Cryptomeria japonica D. Don trees shoot biomass partitioning in a stand located in southeastern Paraná

Partição da biomassa aérea de árvores de *Cryptomeria japonica* D. Don em um povoamento localizado no sudeste do Paraná

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Abstract

The purpose of this study was to evaluate the partitioning of individual dry aboveground biomass in *Cryptomeria japonica* trees, as on its compartments as well as in the vertical profile, and examine whether the Pipe Model Theory, which states a rule between the plant organs, applies to the present case. Data were collected in a plantation established in 1984 in Rio Negro - PR. Twenty representative trees of the population distributed by diameter class were felled and weighed in the field, and their dry biomass were analyzed according to horizontal layers of 5 m wide in the following biomass compartments: sapwood, heartwood, bark, branches and foliage. Biomass is mostly composed by the stem (73.67%). In the wood, 41.66% of the biomass corresponds to sapwood, 26.66% to heartwood and 5.35% to bark. The canopy accounts for 26.33% of the dry biomass, which is represented at 13.75% by branches and 12.58% by foliage. In the first five meters tree biomass is comprised exclusively of wood and bark. From 5 m crown begins to have participation in biomass, becoming the major fraction from 15 m and above in the vertical profile. The partitioning of biomass in heartwood decreases along the vertical profile of the tree, i.e., it is largest at the base and smaller in the lower stratum. This study indicates that the Pipe Model Theory applies to the *Cryptomeria japonica* forest stand.

Additional keywords: bole; crown; heartwood; japanese cedar; sapwood.

Resumo

Este estudo objetivou avaliar a partição da biomassa aérea seca em árvores de *Cryptomeria japonica*, tanto em compartimentos como no perfil vertical, e examinar se a Teoria do Modelo do Cano (*Pipe Model Theory*), que estabelece uma regra de proporção entre os órgãos da planta, aplica-se ao caso. Os dados foram coletados em um plantio estabelecido em 1984, no município de Rio Negro – PR. Vinte árvores representativas do povoamento distribuídas por classe diamétrica foram derrubadas e pesadas em campo, e suas biomassas secas foram analisadas segundo camadas horizontais de 5 m de amplitude, nos compartimentos: alburno, cerne, casca, galhos e folhas. A biomassa é constituída principalmente pelo fuste (73,67%). No lenho, 41,66% da biomassa correspondem ao alburno, 26,66% ao cerne e 5,35% à casca. A copa compreende 26,33% da biomassa aérea seca, sendo representada por 13,75% de galhos e 12,58% pelas folhas. Nos primeiros cinco metros da árvore, a biomassa é constituída exclusivamente de lenho e casca. A partir de 5 m, a biomassa da copa começa a ter participação, vindo a ter maior fração a partir dos 15 m do perfil vertical do povoamento. A participação do cerne na biomassa decresce ao longo do perfil vertical das árvores, ou seja, é maior na base e menor nas porções mais altas. Este estudo indica que a Teoria do Modelo do Cano se aplica ao povoamento florestal de *Cryptomeria japonica*.

Palavras-chave adicionais: alburno; cedro-japonês; cerne; copa; fuste.

Introduction

Forest ecosystems represent about 80% of terrestrial biomass (Gardner & Mankin, 1981; Kindermann et al., 2008). Biomass is a term used to express the plant or animal matter mass amount, dead or alive (Silveira et al., 2008). The forest biomass term can mean all the existing biomass in the forest or only its tree fraction (Sanquetta, 2002).

Biomass distribution or partition between several tree or forest components, such as foliage, stems, roots, etc., is important to determine its potential

growth (leaves and fine roots), structural stability (stem and thick roots) and its products economic use (mainly the stem) (Landsberg & Sands, 2011). The relative biomass amount in several organs, also called biomass allocation, varies among species, age (time) and sites (Poorter et al., 2012).

Biomass partitioning models have been proposed in order to understand the allometric relation between the different tree parts and populations. Shinozaki et al. (1964) proposed the so-called Pipe Model Theory to describe biomass vertical distribution along an individual tree vertical profile, which, according to authors, also works for stands. This theory has been used by several authors (Waring et al., 1982; Chiba, 1998; Jelonek et al., 2008; Dean et al., 2013) to explain plants form and function in general, particularly of trees. However, there are few practical studies on tree species biomass vertical distribution (Gillespie et al., 1994; Telenius & Verwijst, 1995; Yen et al., 2013). In Brazil, this type of study is very recent, especially with conifer species.

Cryptomeria japonica, known as Japanese cedar, is a native of Japan's temperate region conifer and of part of China, where is one of the most commercially important species. In Brazil, it is planted on a small scale for decades, although having a recognized silviculture potential, particularly for high-quality timber production. In Brazil, the species has great growth in localities with temperatures between 12 and 14 ºC, with average annual rainfall above 2.000 mm (Alves et al., 1984). Capaldi (2002) highlights the rapid growth, especially in the early years, when it can be similar to species of great importance in Brazilian forestry, such as *Pinus taeda* (Dobner Júnior et al., 2013).

This study aims to analyze biomass partition into compartments (stem, branches and leaves) and in *Cryptomeria japonica* D. Don adult subject vertical profile, established in pure planting. It also aims to test whether the Pipe Model Theory, proposed by Shinozaki et al. (1964), which is widely employed in plant species studies, applies to describe biomass vertical distribution along the individual tree vertical profile.

Material and methods

Study area characterization

This study was developed in a *Cryptomeria japonica* stand implanted between February and April 1980, in Rio Negro Experimental Station, which belongs to the Federal University of Paraná. The station is located along the BR-116 highway, whose office is located about 5 km from the city of Rio Negro, State of Paraná. Planting implementation took place with 1.667 trees/hectare and spacing of 3 m x 2 m, with no commercial thinning being carried out in the area until assessment time. Further silvicultural population details are found in Shimizu & Maiochi (2007).

The region is located in the second Paraná plateau, in the southeast of the state, in latitude 26°06'

South and longitude 49°47' West, with an average altitude of 780 meters. According to Köppen classification, the climate is characterized as Cfb, with the warmest month mean temperature being below 22° C (Pereira, 2009). The historical rainfall for the study site is between 1.400 and 1.600 mm annually (Simepar, 2008 *apud* Pereira, 2009). The region soil was characterized by Shimizu & Maiochi (2007) as low fertility red-yellow Podzolic, with high aluminum content, high acidity and low phosphorus content. Site soil analysis details are found in Carvalho (2011).

Trees sampling and measurement

For this study, twenty dbh values in the amplitude distribution range were randomly selected within the diameter classes observed in the stand. Subsequently, individuals who represented the selected dbhs were found, therefore being stand representative trees when planting was carried out 30 years ago. Trees were measured at diameter at breast height (dbh), i.e., 1.30 m from the soil surface, using a mechanical caliper. Each tree total height was directly measured with tape after its chop down, performed with chainsaw.

Subsequently, the biomass weighing technique of 5 m horizontal layers was applied, according to tree profile, what is called stratified clipping technique (Sanquetta, 2002). Stem, branches and foliage biomass were compartmentalized in horizontal sections corresponding to vertical positions relative to the total tree height and determined with digital 0.1 kg precision scale. Three representative discs of each tree were collected, which corresponded to trees base, middle and top. Leaves and branches samples were also collected and taken to the laboratory for analysis.

Laboratory analysis and statistics

Samples were dried in an oven at 70 °C. Bark was removed from stem discs. The sapwood disk wood portion was also separated from that of the heartwood, with chisel and hammer, and magnifying glass observation. After drying, samples fresh biomass conversion to dry was performed for the studied compartments.

Biomass Expansion Factor (BEF) was calculated to the sampled trees, according to the methodology shown in Sanquetta et al. (2011).

$$\text{BEF} = \frac{P_{crown} + P_{stem}}{P_{stem}} = \frac{P_{shoot}}{P_{stem}}$$

Where:
BEF - Biomass expansion factor (dimensionless);
Pcrown - tree crown dry weight (g);
Pstem - tree stem dry weight (g);
Pshoot - tree stem dry weight + tree crown weight (g).

Biomass data for heartwood and sapwood, bark, branches and foliage compartments were organized into 5 sections of equal amplitude in relation to trees total height: <5m, 5 to 10 m, 10.1 to 15m, 15

to 20m, 20.1 to 25 m, greater than 25 m.

     Results were submitted to Kolmogorov--Smirnov's (D), Cramér-von Mises's (W2), Anderson-Darling's (A2), Kuiper's (V), Watson's (U2), Lilliefors' (D) and Shapiro-Wilk's (W) normality tests, which were available on ASSISTAT software. Individual tree biomass variance homogeneity analysis per section was also carried out through Bartlett's test for a value of α = 0.05.

     A regression equation was adjusted to estimate the individual dry above-soil biomass for twenty trees under study. The adjusted model was as follows:

$$\ln(b) = \beta_0 + \beta_1 \ln(dbh) + \beta_2 \ln(ht)$$

Where:
b - dry above-soil biomass (kg);
dbh - diameter at breast height (cm);
ht - total height (m);
β_0, β_1, β_2 - ordinary linear regression adjusted coefficients.

     Each model was defined in accordance with the adjusted determination coefficient ($R^2_{aj.}$) and estimate standard error in percentage ($Syx\%$) (Sanquetta et al., 2014). Based on individual estimates, the stand biomass stock was estimated.

     Pipe Model Theory application was graphically assessed. According to Shinozaki et al. (1964), the theory is based on the relation between foliar biomass (C (z)) and other organs corresponding cumulative series (F (z)) in each z horizontal layer along the tree vertical profile. C(z) and F(z) graphical analysis indicates the presence of two lines. One is oblique, showing proportionality between F(z) and C(z), and the other is horizontal, in the tree base, where there is no foliage.

Results and discussion

     Above-soil total biomass data used in this study showed normality, according to the statistical tests. Bartlett's test indicated individual biomass homogeneity variance by 5 m section.

     Diameter at breast height (dbh) and sampled trees mean total height were of 25.27 cm and 22.23 m, respectively. It was also noticed that, for dbh variable, distribution median was of 24.04cm, and mode was of 21.96 cm, indicating a slightly asymmetrical distribution. dbh minimum and maximum values were of 17.19 and 35.33 cm. The total height variable had 23.12 m median and 23.10 m mode, indicating symmetrical distribution, with minimum and maximum distribution values of 12.80 and 27.50 m, respectively (Table 1).

     The individual biomass equation adjusted for ordinary linear regression was: ln(b) = -1.8860 + + 2.2569 ln (dbh) + 0.8199 ln (ht), with satisfactory adjustment degree, with 0.8694 $R^2_{aj.}$ and 6.62% $S_{yx}\%$.

Table 1 – Breast height diameter and total height descriptive statistics of 20 *Cryptomeria japonica* trees planted in 1980, in Rio Negro municipality, Paraná state.

Variable	Mean	Minimum	Maximum	Standard Deviation	CV(%)	n
dbh (cm)	25.27	17.19	35.33	5.40	21.37	20
Total height (m)	22.23	12.80	27.50	3.57	16.05	20

     The 20 samples above-soil mean individual dry biomass was of 283.41 kg per tree, with 208.78 kg in the stem compartment (73.67% of the individual dry biomass), of which 118.06 kg corresponded to sapwood (26.66%), 75.55 kg to the heartwood (41.66%) and 15.17 kg to the bark (5.35%). Crown individual mean dry biomass was of 74.63 kg (i.e., with 26.33% individual dry biomass participation), with 35.66 kg of foliage (12.58%) and 38.97 kg of branches (13.75%) (Figure 1, Table 2).

Table 2 – Average above-soil biomass partitioning for 20 *Cryptomeria japonica* trees planted in 1984 in Rio Negro municipality, Paraná state.

Stem dry biomass (kg)				
Compartment	Mean	Standard Deviation	CV(%)	n
Sapwood	118.06	63.17	53.51	20
Hearwood	75.55	39.30	52.02	20
Bark	15.17	2.54	16.74	20
Stem	208.78	103.04	49.35	20
Crown dry biomass (kg)				
Foliage	35.66	62.87	176.30	20
Branches	38.97	52.36	134.36	20
Total dry biomass (kg)				
Total	283.41	147.87	52.18	20

     Based on crown and stem biomass values, BEF values were calculated, which ranged from 1.21 to 1.58, with mean of 1.37 and 8.32% coefficient of variation. BEF indicates stem biomass participation compared to the total above-soil biomass. It is customarily applied when there is tree volume

information (usually obtained through its relation with dbh and total height), and shoot biomass estimation is needed. With wood density information (relating mass over volume), it is possible to estimate tree stem biomass. Then, BEF mean value is applied for tree stem biomass expansion to shoot biomass.

BEF is one of the most employed variables in forest biomass and carbon inventories (IPCC, 2003, 2006). Cheng et al. (2013), studying *Cryptomeria japonica* biomass carbon accumulation in Taiwan, found a value of 1.50 for trees with 30 years old. For this age group, trees analyzed by the authors were thinner and lower than those of the present study: approximately 20 cm dbh and 18 m high. Lim et al. (2013) and Jung et al. (2014), while conducting related studies in South Korea, found values of 1.30 and 1.28 for the species in their studies, respectively.

Despite the large number of studies about the Japanese cedar wood, there are few studies highlighting differences between heartwood and sapwood (Yang et al., 1994; Carneiro et al., 2009; Pinto & Iwakiri, 2013). Heartwood is the highest value portion in the timber market, as it has favorable characteristics in several applications, such as higher basic density and a higher resistance against fungal attack. As it is developed in cone form into the sapwood, the heartwood is often not found at the tree top (Yang et al., 1994), a fact reported in *Pinus radiata* (Wilkes, 1991) and *Eucalyptus grandis* (Wilkins, 1991). Due to heartwood characteristic formation, the tendency is of sapwood developing lower biomass per volume unit in relation to the heartwood. In this study, heartwood specific basic mean was of 0.40, and sapwood was of 0.37 g cm^{-3}, what, despite the small difference in

density, as also depicted by Sanquetta et al. (2013), when multiplied by the respective volumes, resulted in a bit different and more inaccurate estimate than an average density for the whole wood, supporting the statement above. However, it is noted that in this study there was a higher biomass in the sapwood, considering that it represents higher volume compared to the heartwood, a fact explained by the higher volume amount proportionally than what is allocated at the heartwood compartment.

Regarding the mean vertical biomass partition, it was observed that in the first five meters high, biomass consists exclusively of wood, in which sapwood has the highest participation and bark the lowest percentage. In the tree base, heartwood participation in the wood fraction reaches about 40%, decreasing with height, being 26% at the highest portion (between 20 and 25 m). In the 5-10 m high stratum, the crown begins having a role in biomass, but in a lower percentage, with the wood providing a larger fraction, particularly sapwood. From then, crown participation grows, which is represented by branches and foliage. At 15 m, these fractions become dominant, reducing stem participation (Figure 2).

Taking the adjusted equation and the forest inventory data carried out at 30 years of age as basis, it was estimated that the above-soil biomass per hectare in the stand in question is of 237.80 t ha^{-1}. These values are comparable to pine and Araucaria stands, with close ages to those of this study, researched by Watzlawick (2003) in General Carneiro, PR. There are no comparable data for *C. japonica* in Brazil.
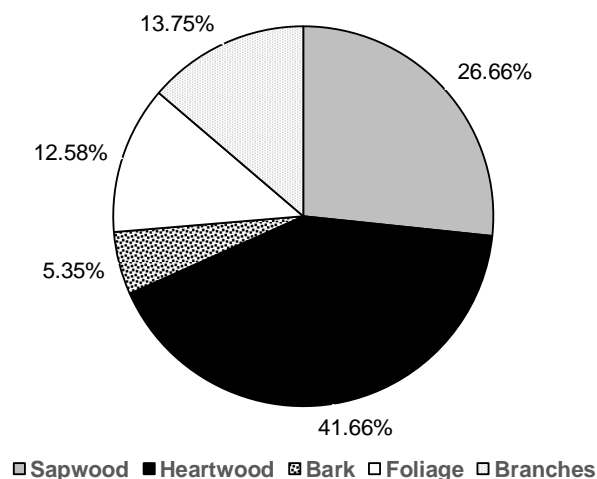

Figure 1 – Individual above-soil dry biomass partitioning per compartment in 20 *Cryptomeria japonica* trees planted in 1980 in Rio Negro municipality, Paraná state.

Regarding biomass mean vertical partition, for diameter classes of <20 cm, 20-25 cm and >25 cm, it was observed that in the first five meters high biomass

consisted exclusively of wood, in which sapwood has the majority participation, and bark appears in a lower percentage. At the tree base, heartwood participation in

the fraction is higher (Figure 2a), decreasing with height towards the highest part (between 15 and 20 m). In 5--10 m high stratum, the crown begins to have a share in biomass, but to a lower extent, with wood providing a larger fraction, particularly the sapwood. From then, crown participation, which is represented by branches and foliage. The largest wood share can be seen in

terms of biomass mean vertical partition in 20-25 cm and >25 cm diameter classes, where up to 25 m in height represent much of this portion (Figure 2b,c). It was noticed that, for the different diameter classes, biomass vertical distribution mean tendencies are similar, although changing such proportions magnitude.

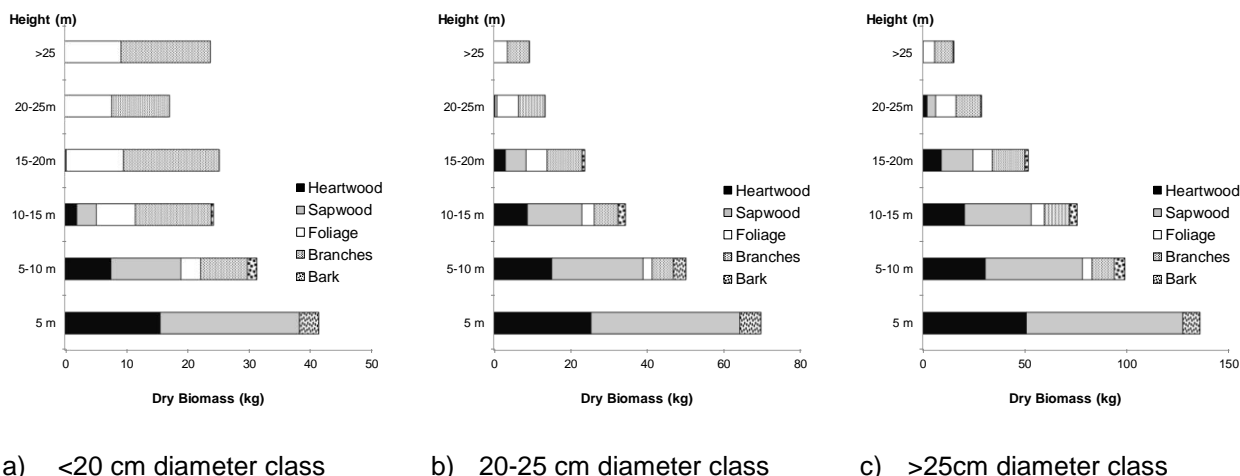a)   <20 cm diameter class   b)   20-25 cm diameter class   c)   >25cm diameter class

Figure 2 – Individual above-soil dry biomass vertical partitioning in 20 *Cryptomeria japonica* trees planted in 1980 in Rio Negro municipality, Paraná state.

The relation between C(z) and F(z) for this study data suggest the existence of two lines, an oblique and a horizontal, pointing out that the Pipe Model Theory applies to the case (Figure 3). In this theory, there is a direct relation between each leaf biomass portion and the corresponding non-foliar portion, like interconnected pipes (Shinozaki et al., 1964). It is what is perceived by observing two lines (pipes) that are directly connected from C(z) and F(z) points adjustment. In other words, for each leaf tissue

portion there is a corresponding stem portion. Authors also found that this relation is expressed by the oblique line on the tree top, which becomes the horizontal line on the bottom part, where there is no foliage. According to the authors, this due to heartwood formation, which consists of tissues that acquire the support function and lose the conduction function in the plant basal part, what is called *"disused pipes"*, or pipes that are not used by the plant for sap conduction purposes.
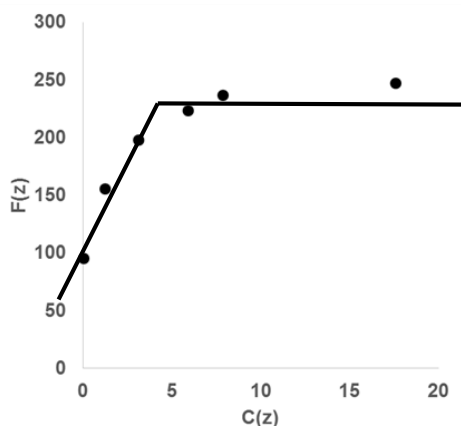

Figure 3 – Relation between biomass foliage (C(z)) and accumulated non-foliage biomass (F(z)) by horizontal stratum in 20 *Cryptomeria japonica* trees planted in 1980 in Rio Negro-PR.

Conclusions

Cryptomeria japonica major biomass fraction grown in pure stands condition is represented by the

stem and, in this compartment, the sapwood corresponds the highest percentage;

In the tree first five meters, biomass consists exclusively of wood and bark. From 5 m, crown biomass

starts to have a share, coming out to be the largest fraction from the 15 m vertical profile;

      There is a relation between foliage biomass and the stem and branches accumulated biomass, what indicates that the Pipe Model Theory applies to *Cryptomeria japonica* afforestation.

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