) reported a significant reduction on the CAI_d associated to the water deficit for this species, which explains, along with the well-drainage soil, the higher diameter growth at high INP altitudes, where there is higher rainfall and relative humidity during the dry season (IAPAR 2017).

CONCLUSION

In summary, this study contributes to the management and conservation of the Atlantic Forest, providing ecological information and diametric growth for *Balfourodendron riedelianum*, *Cordia trichotoma* and *Ocotea diospyrifolia*, native species of commercial importance. Fitted models provided the Biological Rotation Age based on the diameter and respective Minimum Diameter Logging for each species in the Iguaçu National Park (55 years with 18.27 cm for *B. riedelianum*, 45 years with

26.56 cm for *C. trichotoma* and 44 years with 26.05 cm for *O. diospyrifolia*). The environmental conditions of SSF Typical Submontane (<600 m) favored the diametric growth of *B. riedelianum* and *O. diospyrifolia*. On the other hand, *C. trichotoma* presented higher diametric growth in the Ecotone SSF/MOF (>600 m), where trees face well-drained soils with low fertility, high rainfall and high relative humidity during the dry season.

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AUTHOR CONTRIBUTIONS

Ronan Felipe de Souza performed the data collection, data processing and text writing activities. Tomaz Longhi-Santos performed laboratory analysis and identification of morphological structures of samples of each species. Sebastião do Amaral Machado, conducted the orientation and monitoring of the activities, as well as contributed to the writing of the final manuscript.

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