SEASONAL DIAMETER INCREMENT FOR 7 SPECIES FROM AN OMBROPHYLLOUS MIXED FOREST, SOUTHERN STATE OF PARANÁ, BRAZIL

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Recebido para publicação: 28/08/2007 – Aceito para publicação: 20/03/2008

Abstract

Seasonal diameter increment for seven species from an Ombrophyllous Mixed Forest located in São João do Triunfo, South of the State of Paraná was evaluated from September 1998 to September 2005 (a seven year period) using dendrometric bands. Sixty-one *Araucaria angustifolia* trees, 19 *Nectandra grandiflora*, 12 *Campomanesia xanthocarpa*, 10 *Cinnamomum vesiculosum*, 10 *Prunus brasiliensis*, 9 *Ocotea porosa* and 8 *Matayba elaeagnoides* were studied. Within each species measurements were taken at the end of each season. The diameter increment was evaluated using Randomized Complete Block Design by species, by year, and even by season. The analyses were carried out for six years (September, 1999 to September, 2005) and led one to conclude that diameter increment rate in the summer was greater than in the spring, followed by autumn and winter, corresponding to 53, 26, 17 and 4% of the annual yield respectively. *Prunus brasiliensis* and *Nectandra grandiflora* showed the highest annual increment rates. The mean annual increments from the six broadleaved studied trees were 0.262 cm, and 0.122 cm for *Araucaria angustifolia*. Diameter increments correlated to temperature and precipitation, indicated that temperature has higher effect on increment (r = 0.72) than precipitation (r = 0.49).
Keywords: Forest growth; dendrometric bands; Mixed Araucaria Forest.

Resumo

Incremento sazonal do diâmetro de 7 espécies de uma Floresta Ombrófila Mista no Sul do Paraná. O incremento sazonal em diâmetro de sete espécies de uma Floresta Ombrófila Mista localizada em São João do Triunfo, região sul do estado do Paraná, foi avaliado durante sete anos (período de setembro de 1998 a setembro de 2005), com o uso de cintas dendrométricas. Foram incluídas no estudo 61 árvores de *Araucaria angustifolia*, 19 de *Nectandra grandiflora*, 12 de *Campomanesia xanthocarpa*, 10 de *Cinnamomum vesiculosum*, 10 de *Prunus brasiliensis*, 9 de *Ocotea porosa* e 8 de *Matayba elaeagnoides*. Para cada espécie, foram realizadas medições ao final de cada estação do ano. O incremento em diâmetro foi avaliado com análises de variância usando-se o delineamento em blocos casualizados para as espécies, anos e ainda por estação. Pelas análises realizadas para seis anos (período de setembro de 1999 a setembro de 2005), concluiu-se que a maior taxa do incremento em diâmetro ocorreu no verão, seguida da taxa de incremento na primavera, no outono e no inverno, responsáveis por 53, 26, 17 e 4% da produção anual, respectivamente. *Prunus brasiliensis* e *Nectandra grandiflora* apresentaram as maiores taxas de incremento. A média do incremento anual em diâmetro das seis folhosas estudadas foi de 0,262 cm; a da *Araucaria angustifólia,* 0,122 cm. A correlação entre o incremento em diâmetro, a temperatura e a precipitação indicou que a temperatura influencia mais o incremento (r = 0,72) do que a precipitação (r = 0,49).
Palavras-chave: Crescimento; cintas dendrométricas; Floresta Ombrófila Mista.

INTRODUCTION

Tree growth consists of the elongation and thickening of roots, bole and branches, including changes in size, weight and form. Linear growth of all parts of trees results from physiological activities of the primary meristem; diameter growth results from activities of the secondary meristem or cambium, which produces new wood and bark between the old wood and bark (HUSCH *et al.*, 1982).

According to Vanclay (1994) and Prodan *et al.* (1997) growth is the increasing of dimensions of one or more individuals in a forest in a certain period of time. These dimensions can be diameter, height, volume, biomass and basal area, among others. Meanwhile, production refers to the dimensions at the end of certain period. Therefore, production is the accumulated growth, while growth is the production rate.

According to Husch *et al.* (1982) and Lamprecht (1990), tree growth is influenced by genetic capabilities of the species interacting with the environment. Environmental influences include climatic factors (air temperature, precipitation, wind and insolation); soil characteristics (physical, chemical, moisture and microorganisms); topographic characteristics (slope, elevation and aspect); and competition (influence of other trees, lesser vegetation and animals).

Fritts (1958) demonstrated that variations in diametric growth exist during the twenty-four hours of a day, as the result of climatic factors, especially the ones that have influence on the hydration and dehydration of the tree. For annual periods, the growth has its typical curve, which can vary from year to year, mainly due to climatic changes.

Lojan (1965) verified a positive correlation between the fortnightly growth of six tropical species with rainfall, and a negative correlation with sunlight. For the deciduous species, the growth period and dormancy did not seem to be influenced by rain, but by internal factors. The perennial species grew during the whole year, but at a more reduced rate in the dry season. Regarding to temperature, there was no a clear distinction.

Loetsch *et al.* (1973) mentioned that diameter is an essential variable for volume calculation, so therefore diameter increment is the most important component for determination of volume increment and to describe the dynamics of natural forests (ENRIGHT; OGDEN, 1979), especially because age is difficult to determine (CHAMBERS *et al.*, 1998).

Alder (1980) discussed several tests of growth measurement with emphasis on tropical forests. This author mentioned the tests of permanent plots, dendrometric bands and analysis of growth rings. In experimental plots usually measured periodically after a determined number of years, diameter tapes are used. However, for shorter periods, for example hours or days, it is necessary to use more accurate equipment, such as dial-gauge micrometers, recording dendrographs and transducers, as also mentioned by Husch *et. al.* (1982).

In temperate forests, metal dendrometers have been used since 1944 (KEELAND and SHARITZ, 1993) and according to Silva *et al.* (2002), publications on the use of these dendrometers in tropical forests are rare.

In general, dendrometric bands consists of a band of aluminum (or other materials, such as steel or fiberglass) which encircles the tree held firmly on the trunk by coil spring. The band can be marked in inches or centimeters and in tenths of one inch or one centimeter and with a vernier, which permits approximations to 0.01 inch or 0.01 cm (HALL, 1944).

Liming (1957) developed a methodology for construction of a dendrometric band using aluminum. According to the author, the bands are easy to build and low cost instruments. They accurately measure small changes in the tree dimensions, being recommended for studies that require measurements over a short period of time, such as the seasonal increment in diameter.

Still according to the author the dendrometric bands present several advantages and disadvantages when compared to the other dendrometers. He indicated as advantages the great good precision of the measurements, low cost and ease in construction, as well as the speed of installation. As disadvantages, he pointed out the overlap of part of the band caused by the great resistance of the spring, causing measurement errors, displacement of the band caused by animals or falling branches, need for inspection to correct such problems, and loss of precision for trees with DBH smaller than 8 cm. However, the author said that the advantages overcome the disadvantages when the work involves a large number of trees.

Bower and Blocker (1966) studied the precision of the measurements of the diameter increment using dendrometric bands and tapes. According to these authors, the bands are reliable for measurements over short periods of time, but they should be installed one year before the period that measurements will start, as the bands tend to underestimate the diameter growth in the first year of evaluation. Nevertheless, this underestimate could be confused with a reduced increment, mainly in areas with well defined seasons (KEELAND; SHARITZ, 1993).

Silva *et al.* (2002) used a metal dendrometric band to evaluate the monthly increment in 272 trees in the central Amazonian. The increments were measured over 19 months but the authors used only the data of the last 12 months. They considered that the 7 initial months as an adaptation period for the bands, and concluded that the band was useful and precise enough to monitor the monthly diameter growth.

Poole (1986) undertook studies using dendrometric bands for determination of the seasonal diameter growth of a *Eucalyptus regnans* stand located in Kinleith, New Zealand. The results showed that the maximum diameter growth occurred in the spring and the minimum growth occurred in the winter.

Botosso *et al.* (2000) used dendrometric bands for determination of monthly growth, relating it with the pluviometric variation. The studies were undertaken for 3 planted species originating from the Terra Firme Forest (Amazon). They verified that the increment in circumference was affected by precipitation, that is, the 3 species evaluated presented no growth or very reduced growth in the period with hydric stress and an accentuated increment immediately after the first precipitations rainfall of the rainy season.

Ferreira-Fedele *et al.* (2004) studied the monthly periodicity of diameter growth of *Esenbeckia leiocarpa* Engl. (Guarantã) in two areas in the southeast of São Paulo State. They used dendrometric bands made of steel developed by themselves. The authors correlated the increment rate with climate, phenology and growth conditions (sociological position) of the individuals. They concluded that the growth of the species was influenced by the analyzed factors and that the dendrometric bands used were accurate, practical and efficient in determining the increment rates.

Higuchi *et al.* (2003) concluded that dendrometric bands and the automatic dendrometers are practical and efficient when used to monitor growth of the trees and forest stands. In modeling and simulation of forest dynamics, managed or unmanaged, when more accurate basic information is necessary to feed statistical models, the measurement with bands and with dendrometers becomes even more important. The reliability of the measurements with these instruments depends on considerations about the bole form, phenology of the species and occurrence of infestations in the bole, such as vines, termites and/or parasites.

The object of this research was to evaluate the seasonal and annual increment for the diameter of 7 species of an Ombrophyllous Mixed Forest, over 7 years, with the use of dendrometric bands and to correlate growth rates with precipitation and temperature.

METHODS

Study location and characterization of the experimental area

The experiment was installed in the Experimental Station of *São João do Triunfo (State of Paraná)*, belonging to the Federal University of Paraná. It is located on the second plateau of the State of Paraná, 125 km from Curitiba (State capital), with altitude of 780 m, and geographical coordinates of 25°34'18" S and 50°05'56" W. The experimental area is divided in 30 plots of one hectare each, and the research area was in one of these plots (number 18).

According to Köppen climatic classification, the area presents a Cfb type climate, with annual average temperatures between 14°C and 19°C, and annual precipitation between 1250 and 2000 mm. Durigan (1999) verified the presence of several types of soils according to the Brazilian System of Soil Classification: *Cambissolos, Litólicos, Latossolos Vermelho-Escuros and Podzólicos Vermelho-Amarelos.*

Based on the classification proposed by IBGE (1992), the vegetation typology characteristic of the study area is Ombrophyllous Mixed Mountain Forest. More than 30 years ago, a selective exploitation of *Araucarias* in the forest under study was undertaken. The area can be considered as being a very altered primary formation, or a developed secondary formation, because it has some primary formation structural characteristics and some anthropic interventions characteristic of secondary formations (SCHAAF, 2001).

Species studied

The species studied were selected in function of their commercial importance, abundance and dominance. Dendrometric bands were installed on 129 trees. Table 1 presents the seven species studied with their scientific name, family and number of trees measured.

Data collection

The bands were made of aluminum whose construction details can be found in Figueiredo Filho *et al.* (2002). The readings were undertaken at the beginning of each season from September of 1998 (beginning of spring) to the winter of 2005, totaling 7 years of study.

Table 1. Species studied, families and number of trees.
Tabela 1. Espécies estudadas, famílias e número de árvores.

Scientific name	Family	Number of trees
Araucaria angustifolia (Bertol.) Kuntze.	Araucariaceae	61
Nectandra grandiflora Ness & C. Mart. ex Nees	Lauraceae	19
Campomanesia xanthocarpa O. Berg	Myrtaceae	12
Cinnamomum vesiculosum (Nees) Kosterm.	Lauraceae	10
Prunus brasiliensis (Cham. & Schltdl.) Dietrich	Rosaceae	10
Ocotea porosa (Nees & C. Mart.) Barroso	Lauraceae	09
Matayba elaeagnoides Radlk.	Sapindaceae	08
Total		129

The conditions of growth for each tree were also found using field observations, with the following factors being evaluated: 1-dead; 2-stratum (superior, medium and inferior); 3-crown development in relation to the tree size (normal, medium and low); 4-competition with other trees; 5-broken.

Data analysis

The average increments of the species were analyzed individually, beginning with the analysis of the broadleaved group. Considering the importance of the *Araucaria angustifolia* for the ecosystem under study, the growth of this specie was also evaluated by DBH class (cm): 10 - 19.9; 20 - 29.9; 30 - 39.9; 40 - 49.9, and larger than 50 cm.

Statistical tests were used to evaluate the data, which were first submitted to the Bartlett test ($p>0.05$) in order to verify the homogeneity of the variances. After this, an analysis of variance (ANOVA) was applied considering Randomized Complete Block Design (RCBD) in the following situations:

a) For the seven years of study (treatments) with the seven species (blocks);

b) For the last six years of study (treatments) with the seven species (blocks);

c) For the seasons (treatments) with the seven species (blocks);

d) For the five diameter classes of *Araucaria angustifolia* (treatments) with the last six years of study (blocks).

The ANOVA for the situation described in item "a" was undertaken for the purpose of analyzing the need of a period for adaptation of the bands according to recommendations by Bower and Blocker (1966), and Silva *et al.* (2002). When the ANOVA detected differences among treatments, the Tukey test was used ($p<0.05$) for comparison of the means.

Pearson's simple linear correlation (r) was also used in order to verify the influence of precipitation and temperature on the seasonal diameter increments. In this case, the trees that did not present positive growth during the period studied were eliminated from the analysis. Climate data were supplied by SIMEPAR (Meteorological System of Paraná), collected from the Meteorological Station of Lapa, the closest one to the area of study.

RESULTS AND DISCUSSION

Table 2 shows the results of the increments per season, by species and by broadleaved group, while table 3 presents the increments of the *Araucaria angustifolia* by diameter class. Both tables although provide the increment from trees that presented positive growth during the seven years of the study. It should be emphasized that the means are weighted averages, and that for computation of the increments as presented in item 3.1, the measurements from the first year of research were excluded.

Band adaptation period

A statistical analysis was undertaken using ANOVA with data for annual production (Table 2), considering the years of study (7) as treatments and the species (7) as blocks. Before undertaking ANOVA, the Bartlett test was applied, which indicated that the variances are homogeneous ($p>0.05$), both for treatments and for blocks.

Table 2. Seasonal and annual diameter increment by species.
Tabela 2. Incremento diamétrico sazonal e anual por espécie.

Species	Number of trees	Year	Diameter increment (cm)				
			Spring	Summer	Autumn	Winter	Annual
Araucaria angustifolia	61	1	0.006	0.014	0.017	0.004	**0.040**
		2	0.051	0.061	0.018	0.016	**0.146**
		3	0.047	0.055	0.007	0.004	**0.114**
		4	0.034	0.034	0.021	0.003	**0.092**
		5	0.016	0.015	0.009	-0.003	**0.038**
		6	0.064	0.065	0.030	0.009	**0.168**
		7	0.070	0.047	0.042	0.016	**0.175**
		Mean	**0.047**	**0.046**	**0.021**	**0.008**	**0.122**
Nectandra grandiflora	19	1	0.003	0.156	0.075	0.008	**0.243**
		2	0.117	0.157	0.022	0.017	**0.313**
		3	0.075	0.154	0.045	0.028	**0.303**
		4	0.136	0.218	0.044	0.000	**0.397**
		5	-0.003	0.151	0.030	0.027	**0.204**
		6	0.144	0.193	0.042	0.000	**0.379**
		7	0.072	0.127	0.039	0.010	**0.248**
		Mean	**0.090**	**0.167**	**0.037**	**0.014**	**0.307**
Campomanesia xanthocarpa	12	1	0.004	0.032	0.020	0.000	**0.056**
		2	0.040	0.127	0.028	0.028	**0.223**
		3	0.084	0.195	0.020	0.000	**0.298**
		4	0.092	0.211	0.020	0.004	**0.326**
		5	0.048	0.183	0.028	0.004	**0.263**
		6	0.068	0.271	0.040	0.004	**0.382**
		7	0.085	0.093	0.044	-0.006	**0.215**
		Mean	**0.051**	**0.130**	**0.024**	**0.002**	**0.206**
Cinnamomum vesiculosum	10	1	0.019	0.083	0.045	0.013	**0.159**
		2	0.080	0.181	0.019	0.029	**0.309**
		3	0.169	0.127	0.054	0.006	**0.357**
		4	0.108	0.210	0.038	0.016	**0.372**
		5	0.080	0.162	0.010	0.010	**0.261**
		6	0.064	0.156	0.016	0.003	**0.239**
		7	0.083	0.080	0.029	0.000	**0.191**
		Mean	**0.097**	**0.153**	**0.028**	**0.011**	**0.288**
Prunus brasiliensis	10	1	0.032	0.102	0.092	0.029	**0.255**
		2	0.080	0.162	0.070	0.022	**0.334**
		3	0.118	0.137	0.070	0.029	**0.353**
		4	0.137	0.251	0.108	0.010	**0.506**
		5	0.092	0.242	0.060	0.029	**0.423**
		6	0.095	0.197	0.076	0.013	**0.382**
		7	0.067	0.153	0.067	0.016	**0.302**
		Mean	**0.098**	**0.190**	**0.075**	**0.020**	**0.384**
Ocotea porosa	09	1	0.014	0.021	0.042	0.007	**0.085**
		2	0.028	0.170	0.035	0.014	**0.248**
		3	0.050	0.166	0.057	0.011	**0.283**
		4	0.014	0.163	0.064	0.000	**0.241**
		5	0.000	0.159	0.039	0.007	**0.205**
		6	0.028	0.152	0.050	0.007	**0.237**
		7	0.039	0.110	0.053	0.000	**0.202**
		Mean	**0.027**	**0.153**	**0.050**	**0.006**	**0.236**
Matayba elaeagnoides	08	1	0.000	0.000	0.004	0.004	**0.008**
		2	0.016	0.016	0.012	0.004	**0.048**
		3	0.020	0.103	-0.016	0.004	**0.111**
		4	0.008	0.056	0.036	0.004	**0.103**
		5	-0.016	-0.004	0.016	0.000	**-0.004**
		6	0.016	0.052	0.056	0.000	**0.123**
		7	0.056	0.004	0.028	0.012	**0.099**
		Mean	**0.017**	**0.038**	**0.022**	**0.004**	**0.080**

Species	Number of trees	Year	Diameter increment (cm)				
			Spring	Summer	Autumn	Winter	Annual
Broadleaved (1)	69	1	0.011	0.079	0.051	0.010	**0.150**
		2	0.066	0.136	0.029	0.018	**0.249**
		3	0.083	0.141	0.039	0.015	**0.278**
		4	0.088	0.181	0.050	0.004	**0.323**
		5	0.027	0.145	0.029	0.015	**0.215**
		6	0.077	0.164	0.043	0.003	**0.287**
		7	0.069	0.101	0.043	0.005	**0.218**
		Mean	**0.068**	**0.145**	**0.039**	**0.010**	**0.262**
All trees (2)	129	1	0.008	0.048	0.035	0.007	**0.098**
		2	0.059	0.101	0.024	0.017	**0.200**
		3	0.066	0.100	0.024	0.010	**0.200**
		4	0.062	0.112	0.036	0.004	**0.214**
		5	0.022	0.083	0.020	0.006	**0.131**
		6	0.071	0.117	0.037	0.004	**0.229**
		7	0.069	0.076	0.043	0.010	**0.198**
		Mean	**0.058**	**0.098**	**0.030**	**0.009**	**0.195**
Growing trees (3)	88	1	0.012	0.068	0.050	0.010	**0.140**
		2	0.085	0.140	0.034	0.021	**0.281**
		3	0.093	0.138	0.039	0.017	**0.287**
		4	0.093	0.161	0.049	0.005	**0.308**
		5	0.032	0.126	0.028	0.014	**0.201**
		6	0.103	0.168	0.052	0.011	**0.335**
		7	0.095	0.109	0.059	0.016	**0.279**
		Mean	**0.083**	**0.140**	**0.044**	**0.014**	**0.282**

(1) Six species of broadleaved group. (2) all trees in the study. (3) group of trees that presented positive growth.
All means were calculated using only data from the 2nd to the 7th year.

Table 3. Seasonal and annual diameter increment for *Araucaria angustifolia* by DBH class.
Tabela 3. Incremento diamétrico sazonal e anual de *Araucaria angustifolia* por classes de DAP.

Classes of DBH (cm)	Number of trees	Year	Diameter increment (cm)				
			Spring	Summer	Autumn	Winter	Annual
10 - 19.9	09	1	0.000	0.000	0.004	0.000	**0.004**
		2	0.014	0.011	0.000	0.007	**0.032**
		3	0.021	0.018	-0.007	0.000	**0.032**
		4	0.000	0.014	-0.014	0.000	**0.000**
		5	-0.004	-0.004	-0.004	0.000	**-0.011**
		6	0.007	0.021	0.011	-0.007	**0.032**
		7	0.018	0.021	0.011	-0.007	**0.042**
		Mean	**0.009**	**0.014**	**-0.001**	**-0.001**	**0.021**
20 - 29.9	10	1	0.000	0.013	0.013	0.003	**0.029**
		2	0.054	0.041	0.006	0.010	**0.111**
		3	0.041	0.035	-0.003	-0.006	**0.067**
		4	0.003	0.019	0.010	-0.013	**0.019**
		5	0.019	0.013	0.010	-0.029	**0.013**
		6	0.048	0.041	0.025	-0.003	**0.111**
		7	0.064	0.022	0.022	0.010	**0.118**
		Mean	**0.038**	**0.029**	**0.012**	**-0.005**	**0.073**
30 - 39.9	12	1	0.013	0.016	0.013	0.005	**0.048**
		2	0.045	0.053	0.011	0.016	**0.125**
		3	0.053	0.069	0.013	-0.008	**0.127**
		4	0.058	0.029	0.021	0.003	**0.111**
		5	0.058	0.016	0.003	0.000	**0.077**
		6	0.072	0.069	0.029	0.003	**0.172**
		7	0.074	0.042	0.040	0.016	**0.172**
		Mean	**0.060**	**0.046**	**0.019**	**0.005**	**0.131**

Classes of DBH (cm)	Number of trees	Year	Diameter increment (cm)				
			Spring	Summer	Autumn	Winter	Annual
40 - 49.9	19	1	0.008	0.013	0.025	0.005	**0.052**
		2	0.067	0.075	0.044	0.023	**0.210**
		3	0.065	0.059	0.018	0.022	**0.164**
		4	0.059	0.059	0.037	0.010	**0.164**
		5	0.018	0.032	0.010	0.008	**0.069**
		6	0.090	0.087	0.040	0.015	**0.233**
		7	0.099	0.075	0.057	0.022	**0.253**
		Mean	**0.066**	**0.065**	**0.034**	**0.017**	**0.182**
50 - 59.9	11	1	0.003	0.023	0.020	0.003	**0.049**
		2	0.055	0.104	0.009	0.017	**0.185**
		3	0.038	0.084	0.000	0.000	**0.122**
		4	0.020	0.026	0.032	0.009	**0.087**
		5	-0.020	0.000	0.026	-0.003	**0.003**
		6	0.069	0.081	0.035	0.009	**0.194**
		7	0.064	0.046	0.064	0.029	**0.203**
		Mean	**0.038**	**0.057**	**0.027**	**0.010**	**0.132**
All trees (1)	61	1	0.006	0.014	0.017	0.004	**0.040**
		2	0.051	0.061	0.018	0.016	**0.146**
		3	0.047	0.055	0.007	0.004	**0.114**
		4	0.034	0.034	0.021	0.003	**0.092**
		5	0.016	0.015	0.009	-0.003	**0.038**
		6	0.064	0.065	0.030	0.009	**0.168**
		7	0.070	0.047	0.042	0.016	**0.175**
		Mean	**0.047**	**0.046**	**0.021**	**0.008**	**0.122**
Growing trees (2)	38	1	0.009	0.020	0.027	0.006	**0.062**
		2	0.080	0.096	0.028	0.024	**0.228**
		3	0.074	0.083	0.019	0.011	**0.187**
		4	0.059	0.054	0.035	0.007	**0.155**
		5	0.020	0.032	0.016	0.004	**0.072**
		6	0.102	0.097	0.045	0.011	**0.255**
		7	0.108	0.072	0.061	0.025	**0.266**
		Mean	**0.074**	**0.072**	**0.034**	**0.014**	**0.194**

(1) All trees in the study. (2) group of the *araucária* trees that presented positive growth.
All means were calculated using only data from 2nd to the 7th year.

The ANOVA presented in table 4 shows that there were significant differences, both for treatments and for blocks (p<0.001). Thus, the Tukey test was applied (Table 5), and the results indicate that there was significant difference among treatments (years of measurement), evidencing that the mean of the first year is statistically equal only to the mean of the fifth year, but considerably lower than the means from the other years of the study.

Table 4. ANOVA (RCBD) for the annual diameter increment (cm) for the species.
Tabela 4. ANOVA do incremento diamétrico anual (cm) para as espécies.

Source of variation	df	SS	MS	F	*p-value*
Treatment (1)	6	0.114	0.019	8.3868 ***	0.000
Block (2)	6	0.458	0.076	33.5614 ***	0.000
Error	36	0.082	0.002	-	-
Total	48	0.654	-	-	-

df = degrees of freedom; SS = sum of squares; MS = mean square; F = Fisher's values; *p-value* = probability values.
(1) years, (2) species. *** p<0.001.

Table 5. The Tukey HSD Test ($P<0.05$) for comparing means of the increment (cm) between years.
Tabela 5. Teste de Tukey ($P<0,05$) para comparação das médias do incremento (cm) entre os anos.

Years	Means	Ranked order(a)	Contrast(b)							
			Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**
4	0.2759	A	**1**	0						
6	0.2542	AB	**2**	-0.1024*	0					
3	0.2484	AB	**3**	-0.1280*	-0.0256	0				
2	0.2228	AB	**4**	-0.1554*	-0.0530	-0.0274	0			
7	0.2046	AB	**5**	-0.0651	0.0373	0.0629	0.0903*	0		
5	0.1857	BC	**6**	-0.1339*	-0.0314	-0.0059	0.0216	-0.0687	0	
1	0.1203	C	**7**	-0.0841*	0.0183	0.0439	0.0713	-0.0190	0.0497	0

a) years with the same letters do not statistically differ amongst themselves. b) contrast between means from +/- 0,0795 of limits.
* denotes a statistically significant difference.

This difference could be attributed to the period necessary for adaptation of the bands as recommend by Bower and Blocker (1966), and Silva *et al.* (2002).

An analysis of temperature and precipitation data for the first year presented in table 16 and Fig. 6 shows that these climatic factors were not different from those for other years, emphasizing and confirming the importance of the recommendation from the authors mentioned above in reference of using a one year period of adaptation for the bands.

Annual increment of the studied species

For the results of the analysis of the data from seven years of measurement, an ANOVA (Table 6) was once again applied excluding the data from first year. The analysis showed that the *Fisher* F value decreased for the treatments ($p<0.05$), indicating that differences among the means decreased, and that only year 4 was statistically different from year 5 as shown by the Tukey test (Table 7).

Table 6. ANOVA (RCBD) for annual diameter increment (cm) of the species.
Tabela 6. ANOVA para o incremento diamétrico anual (cm) das espécies.

Source of variation	df	SS	MS	F	*p-value*
Treatment (1)	5	0.040	0.008	3.1947 *	0.020
Block (2)	6	0.406	0.068	27.2076 ***	0.000
Error	30	0.075	0.002	-	-
Total	41	0.654	-	-	-

df = degrees of freedom; SS = sum of squares; MS = mean square; F = Fisher value; *p-value* = probability value.
(1) = years; (2) = species; * = $p<0.05$; *** = $p<0.001$.

Table 7. The Tukey HSD Test ($P<0.05$) for comparing means increment (cm) between years.
Tabela 7. Teste de Tukey ($P<0,05$) para comparação dos incrementos médios (cm) entre os anos.

Years	Means	Ranked order(a)	Contrast(b)					
			Years	**2**	**3**	**4**	**5**	**6**	**7**
4	0.2759	A	2	0					
6	0.2542	AB	3	-0.0256	0				
3	0.2484	AB	4	-0.0530	-0.0274	0			
2	0.2228	AB	5	0.0373	0.0629	0.0903*	0		
7	0.2046	AB	6	-0.0314	-0.0059	0.0216	-0.0687	0	
5	0.1857	B	7	0.0183	0.0439	0.0713	-0.0190	0.0497	0

a) years with the same letters do not statistically differ amongst themselves. b) contrast between means from +/- 0,08101 of limits.
* denotes a statistically significant difference.

The Tukey test (Table 8) shows that there were significant differences among the increment of the species (blocks) involved in the study. It is possible to graphically visualize the behavior of the increments (Figure 1) of the six broadleaved species separated, and the figure 2 these species are grouped to compare with *Araucaria angustifolia* conifer, by season and by year of observation. The presentation of the graphs is in decreasing order of increment values, and the years were also exchanged to facilitate comparison.

Table 8. The Tukey HSD Test ($p<0.05$) for comparing means increment (cm) between species.
Tabela 8. Teste de Tukey ($p<0,05$) para comparação dos incrementos médios (cm) entre as espécies.

Species	**Means**	**Ranked order**[a]
Prunus brasiliensis (Pr)	0.3836	A
Nectandra grandiflora (Ne)	0.3074	AB
Cinnamomum vesiculosum (Ci)	0.2881	BC
Ocotea porosa (Oc)	0.2358	BC
Campomanesia xanthocarpa (Ca)	0.2065	CD
Araucaria angustifolia (Ar)	0.1220	DE
Matayba elaeagnoides (Ma)	0.0802	E

Contrast[b]

Species	**Ar**	**Ne**	**Ca**	**Oc**	**Ma**	**Ci**	**Pr**
Ar	0						
Ne	-0.1852*	0					
Ca	-0.0843	0.1008*	0				
Oc	-0.1138*	0.0713	-0.0295	0			
Ma	0.0422	0.2273*	0.1265*	0.1560*	0		
Ci	-0.1660*	0.0192	-0.0817	-0.0522	-0.2082*	0	
Pr	-0.2612*	-0.0760	-0.1768*	-0.1473*	-0.3033*	-0.0952*	0

a) species with the same letters do not statistically differ amongst themselves. b) contrast between means from +/- 0,0908 of limits.
* denotes a statistically significant difference.

The diameter increment of *Prunus brasiliensis* is statistically larger, while *Matayba elaeagnoides* had smaller growth, and statistically different from the other species. As observed in figure 1, this species did not have a regular growth during the years of the study, being found that only two trees (of a total of 8) presented increments (Table 15). The others six trees did not have favorable conditions for growing: one dead tree, one with strong competition from neighbors and four in the senility phase.

Schaaf (2001), Durigan (1999), Pizatto (1999) and Figueiredo Filho *et al.* (2006) evaluated the periodic annual increment (PAI) in diameter of some species that compose the Ombrophyllous Mixed Forest. The first three authors worked with species from the same forest researched for this study, while Figueiredo Filho *et. al.* (2006) worked with data from the Ombrophyllous Mixed Forest located in the south center regions of the State of Parana. Table 9 presents the results obtained by these authors, and by this study.

The differences in increments observed among the studies mentioned in table 9 could have occurred due to several factors, such as, selected individuals, location (site and competition), different microclimate conditions, phase of tree growth, and phase of forest succession, among others.

Table 9. Periodic annual increment obtained by other authors and annual increment obtained in this study.
Tabela 9. Incremento periódico anual obtido por outros autores e incremento anual obtido nesta pesquisa.

Species	**Schaaf (79-98)**	**Durigan (97-98)**	**Pizatto (95-98)**	**Figueiredo Filho (03-05)**	**This research (99-05)**
Prunus brasiliensis	0.28	0.35	0.41	-	0.38
Nectandra grandiflora	0.31	0.33	0.26	0.14	0.31
Cinnamomum vesiculosum	0.31	0.34	0.37	-	0.29
Ocotea porosa	0.37	0.46	0.32	0.24	0.24
Campomanesia xanthocarpa	0.20	0.30	0.16	0.23	0.21
Araucaria angustifolia	0.32	0.42	0.24	0.36	0.12
Matayba elaeagnoides	0.17	-	0.16	-	0.08

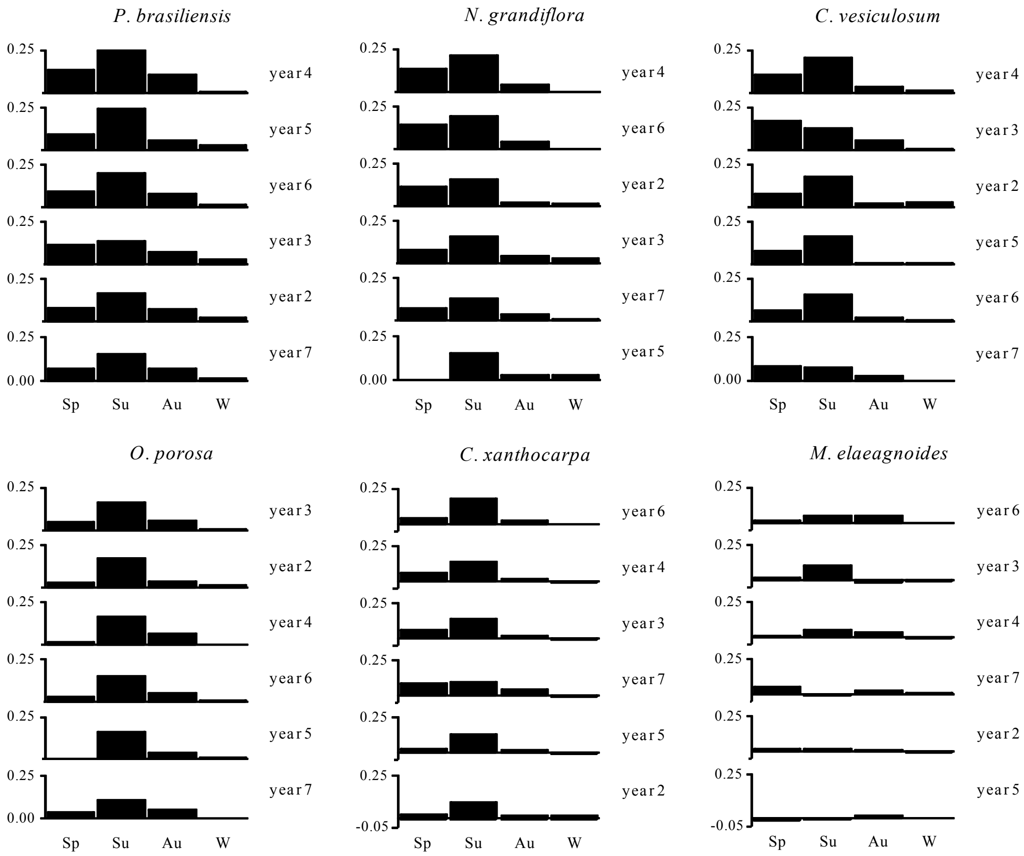

Figure 1. Seasonal and mean annual increment in diameter (cm) for each broadleaved species: (Sp) spring, (Su) summer, (Au) autumn and (W) winter.

Figura 1. Incremento médio anual e sazonal do diâmetro (cm) para cada espécie de folhosas: (Sp) primavera, (Su) verão, (Au) outono e (W) inverno.

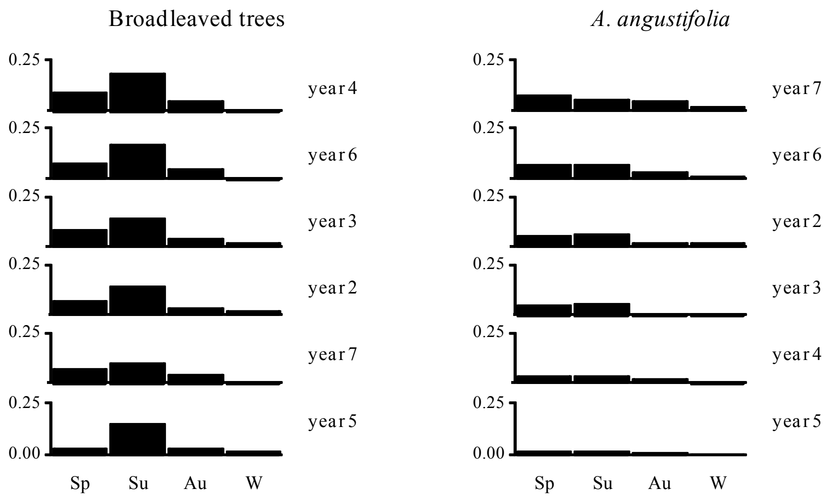

Figure 2. Seasonal and mean annual increment in diameter (cm) for the broadleaved group and the *Araucaria angustifolia* conifer: (Sp) spring, (Su) summer, (Au) autumn and (W) winter.

Figura 2. Incremento médio anual e sazonal do diâmetro (cm) para o grupo de folhosas e para *Araucaria angustifolia*: (Sp) primavera, (Su) verão, (Au) outono e (W) inverno.

Seasonal increment of the species studied

A Complete Randomized Block Design was carried out to test statistical differences among increments by seasons (treatments), using all species as blocks. The means by season did not include the first year of study (Table 2).

Firstly, the seasonal data of the species were used for the analysis instead of means for each season, but the Bartlett test showed that the variances were not homogeneous, in this case ($p<0.05$); and due to no or negative increments, it was not possible the transformation of the data. Finally, using the means of the seasons, the data were transformed to a logarithmic scale (naeperian base), thus homogenizing the variances ($p>0.05$) for treatments and for blocks.

Table 10 shows the variance analysis of the treatments (seasons). The *F* value indicated that differences exist among both treatments ($p<0.001$), and blocks ($p<0.01$), thus Tukey test was used (Table 11).

Table 10. ANOVA (RCBD) for seasonal diameter increment (cm).
Tabela 10. ANOVA para o incremento diamétrico sazonal (cm).

Source of variation	**df**	**SS**	**MS**	**F**	***p-value***
Treatment (1)	3	26.986	8.995	46.9733 ***	0.000
Block (2)	6	6.921	1.153	6.0236 **	0.001
Error	18	3.447	0.191	-	-
Total	27	37.354	-	-	-

df = degrees of freedom; SS = sum of squares; MS = mean square; F = Fisher value; *p-value* = probability value.
(1) = seasons; (2) = species; *** = $p<0.001$; ** = $p<0.01$.

Table 11. The Tukey HSD Test ($p<0.05$) for comparing mean increments (cm) between seasons.
Tabela 11. Teste de Tukey ($p<0,05$) para comparação do incremento médio (cm) entre as estações.

Seasons	**Means**	**Ranked order**[(a)]	**Contrast**[(b)]				
			Seasons	Spring	Summer	Autumn	Winter
Summer	0.1253	A	Spring	0			
Spring	0.0609	B	Summer	-0.7438*	0		
Autumn	0.0366	B	Autumn	0.4382	1.1820*	0	
Winter	0.0091	C	Winter	1.9506*	2.6944*	1.5124*	0

a) seasons with the same letters do not statistically differ amongst themselves. b) contrast between mean (logarithmic) from +/- 0,66255 of limits.* denotes a statistically significant difference.

This test revealed that the average increment in the summer is superior and different from those in the other seasons. The average increments in the spring and autumn are equals, while in the winter, besides presenting the smallest growth, it is statistically different from the growth rates in the other seasons. Homogeneity and standardization of increment are noticed (Figure 1), that is the tendency is the same for almost all species, that start to increase their growth rhythm in the spring, reaching their maximum growth in the summer, declining in the autumn, with practically no increment in the winter.

The values in table 12 show that the mean annual increment of the species in spring is 26%, rising to 53% in the summer, 17% in the autumn and falling to 4% in the winter. Classifying these data in decreasing order beginning with winter (Figure 3), it is observed that the *Araucaria angustifolia* is contributing more to the mean in the winter, while in the summer the inverse occurs, confirming the adaptation and development of this species in low temperatures.

Table 12. Rate of mean increment (%) for the species by season.
Tabela 12. Taxa do incremento médio (%) das espécies por estação.

Species	**Spring**	**Summer**	**Autumn**	**Winter**
Araucaria angustifolia	38.5	37.9	17.5	6.2
Prunus brasiliensis	25.6	49.7	19.6	5.1
Matayba elaeagnoides	20.7	47.1	27.3	5.0
Nectandra grandiflora	29.3	54.2	12.0	4.5
Cinnamomum vesiculosum	33.7	53.0	9.6	3.7
Ocotea porosa	11.2	65.0	21.0	2.7
Campomanesia xanthocarpa	24.6	63.0	11.4	1.0
Mean	**26**	**53**	**17**	**4**

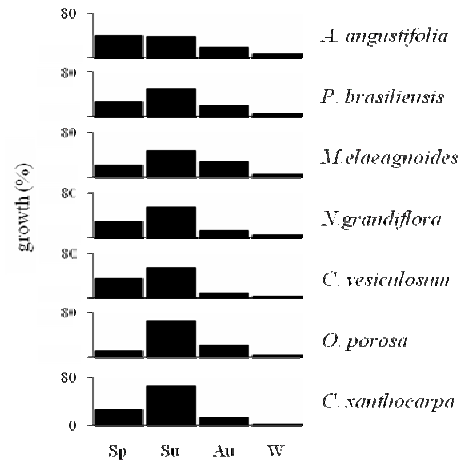

Figure 3. Rate of mean increment (%) for the species by seasons. (Sp) spring, (Su) summer, (Au) autumn and (W) winter.
Figura 3. Taxa do incremento médio (%) das espécies por estação. (Sp) primavera, (Su) verão, (Au) outono e (W) inverno.

Increment of *Araucaria* by DBH class

For evaluation of increments by diameter class (DBH) of the *Araucaria angustifolia*, ANOVA was also used. Diameter classes were considered as treatments, and years of studies as blocks. For treatments and blocks, the Bartlett test was significant with $p>0.01$ and $p>0.05$ respectively. The ANOVA (Table 13) indicated the existence of differences for treatments and for blocks ($p<0.001$).

Table 13. ANOVA (RCBD) for annual increment by diameter class (cm) of *Araucaria*.
Tabela 13. ANOVA do incremento anual por classes de diâmetro (cm) de *Araucaria*.

Source of variation	**df**	**SS**	**MS**	**F**	***p-value***
Treatment (1)	4	0.092	0.023	33.1691 ***	0.000
Block (2)	5	0.059	0.012	17.0307 ***	0.000
Error	20	0.014	0.001	-	
Total	29	0.165	-	-	

df = degrees of freedom; SS = sum of squares; MS = mean square; F = Fisher value; *p-value* = probability value.
(1) = class; (2) = years; *** = $p<0.001$.

The Tukey test (Table 14) revealed that *araucaria* diameter classes I and II have mean increments that are inferior and that statistically differ from the classes III, IV and V. Figure 4 shows the mean increments of *araucarias* by diameter class, by season and by year of observation.

Table 14. The Tukey HSD Test ($p<0.05$) for comparing mean annual increment (cm) between diameter class of *Araucaria*.
Tabela 14. Teste de Tukey ($p<0,05$) para comparação do incremento médio anual (cm) entre as classes de diâmetro de *Araucaria*.

Classes	**Means**	**Ranked order**(a)	**Contrast**(b) **Classes**	I	II	III	IV	V
Class IV	0.1821	A	I	0				
Class V	0.1322	B	II	-0.0520*	0			
Class III	0.1309	B	III	-0.1095*	-0.0575*	0		
Class II	0.0732	C	IV	-0.1610*	-0.1090*	-0.0515*	0	
Class I	0.0212	D	V	-0.1112*	-0.0592*	-0.0012	0.0498*	0

a) classes with the same letters do not statistically differ amongst themselves. b) contrast between mean from +/- 0,045397 of limits. * denotes a statistically significant difference.

Low increment rates are found for diameter classes I and II, and there are even negative increments, as a consequence of dominated position that these trees have in the forest, not having appropriate conditions for their development.

By observing the majority of DBH classes, it was found that the increment in the summer is similar to that one in the spring, different from that which occurred with the other species (broadleaved) that showed a very large increment in the summer (Figure 1 and 2).

It is important to mention that some trees can present regular growth for several measurements, and unexpectedly, some negative increments appear. This can occur even with the mean (Table 2). In general, this is related to the dilation or not of the bark, due to the degree of humidity at the moment of measurement or to the bark detachment, making the spring of the band contract (FRITTS, 1958).

Increment rate considering only the trees with positive growth

The analysis mentioned in previous items point out the growth of species in their natural environment of an Ombrophyllous Mixed Forest in an advanced phase of secondary succession, that is, the individuals are in intense competition, actively participating in the forest dynamic. In this item, an evaluation was undertaken based on the trees that presented positive growth in the period studied with the purpose of expressing a condition closer to that of an *Araucaria* Forest under a management regime.

With the increment data and the growth conditions of the trees surveyed in field, it was found that 41 of the trees sampled did not present an increment rate due to factors such as: low crown proportion in relation to the size of the tree, heliophyle species positioned in medium or inferior stratum, competing with other trees, or while even in good conditions in a senile phase of growth, leading to no increment.

Table 15 and figure 5 present the periodic increment of all trees studied and also of as well as those that presented positive growth for calculation of the percentage increment. An accentuated difference was observed in the increment rates (on average, 45% larger for the species studied) for the period when only those trees considered with conditions close to free growth were included.

Table 15. Annual increment (cm) and its increase in percentage for growing trees species.
Tabela 15. Incremento annual (cm) e seu aumento em porcentagem para as espécies em crescimento.

Species	All trees		Growing trees		Increase (%)
	Nº. trees	A.I.	Nº. trees	A.I.	
Prunus brasiliensis	10	0.384	9	0.426	11
Nectandra grandiflora	19	0.307	17	0.342	11
Cinnamomum vesiculosum	10	0.288	8	0.356	24
Ocotea porosa	9	0.236	6	0.345	46
Campomanesia xanthocarpa	12	0.206	8	0.302	46
Araucaria angustifolia	61	0.122	38	0.194	59
Matayba elaeagnoides	8	0.080	2	0.207	158
Total / weighted mean	129	0.195	88	0.282	45

It was expected that trees in forests under management have a superior growth than those growing in unmanaged forests and in competition. The results show that, instead of growing at a rate of 0.195 cm/year (in competition), trees in managed forests can grow at rates of 0.282 cm/year, varying from species to species.

Matayba elaeagnoides presented the most growth problems, because six trees did not grow due to the factors previously mentioned. *Araucaria angustifolia* had large number of trees without growth (23), of which 35% (8 trees) belong to the diameter class I, 22% (5 trees) to the class II, 22% (5 trees) to the class III, 13% (3 trees) in the class IV and 9% (2 trees) in the class V.

In the first three diameter classes (10 to 40 cm) all trees (18) are in the medium and inferior strata. For being light-demanding species in youth/adult phase, these trees presented low crown development and one case of a broken crown, as verified in the field.

For the other diameter classes (>40 cm), all of the trees are in the superior stratum presenting a normal and well developed crown, including the five trees that did not present development, probably because they were in a senile phase. Meanwhile, the trees of the species *Prunus brasiliensis* were in the medium stratum with one case of mortality, classified as broken.

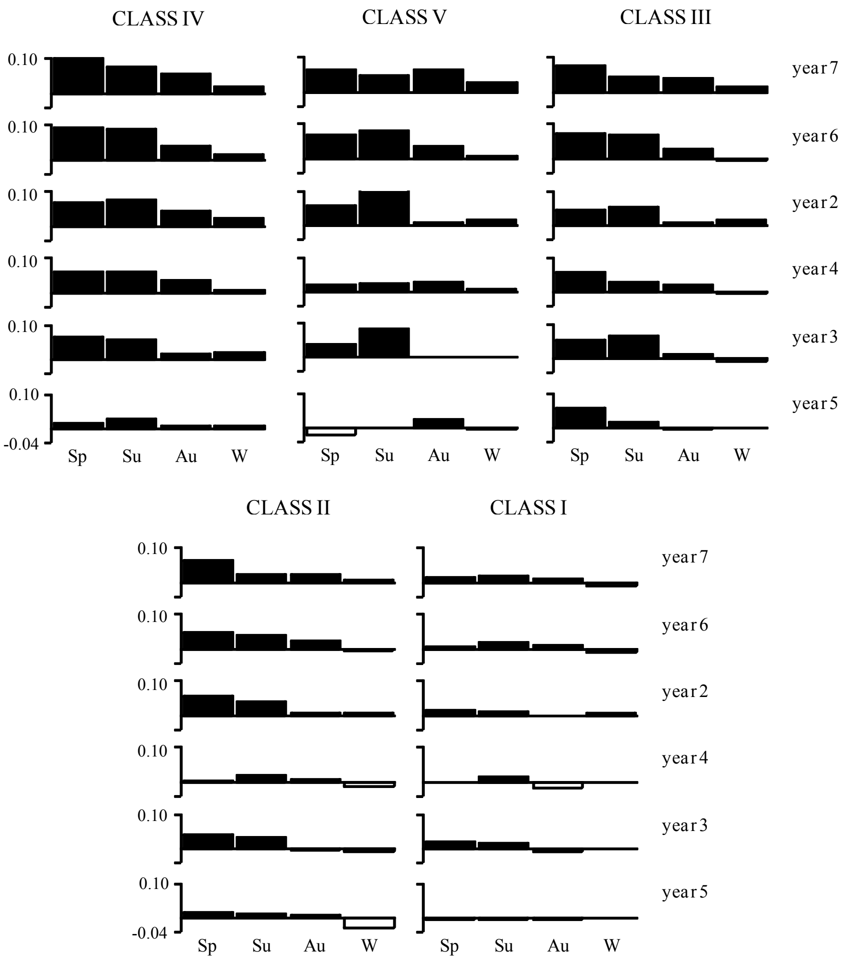

Figure 4. Seasonal and mean annual increment by diameter class (cm) for *Araucaria*: (Sp) spring, (Su) summer, (Au) autumn and (W) winter.

Figura 4. Incremento médio anual e sazonal por classes de diâmetro (cm) de *Araucaria*: (Sp) primavera, (Su) verão, (Au) outono e (W) inverno.

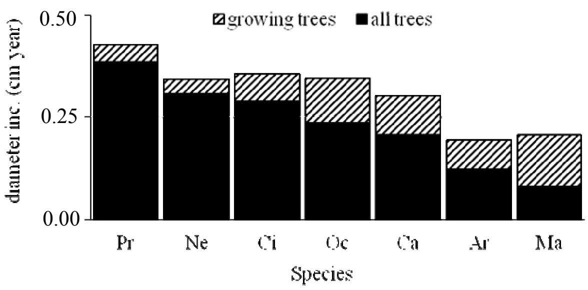

Figure 5. Annual increment (cm) by species for all trees and the group with positive growth. *(Pr) Prunus* sp.*, (Ne) Nectandra* sp.*, (Ci) Cinnamomun* sp.*, (Oc) Ocotea* sp.*, (Ca) Campomanesia* sp.*, (Ar) Araucaria* sp.*, and (Ma) Matayba* sp.

Figura 5. Incremento anual (cm) das espécies para todas as árvores e para o grupo de árvores com crescimento positivo. *(Pr) Prunus* sp.*, (Ne) Nectandra* sp.*, (Ci) Cinnamomun* sp.*, (Oc) Ocotea* sp.*, (Ca) Campomanesia* sp.*, (Ar) Araucaria* sp. e *(Ma) Matayba* sp.

Correlation of diameter increment with temperature and precipitation

The average temperature and precipitation by season during the years of this study are shown in table 16 and figure 6. In this case, data is intentionality presented for the first year for comparison. The simple linear correlation of temperature and precipitation with the seasonal increment is presented in table 17.

Table 16. Temperature and precipitation by season during the seven years studied.
Tabela 16. Temperatura e precipitação por estação durante os sete anos de estudos.

Year	Temperature (ºC)				Precipitation (mm)			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
1	17.7	20.5	15.0	14.4	400.8	407.0	317.8	260.6
2	16.5	20.2	16.2	13.1	331.8	439.8	149.0	381.6
3	18.6	21.6	18.4	14.4	258.4	537.0	249.2	296.4
4	18.4	20.8	18.5	14.5	231.6	429.0	228.6	342.0
5	19.1	21.5	16.4	14.7	374.8	514.0	193.6	142.6
6	18.2	19.8	15.5	14.8	292.0	391.8	338.2	192.2
7	18.0	20.5	17.5	14.9	439.6	340.0	359.2	403.6
Mean	**18.1**	**20.7**	**16.8**	**14.4**	**332.71**	**436.94**	**262.23**	**288.43**

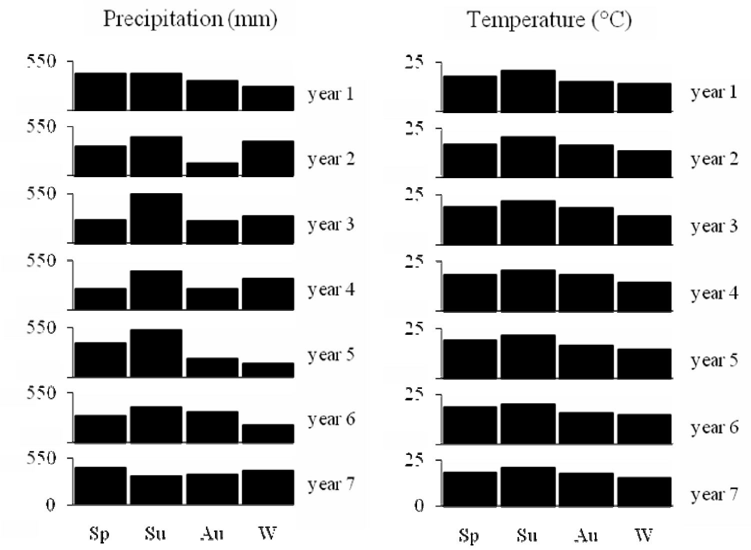

Figure 6. Temperature and precipitation by season during the seven years studied. (Sp) spring, (Su) summer, (Au) autumn and (W) winter.
Figura 6. Temperatura e precipitação por estação durante os sete anos de estudo. (Sp) primavera, (Su) verão, (Au) outono e (W) inverno.

Table 17. Simple linear correlation between increment of the species and climatic data.
Tabela 17. Correlação linear simples entre o incremento das espécies e os dados climáticos.

Species	Mean temperature (ºC)	Precipitation (mm)
Prunus brasiliensis	0.88	0.44
Cinnamomum vesiculosum	0.84	0.48
Ocotea porosa	0.84	0.62
Campomanesia xanthocarpa	0.82	0.60
Nectandra grandiflora	0.78	0.42
Araucaria angustifolia	0.59	0.38
Matayba elaeagnoides	0.28	0.46
Mean	**0.72**	**0.49**

It was found that the increment is more correlated with temperature (0.72) than with precipitation (0.49), however for the species *Matayba elaeagnoides* the correlation was very inferior to that for the other species. This can be the result of the reduced number (2) of growing trees used for calculation of the correlation, as already mentioned.

It can be seen in figure 6 that the temperature has a similar pattern to the increment, higher in the summer followed by spring, autumn and winter, not differing much between years, while precipitation, in some cases is higher in the summer, but in general it showed irregular variations during the seasons for the 7 years.

CONCLUSION

The measurements obtained with dendrometric bands in the first year can generate increments that aren't very accurate. Results from this study indicate a necessity of a period of at least 12 months for the adaptation of the bands, confirming other authors' conclusions.

Considering the 129 trees studied, the species that presented the highest annual rates of growth were *Prunus brasiliensis* (0.384 cm) and *Nectandra grandiflora* (0.307 cm). *Matayba elaeagnoides* had the smallest growth (0.08 cm) due to mortality problems, competition and growth stagnation;

The mean increment of the species in the spring was 26% of the annual rate, reaching 53% in the summer, 17% in the autumn and falling to 4% in the winter. The increment of *Araucaria angustifolia* is better distributed throughout the seasons, while the broadleaved increment is concentrated in the summer.

The mean of the annual increment for the seven species was 0.195 cm; being 0.262 cm for the six broadleaved and 0.122 cm for the *Araucaria*.

The diameter class I of *Araucaria angustifolia* (<20 cm) in the forest being studied did not present growth, due to the sociological position that was found, with dead trees and without crown development;

When considering only trees with positive growth in the period studied, in the analysis, that is, those trees with conditions close to free growth, an increment of 45% was observed (mean) in the diameter increment rate (PAI increased from 0.195 to 0.282 cm/year) for the 7 species;

The growth rate showed more correlation with the average temperature (r=0.72) than with the precipitation (r=0.49).

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