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Vertical distribution of aboveground biomass in a seasonal deciduous forest

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ABSTRACT

Knowledge of aboveground biomass stock in Seasonal Deciduous Forests is imperative for the implementation of mechanisms to reduce emissions from deforestation, forest degradation and land reclamation. The present study analyzed the vertical distribution of aboveground biomasses in a Seasonal Deciduous Forest in Rio Grande do Sul state, Brazil. Seven 12 x 12 m plots were established, and all trees inside the plots were weighed directly in the field. Subplots of 5 x 5 m and 1 x 1 m were marked within the main plots to quantify the remaining vegetation. Average dry aboveground biomass was 316.5 Mg ha^{-1}, trees with diameter at breast height (DBH) greater than 10 cm accounting for over 89% of this biomass. Therefore, biomass determination of large trees deserves special attention, since they represent a large part of the biomass of this forest ecosystem. Biomass of plants taller than 1.3 m and with diameter at breast height < 5 cm was 6.9 Mg ha^{-1}, and that of plants lower than 1.3 m was 1.5 Mg ha^{-1}. Average litter mass was 15.6 Mg ha^{-1}. Trees of large diameters must be analyzed very carefully for quantify the biomass and carbon in the forests, because few individuals might represent a large part of the biomass of a forest ecosystem.

Key words: Atlantic forest; carbon sequestration; forest biomass; litter; tree biomass

Distribuição vertical da biomassa acima do solo em floresta estacional decidual

RESUMO

É imprescindível o conhecimento do estoque de biomassa acima do solo em Florestas Estacionais Deciduais (FED) para a implementação de mecanismos de redução de emissões por desmatamento e degradação florestal e por recuperação de áreas degradadas. O presente estudo analisou a distribuição da biomassa acima do solo em FED no Rio Grande do Sul, Brasil. Foram instaladas parcelas de 12 x 12 m nas quais toda a vegetação arbórea foi pesada diretamente em campo. Subparcelas de 5 x 5 m e 1 x 1 m foram alocadas dentro das parcelas principais para quantificação da vegetação remanescente. A biomassa aérea total foi de 316,5 Mg ha^{-1}, árvores com o diâmetro à altura do peito (DAP) maior 10 cm representando mais de 89% dessa biomassa. Portanto, a determinação da biomassa das árvores grandes merece atenção especial, já que elas representam uma grande parte da biomassa deste ecossistema florestal. A biomassa das plantas com altura superior a 1,3 m e DAP < 5 cm foi de 6,9 Mg ha^{-1} e das plantas com altura inferior a 1,30 m foi de 1,5 Mg ha^{-1}. A biomassa média da serapilheira foi de 15,6 Mg ha^{-1}. Árvores de grandes diâmetros devem ser analisadas com muito cuidado para quantificar a biomassa e o carbono nas florestas, pois poucos indivíduos podem representar grande parte da biomassa de um ecossistema florestal.

Palavras-chave: Mata Atlântica; sequestro de carbono; biomassa florestal; serapilheira; biomassa arbórea

Introduction

The Atlantic forest was the second largest forest in Latin America, only smaller than the Amazon rainforest, covering almost 1,500,000 km^2 (Ribeiro et al., 2009; IBGE, 2012). In Brazil, the Atlantic forest occupied 1,315,460 km^2, and 48% of this area was composed of seasonal forests (SOS Mata Atlântica, 2017). Currently, less than 8% of the original area is still preserved, mostly in relatively small fragments (Ribeiro et al., 2009). In Rio Grande do Sul state, seasonal forests cover about 13,865 km^2, corresponding to 4.9% of the original area, and the Seasonal Deciduous Forests (SDF; IBGE, 2012) account for most of this area: 11,762 km^2 or 4.2% (SEMA/UFSM, 2001).

Despite the demand to quantify forest biomass accurately, there is still no consensus about the best methodology (direct and/or indirect) to estimate biomass in native forests (Gatto et al., 2011). In the direct (destructive) method, trees are felled and their components are separated and weighted. This method is time-consuming and costly, but it may provide accurate information about biomass (Sanquetta & Balbinot, 2004; Li & Xiao, 2007), although other authors, like Brown et al. (1989), claim that estimations generated from direct methods are usually unreliable since they are based on few small, tendentiously selected plots. Fearnside (1991) contested this criticism and observed that indirect methods (based on forest inventories) may be less biased, but there estimations fall short of the values obtained by direct methods.

Although several systematic studies on quantification and distribution of forest biomass have been conducted in Brazil in areas of tropical SDFs (Ribeiro et al., 2009; Amaro et al., 2013; Soares et al., 2016), studies on forest fragments are still needed, especially on the ones distributed in subtropical areas. There are few studies on forest biomass in the southern Brazilian states, such as those conducted by Watzlawick et al. (2012) and Vogel et al. (2013). It should be noted that these authors studied the distribution of biomass in up to two different strata. Watzlawick et al. (2012) subdivided the vegetation into two segments, trees with diameter at breast height (DBH) above and below 5 cm. Vogel et al. (2013) studied only one stratum in a SDF in the state of Rio Grande do Sul (trees with DBH greater than 3.2 cm), estimating biomass with allometric equations. There are no studies of the vertical distribution of aboveground biomass in SDFs which included herbaceous, shrub and arborous strata.

Considering this situation, the data about vertical distribution of biomass can contribute to knowledge on the characteristics of the ecosystem and can provide a basis for different types of approaches for quantify the biomass and carbon in the forests, and improve projects such as those reducing greenhouse gas emissions from deforestation and forest degradation (REDD) (Corte et al., 2012). The objective of this paper was to analyze the vertical distribution of the aboveground biomass stock and improve the methodology approach for subtropical forests.

Material and Methods

The study was developed in two fragments of a Seasonal Deciduous Forest (SDF) in the municipalities of Frederico Westphalen (27º23’44” South and 53º25’59” West, at an altitude of 520 to 550 m.a.s.l.), designated area 1, and Iraí (27º13’35” South and 53º18’59” West, 240 m.a.s.l.) at the confluence of Uruguay and the Várzea Rivers, designated area 2. All collection and processing of data were carried out from January to March 2011 in Frederico Westphalen and from May to July 2012 in Iraí.

The local climate, according to the Köppen classification, is humid subtropical (Cfb), with a balanced rainfall pattern, reduced in the winter season, averaging between 1,700 and 1,900 mm year^{-1}, and with an average annual temperature between 20 and 23 ºC (Rossato, 2014). The sites soils of Frederico Westphalen and Iraí are classified as red latosols and eutrophic regosols, respectively (Santos et al., 2013).

Seven sampling units (SU), composed of 12 x 12 m (144 m²) plots (Watzlawick et al., 2012), were established: three in area 1 and four in area 2. Two 5 m x 5 m (25 m²) and three 1 x 1 m (1 m²) subplots were established within each plot. All living small plants with total height lower than 1.3 m that was found in the 1 m^2 subplot were classified as Stratum 1 (S1) and cut at ground level. All plants with height greater than 1.3 m and diameter at breast height (DBH) < 5 cm in the 25 m² subplots were classified as Stratum 2 (S2). In the same subplots, all plants with DBH between 5 and 10 cm were classified as Stratum 3 (S3). The plants of both S2 and S3 were cut and separated into trunk plus branches (TB) and leaf (L) fractions. In the 144 m^2 plots all plants with DBH > 10 cm were classified as Stratum 4 (S4). These plants (trees) were cut and separated in six fractions: 1) trunk (T; considered until the height morphological inversion point - HMIP); 2) trunk bark (BK); 3) large branches (LB; ≥ 5 cm diameter); 4) small branches (SB; diameter ≤ 4,9 cm), 5) leaves; and 6) miscellaneous (MI), composed of lianas, epiphytes and all other types of plant material adhered to another plant. HMIP is morphometric when the individual has changed its trunk structure for crown (Hallé, 2010). In each of the same 144 m^2 plots, ten litter (LT) samples were randomly collected using a 0.25 x 0.25 m template. All the large plant material was weighed separately in the field with a Leader PR-30 dynamometer of 500 kg capacity (precision 100 g).

Samples of all plant fractions were collected for determination of moisture content. Leaves and large and small branches with different diameters were sampled in the upper, middle and bottom layers of the canopy. Discs were cut at half the height of the trunk and had their wood and bark separated, to obtain a bark factor for the trunk. All plant fraction samples, the S1 stratum plants and the litter samples were weighted and dried in a forced air circulation oven at 65° C to determine their dry biomass.

Plants in strata S2, S3 and S4 were taxonomically identified, adopting the botanical classification system of the Angiosperm Phylogeny Group (APG III, 2009) for angiosperms and the classification proposed by Christenhusz et al. (2011) for Gymnosperms. The scientific names of the species were checked from the List of Brazilian Plant Species 2014 (Forzza et al., 2010).

Data analysis used means and their standard errors, coefficients of variation and the confidence intervals for the means with a probability of error of 5%. All calculations were performed using the SAS software (SAS, 2000).

Results

The stratum of the largest plants (S4) was composed of a total of 66 trees, belonging to 34 species, the second size stratum (S3) had 38 trees of 14 species and the stratum of small trees and shrubs (S2) had 120 plants of 25 species (data not shown).

The total average stock of aboveground dry biomass of all strata was 371.1 Mg ha^{-1}, including the litter layer (CV 49.1%) (Table 1). S4 comprised most of this stock (330.5 Mg ha^{-1}; 89.1%), with decreasing stocks in S3 (15.7 Mg ha^{-1}), S2 (6.9 Mg ha^{-1}) and S1 (2.5 Mg ha^{-1}) and a stock of 15.6 Mg ha^{-1} in the litter layer.

The biomass in S4 was almost equally distributed into large branches (121.8 Mg ha^{-1}) and trunks (120.7 Mg ha^{-1}), with decreasing biomasses in small branches (37.8 Mg ha^{-1}), miscellaneous (27.3 Mg ha^{-1}), bark (14.9 Mg ha^{-1}) and leaves (8.0 Mg ha^{-1}).

Separating the trees in S4 into trunk diameter classes shows that biomasses in trunks and large branches increased proportionally more than those in small branches, trunk barks, leaves and miscellaneous (Figure 1).

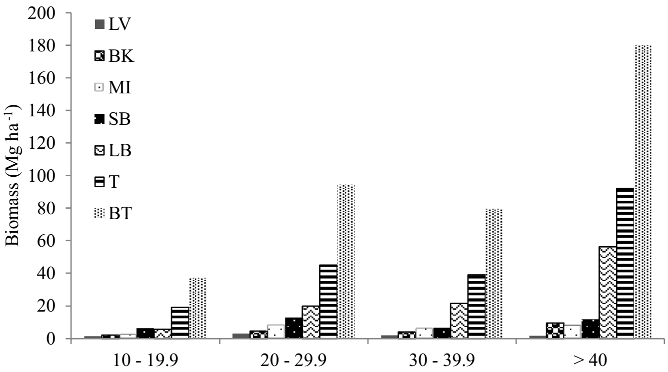

Figure 1. Total biomass and biomass per component, Trunk (T), Large Branches (LB), Small Branches (SB), bark (BK), leaves (LV), Miscellaneous (MI) and total biomass (BT) in each diameter class.

Discussion

The average total aboveground biomass of all seven sampling units (371.1 Mg ha^{-1}) was similar to that of an advanced successional stage of a Montana Mixed Ombrophilous Forest (Watzlawick et al., 2004), which totaled 397.8 Mg ha^{-1}, and it was higher than those of the initial and intermediate successional stages of the same forest, with 69.4 Mg ha^{-1} and 168.8 Mg ha^{-1}, respectively. A lower total biomass (170.0 Mg ha^{-1}) was reported by Socher et al. (2008) for an Alluvial Mixed Ombrophilous Forest, to which the wood contributed 52.84%, the large branches 35.19% and the small branches 5.12%.

The average biomass of all large and small branches (LB + SB) in the seven sampling units added to 43.0% (159.6 Mg ha^{-1}) of the total biomass, a proportion higher than those found by Brun et al. (2005) in a secondary (30.3%) and an initial seasonal deciduous forest (21.5%) also in Rio Grande do Sul state. In both studies, the branches were considered from height morphological inversion point - HMIP. Also considering the morphological inversion point, Watzlawick et al. (2012) found 45.0% of the total biomass allocated to branches.

These results show a trend of increasing biomass allocation to the branches along the development stage. Vogel et al. (2013) generated estimates of higher branch participation (48.8%; followed by trunk wood, 43.3%), in the total biomass of SDFs, adjusting from biomass equations. The continuous process of crown size increase to maximize light interception imposes the need for increased biomass support biomass (trunk structure). On the other hand, increase of the photosynthetically active component (crown) is also necessary. This leads to changes in proportions during tree development to maintain a positive balance between sources and drains (O'Brien et al., 1995).

In the present study, the biomass of miscellanous parts was 27.3 Mg ha^{-1}, about seven times higher than the biomass found in leaves (6.2 Mg ha^{-1}). They represent a large number of vines and lianas found mostly in the higher and thicker (dominant) trees. Some of this vine had diameters from 10 to 15 cm. Few studies have assessed biomass of vines and lianas, separately. Brun et al. (2005) found 14.6 and 7.8 Mg ha^{-1} in fragments of secondary SDF at early (33 years) and medium (53 years) succession stages. This demonstrates that this component

Table 1. Distribution of aboveground plant biomass in four vertical strata (S) and litter biomass (Mg ha^{-1}) in seven sampling units (SU) of Seasonal Deciduous Forest (SDF) in Frederico Westphalen (area 1) and Iraí (area 2) municipalities, Rio Grande do Sul, Brazil.

Area	SU	S4						S3		S2		S1	LT	Total
		T	LB	SB	LV	MI	BK	CG	LV	SB	LV			
1	1	192.6	185.5	70.9	16.3	40.1	13.9	19.6	1.6	4.1	0.8	4.5	13.8	563.7
	2	188.6	155.4	50.5	10.5	34.8	12.5	12.6	0.7	13.2	2.1	2.0	10.6	493.1
	3	153.6	158.4	58.6	18.3	39.6	11.7	3.0	0.5	4.9	0.7	1.2	12.7	463.3
2	4	26.3	30.8	9.5	2.1	24.3	7.4	17.7	1.1	3.5	0.7	3.2	13.5	139.9
	5	49.9	72.0	29.9	4.1	10.6	5.9	1.7	0.1	3.6	0.7	2.8	12.2	193.3
	6	92.7	38.3	13.7	3.2	8.5	11.4	21.1	1.5	4.9	0.6	2.2	10.4	208.3
	7	141.1	212.5	31.5	1.9	33.3	41.8	26.3	2.0	7.6	0.9	1.3	35.9	536.1
Means		**120.7**	**121.8**	**37.8**	**8.0**	**27.3**	**14.9**	**14.6**	**1.1**	**6.0**	**0.9**	**2.5**	**15.6**	**371.1**
SD		65.8	73.6	23.0	7.0	13.2	12.2	9.3	0.7	3.5	0.5	1.2	9.1	182.2
CV%		54.5	60.4	60.8	86.7	48.5	81.5	63.7	62.8	58.3	57.0	47.3	58.3	49.1
CI		120.7 ± 48.8	121.8 ± 54.5	37.8 ± 17.0	8.0 ± 5.2	27.3 ± 9.8	14.9 ± 9.0	14.6 ± 6.9	1.1 ± 0.5	6.0 ± 2.6	0.9 ± 0.4	2.5 ± 0.9	15.6 ± 6.7	371.1 ± 135.0
% of Total		32.5	32.8	10.2	2.2	7.4	4.0	3.9	0.3	1.6	0.2	0.7	4.2	100

S4 = trees with DBH greater than 10 cm; S3 = trees with DBH between 5 and 10 cm; S2 = plants with more than 1.3 m in height and DBH smaller than 5 cm; S4 = plants smaller than 1.3 m; T = trunk biomass; LB = large branches; SB = small branches; LV = leaves; MI = Miscellaneous; BK = bark; SB = stem and branches; LT = Litter; SD = standard deviation (Mg. ha^{-1}); CV% = percentage of coefficient of variation; CI = confidence interval with a 5% probability of error (Mg. ha^{-1})

cannot be disregarded in biomass studies, especially in SDFs. In addition, it indicates that measurements and estimates made with remote sensing techniques should pay attention to the importance of this material for crown tree spectral responses and in the different types of direct and inverse modeling. The shading effect of larger trees can significantly alter canopy spectral responses and interfere with estimates.

The average litter biomass in the seven units was 15.6 Mg ha^{-1}, higher than the average found by Watzlawick et al. (2012) in their study of three regeneration stages (8.01 Mg ha^{-1}) and the biomass reported by Socher et al. (2008) (4.36 Mg ha^{-1}), both in the Mixed Ombrophylous Forest.

The stratification method of above-ground biomass used in this work highlighted the importance of trees with DBH > 10 cm, which justified the detailed analysis of stratum S4, as well as the biomass determined for each one of its fractions. Selecting the largest tree of each of the seven sampling units, among all the 66 trees with DAP ≥ 10 cm, results in a biomass that represents approximately 48.0% of the total biomass, ranging from 27.6 to 82.2% in the different sampling units. When the three thickest trees of each unit are considered, these percentages increase to a range from 60.5% to 94.1% (Figure 2). This information indicates that strategic studies involving large regions or even an entire country should direct their efforts to the measurement of the large trees of the forest.

Some of these trees had hollowed trunks or their trunks were in the process of rotting from their core. Therefore, biomass estimates obtained from the ratio between basic wood density and trunk volume can result in significant errors. According to Machado & Figueiredo Filho (2003), studies about trunk forms should be conducted in "regular" trees, i.e., those with trunks compared to defined geometric figures. However, current biomass estimates need to consider all trees, regardless of species, sanity, genetics, age, etc. This challenging task creates the need for research on biomass evaluation techniques. Trunk irregularities, such as hollows and rotting, related to age and senescence (Muller-Landau, 2004), cause variations in the trunk bark biomass (BK) and in the real volume of the trunk. This source of error in the adjustment of allometric equations to estimate tree biomass must be the subject of future work.

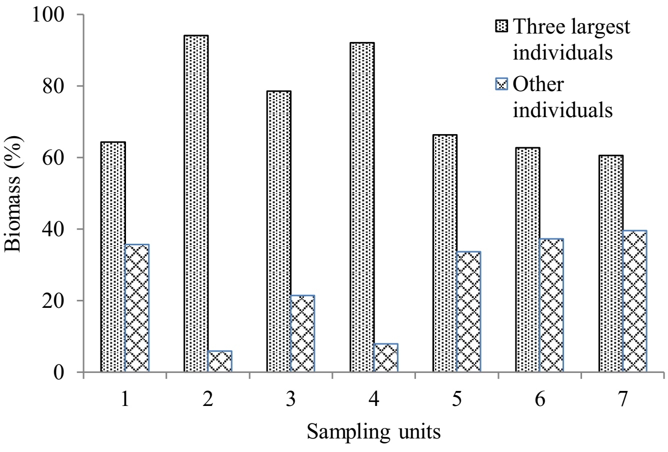

Figure 2. Proportion of the biomass of the three largest trees and of the remaining trees with DBH > 10 cm in relation to the total biomass in each sampling unit.

Sampling by destructive methods has been questioned by some authors (Silveira et al., 2008). Brown et al. (1989) stated that direct methods provide very controversial estimates, because their estimates are usually based on few and small sampling units. However, Fearnside (1991) disputes the criticism made by Brown et al. (1989), noting that although indirect methods are less biased their estimates are far short of all values already obtained through direct methods. The results of this work contribute to the understanding of this controversy, providing information on the distribution of the biomass stock, and consequently of carbon stocks, in subtropical forests. They show, for example, that large-diameter trees should be carefully analyzed, because few individuals may represent more than half of the biomass of the entire forest. In this study, the three largest trees of each sampling unit, combined, accounted for more than 60% of all the aboveground biomass (Figure 2) and very large trees are often those estimated with less precision by allometric equations (Brown et al., 1989).

Conclusions

The Seasonal Deciduous Forest stores 371.1 Mg ha-1 of aboveground biomass. The stratum constituted by trees with diameter at breast height (DBH) > 10 cm corresponds to more than 89% of this total aboveground biomass. Therefore, biomass determination of large trees deserves special attention, since they represent a large part of the biomass of the forest ecosystem. Large branches (32.8%) are the fractions with the largest stock of biomass, followed by trunk (32.5%), small branches (10.2%), miscellaneous parts (7.4%), bark (4.0%) and leaves (2.2%).

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Literature Cited

Amaro, M. A.; Soares, C. P. B.; Souza, A. L.; Leite, H. G.; Silva, G. F. Estoque volumétrico, de biomassa e de carbono em uma floresta estacional semidecidual em Viçosa, Minas Gerais. Revista Árvore, v.37, n.5, p.849-857, 2013. https://doi.org/10.1590/S0100-67622013000500007.

Angiosperm Phylogeny Group - APG III. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. Botanical Journal of the Linnean Society, v.161, p.105-121, 2009. https://doi.org/10.1111/j.1095-8339.2009.00996.x.

Brown, S.; Gillespie, A. J. R.; Lugo, A. E. Biomass estimation methods for tropical forests with applications to forest inventory data. Forest Science, v.35, n.4, p.881-902, 1989. https://www.researchgate.net/publication/233643575_Biomass_Estimation_Methods_for_Tropical_Forests_with_Applications_to_Forest_Inventory_Data. 25 Jan. 2015.

Brun, E. J.; Schumacher, M. V.; Corrêa, R. S.; Brun, F. G. K; Vaccaro, S. Variação sucessional no acúmulo de biomassa em Floresta Estacional Decidual, Santa Tereza-RS. Biomassa & Energia, v.2, n.1, p.47-56, 2005. http://www.renabio.org.br/05-B&E-v2-n1-2005-p47-56.pdf. 03 Jan. 2017.

Christenhusz, M. J. M.; Reveal, J. L.; Farjon, A.; Gardner, M. F.; Mill, R. R.; Chase, M. W. A new classification and linear sequence of extant Gymnosperms. Phytotaxa, v.19, p. 55-70, 2011. https://doi.org/10.11646/phytotaxa.19.1.3.

Corte, A. P. D.; Sanquetta, C. R.; Kirchner, F. F.; Rosot, N. C. Os projetos de redução de emissões do desmatamento e da degradação florestal (REDD). Floresta, v.42, n.1, p.177-188, 2012. https://doi.org/10.5380/rf.v42i1.26316.

Fearnside, P. M.; Greenhouse gas contributions from deforestation in Brazilian Amazonia. In: Levine, J. S. (Ed.) Global biomass burning: Atmospheric climatic and biospheric implications. Boston: MIT, 1991. p.92-105.

Forzza, R. C.; Baumgratz, J. F. A.; Bicudo, C. E. M.; Carvalho Jr., A. A.; Costa, A.; Costa, D. P.; Hopkins, M.; Leitman, P. M.; Lohmann, L. G.; Maia, L. C.; Martinelli, G.; Menezes, M.; Morim, M. P.; Nadruz Coelho, M. A.; Peixoto, A. L.; Pirani, J. R.; Prado, J.; Queiroz, L. P.; Souza, V. C.; Stehmann, J. R.; Sylvestre, L. S.; Walter, B. M. T.; Zappi, D. Catálogo de plantas e fungos do Brasil. Rio de Janeiro: Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, 2010. 2v, 1699p.

Gatto, A.; Barros, N. F.; Novais, R. F.; Silva, I. R.; Leite, H. G.; Villani, E. M. Estoque de carbono na biomassa de plantações de eucalipto na região centro-leste do estado de Minas Gerais. Revista Árvore, v.35, n.4, p.895-901, 2011. https://doi.org/10.1590/S0100- 67622011000500015.

Hallé, F. Arquitectura de los árboles. Boletín de la Sociedad Argentina de Botánica, v.45, n.3-4, p.405-418. 2010. http://www.scielo.org.ar/scielo.php?script=sci_arttext&pid=S1851-23722010000200017. 10 Dez. 2016.

Instituto Brasileiro de Geografia e Estatística - IBGE. Manual técnico da vegetação brasileira. Rio de Janeiro: IBGE, 2012. 271p. http://biblioteca.ibge.gov.br/visualizacao/livros/liv63011.pdf. 10 Dez. 2016.

Li, C.P..; Xiao, C.W. Above- and belowground biomass of Artemisia ordosica communities in three contrasting habitats of the Mu Us desert, northern China. Journal of Arid Environments, v.70, n.2, p.195-207, 2007. https://doi.org/10.1016/j.jaridenv.2006.12.017.

Machado, S. A.; Figuereido Filho, A. Dendrometria. Curitiba: UFPR, 2003. 309p.

Muller-Landau, H.C. Interspecific and Inter-site Variation in Wood Specific Gravity of Tropical Trees. Biotropica, v.36, n.1, p.20-32, 2004. https://doi.org/10.1111/j.1744-7429.2004.tb00292.x,

O'Brien, S.T., Hubbell, S.P., Spiro, P., Condit, P., Foster, R.B. Diameter, height, crown, and age relationship in eight neotropical tree species. Ecology, v.76, n.6, p.1926-1939, 1995. https://doi.org/10.2307/1940724.

Ribeiro, M. C.; Metzger, J. P.; Martensen, A. C.; Ponzoni, F. J.; Hirota, M. M. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation, v.142, n.6, p.1141-1153, 2009. http://dx.doi.org/10.1016/j.biocon.2009.02.021.

Rossato, M. S. Os climas do Rio Grande do Sul: Tendências e tipologias. In: Mendonça, F. (Org.). Os climas do Sul: Em tempos de mudanças climáticas globais. Jundiaí: Paco Editorial, 2014. p.217-271.

Sanquetta, C.R.; Balbinot, R. Métodos de determinação de biomassa florestal. In: Sanquetta, C. R.; Balbinot, R.; Ziliotto, M. A. B. Fixação de carbono: atualidades, projetos e pesquisas. Curitiba: Sanquetta, C. R.; Balbinot, R.; Ziliotto, M. A. B, 2004. p. 47-63.

Santos, H. G.; Jacomine, P. K. T.; Anjos, L. H. C.; Oliveira, V. A.; Lubreras, J. F.; Coelho, M. R.; Almeida, J. A.; Cunha, T. J. F.; Oliveira, J. B. Sistema brasileiro de classificação de solos. 3.ed. Brasília: Embrapa, 2013. 353p.

SAS Institute. SAS – Statistical Analysis System: Programa de computador, ambiente VM. Cary: SAS Institute, 2000.

Secretaria Estadual do Meio Ambiente – SEMA / Universidade Federal de Santa Maria - UFSM. Relatório final do inventário florestal contínuo do Rio Grande do Sul. Porto Alegre: SEMA/UFSM, 2001. http://coralx.ufsm.br/ifcrs/frame.htm. 22 Dez. 2016.

Silveira, P.; Koehler, H. S.; Sanquetta, C. R.; Arce, J. E. O estado da arte na estimativa de biomassa e carbono em formações florestais. Floresta, v.38, n.1, p.185-206, 2008. https://doi.org/10.5380/rf.v38i1.11038.

Soares, C. P. B.; Oliveira, M. L. R.; Martins, F. B.; Figueiredo, L. T. M. Equações para estimar estoque de carbono por hectare nos fustes das árvores de floresta estacional simidecidual. Ciência Florestal, v. 26, n. 2, p. 579-588, 2016. https://doi.org/10.5902/1980509822758.

Socher, L. G.; Roderjan, C. V; Galvão, F. Biomassa aérea de uma Floresta Ombrófila Mista Aluvial no município de Araucária (PR). Floresta, v.38, n.2, p.245-252, 2008. https://doi.org/10.5380/rf.v38i2.11619.

SOS Mata Atlântica. Florestas. A Mata Atlântica. https://www.sosma.org.br/nossa-causa/a-mata-atlantica. 03 Jan. 2017.

Vogel, H. L. M.; Schumacher, M. V.; Trüby, P. Biomassa e macronutrientes de uma Floresta Estacional Decidual em Itaara, RS, Brasil. Revista Árvore, v.37, n.1, p.99-105. 2013. https://doi.org/10.1590/S0100-67622013000100011.

Watzlawick, L. F.; Caldeira, M. V. W.; Viera, M.; Schumacher, M. V.; Godinho, T. O.; Balbinot, R. Estoque de biomassa e carbono na Floresta Ombrófila Mista Montana, Paraná. Scientia Forestalis, v.40, n.95, p.345-352, 2012. http://www.ipef.br/publicacoes/scientia/leitura.asp?Article=06&Number=95. 25 Out. 2016.

Watzlawick, L. F.; Kirchener, F. F.; Sanquetta, C. R.; Schumacher, M. V. Fixação de carbono em Floresta Ombrófila Mista em diferentes estágios de regeneração. In: Sanquetta, C. R.; Balbinot, R.; Ziliotto, M. A. B. (Eds.). Fixação de carbono: atualidades, projetos e pesquisas. Curitiba: Sanquetta, C. R.; Balbinot, R.; Ziliotto, M. A. B., 2004. p.153-173.