Floresta e Ambiente 2018; 25(1): e20160508
http://dx.doi.org/10.1590/2179-8087.050816
ISSN 2179-8087 (online)

Original Article

Silviculture

Biomass and Carbon in a Seasonal Semideciduous Forest in Minas Gerais

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ABSTRACT

The objective of the present study was to quantify the biomass and carbon stock in a Seasonal Semideciduous Forest remnant in southern Minas Gerais. Forest inventory data taken between 2010 and 2013 in permanent plots, was used to estimate biomass with an allometric equation. Basic wood density (Db) and carbon content were determined in the laboratory and the carbon stock was obtained by multiplying biomass by carbon content. The species with the lowest and highest Db were *Nectandra lanceolata* (0.38 g cm^{-3}) and *Machaerium villosum* (0.77 g cm^{-3}). The species that showed the lowest and highest carbon content values were *Casearia decandra* (41.85%) and *Nectandra oppositifolia* (46.57%). The biomass stock for the area was 126.92 ± 0.09 t ha^{-1}, which corresponded to 55.91 ± 0.05 t ha^{-1} of carbon stock and a periodic annual increment of 3.07 t ha^{-1} $year^{-1}$.

Keywords: carbon content, carbon stock, carbon increment, natural forests.

1. INTRODUCTION

Natural forest conservation is a strategy to mitigate global climate change (Sharma et al., 2013), as it increases the carbon stored in forest biomass and reduces the emission of greenhouse gases (GHG) into the atmosphere, which occurs either through deforestation or forest degradation (Lung & Espira, 2015). However, to assess the real contribution of forests to the removal of atmospheric carbon and the magnitude of GHG emissions in the case of deforestation, it is essential to quantify aboveground forest biomass and carbon stock (Gibbs et al., 2007).

In forest ecosystems, woody biomass and its carbon content determine the amount of carbon stored by vegetation (Conti & Díaz, 2013). Nonetheless, in natural forests there is great variation in the capacity of each species to accumulate biomass and store carbon, mainly due to the great diversity of species and the high variability between individuals of the same species (Baker et al., 2004). Therefore, biomass should be carefully evaluated in these forests, because stored carbon will be quantified based on this value (Brown, 1997).

Biomass in natural forests is commonly obtained via indirect methods, mainly using allometric equations, because obtaining biomass directly from felled trees (direct method) is difficult due to technical and legal issues. In general, the few published studies using the direct method are based on a small number of harvested individuals. Moreover, harvesting large trees is rare, therefore most of the equations generated from the direct method are not representative of the whole forest (Parresol, 1999; Chave et al., 2005).

The carbon stock is obtained by multiplying the biomass by the carbon content. Many studies have used the factor 0.5 proposed by the *Intergovernmental Panel on Climate Change* to make the conversion of biomass into carbon stock (Soares & Oliveira, 2002; IPCC, 2003; Houghton, 2005; Ribeiro et al., 2009; Almeida et al., 2010; Paiva et al., 2011; Souza & Fiorentin, 2013). However, the use of a generic value for carbon content can lead to erroneous estimates of the carbon stock, due to the great diversity of species and climatic and topographic conditions to which natural forests are subject.

Therefore, determining the carbon content by species is essential to obtain more accurate estimates of the carbon sequestration capacity of natural forests. Similarly, it is also important to obtain other key variables to determine forest biomass, such as basal area and basic wood density (Chave et al., 2005; Henry et al., 2010). These variables can support studies aiming to develop allometric equations to estimate forest biomass, since they increase the specificity of the biomass estimates by including intrinsic species data.

Several studies have sought to estimate carbon stock for different Brazilian forest typologies, with significant emphasis on the Amazon region (Souza et al., 2012a; Silva et al., 2014, 2015; Nogueira et al., 2015). However, little is known about the Atlantic Forest biome capacity to store carbon. In this biome, the physiognomy with the largest original distribution is the Seasonal Semideciduous Forest. It presents great floristic diversity and has been a constant target of deforestation, with only around 4% of its original forest cover remaining (Brasil, 2007). Despite its ecological importance, few studies have attempted to quantify the carbon stock in this physiognomy (Scolforo et al., 2008a; Ribeiro et al., 2009; Souza et al., 2012b; Amaro et al., 2013; Torres et al., 2013; Carvalho et al., 2014; Gaspar et al., 2014; Figueiredo et al., 2015).

Therefore, this study aimed to quantify the biomass and carbon stock in a Seasonal Semideciduous Forest remnant in southern Minas Gerais.

2. MATERIAL AND METHODS

2.1. Study area

This study was conducted in a forest remnant belonging to *Companhia Energética de Minas Gerais - CEMIG*, located upstream from the Camargos reservoir, on the right bank of Grande River, in Itutinga, Minas Gerais (Figure 1). The forest remnant has 1.2 hectares (21°19'25" S, 44°36'50" W) and covers a riparian area of Seasonal Semideciduous Forest with no record of recent anthropogenic intervention.

The natural vegetation of the study area is constituted by different forest formations, with a predominance of the seasonal semideciduous forest physiognomy (Scolforo et al., 2008b). The climate of the region is a transition between Cwa and Cwb, according to Köppen's

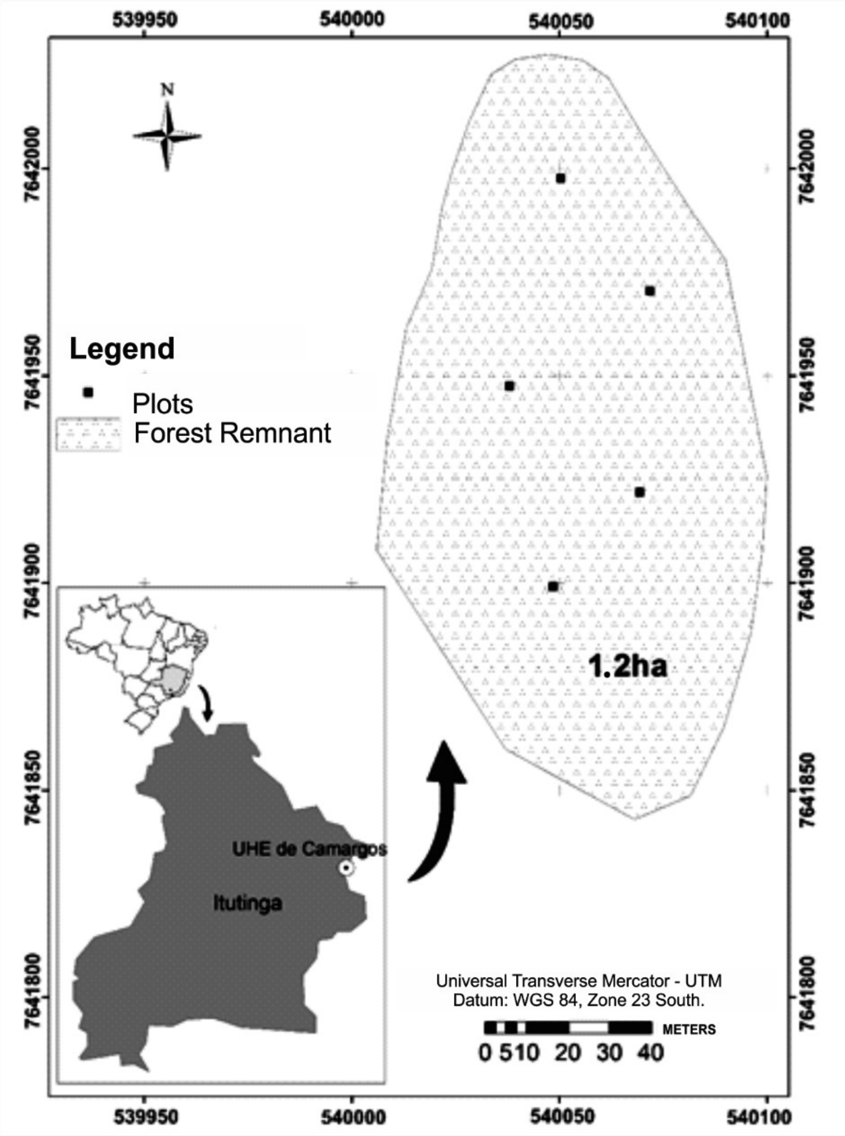

Figure 1. Forest remnant area around the Camargos reservoir, Itutinga, MG.

climate classification (Antunes, 1986). The average local altitude is 900 m; the average annual rainfall and temperature are 19.4 °C and 1529.7 mm, respectively, with a dry period from April to September. The dominant soil type in the study area is the Red Latosol.

2.2. Determination of biomass, basic wood density and carbon content

In 2010, a first forest inventory was conducted in five permanent plots of 20 m × 20 m established in the forest remnant. In each plot, all trees with a circumference at 1.30 m from the ground (CBH) ≥ 15 cm were recorded, identified botanically and had their total height and CBH measured. Trees with multiple stems had all the stems measured and the equivalent diameter calculated (Soares et al., 2011). In July 2013, a second forest inventory was conducted using the same criteria adopted in 2010. Subsequently, the parameters related to the horizontal structure (density, dominance, frequency and importance value) were estimated, according to Moro & Martins (2011).

Dry woody biomass of the tree stratum (DB) was estimated using Equation 1 (Scolforo et al., 2008c):

$$\ln(\mathrm{DB}) = -10.9532786932 + 2.5464820134 \times \ln(\mathrm{DBH}) + 0.4667754371 \times \ln(H) \quad (1)$$

$(\bar{R}^2 = 95.71;\ S_{yx} = 41.74\%)$

in which: DB = dry biomass (t ha^{-1}); DBH = diameter at 1.30m from the ground (cm); H = total height (m).

The horizontal structure (Value of Importance - VI and basal area) was used to determine the basic wood density and carbon content. Twenty species (about 40% of the total) of high ecological importance that contribute 87% of the total basal area of the site, were selected. The minimum number of trees sampled per species was proportional to the value of the relative density obtained from the forest inventory (Scolforo & Thiersch, 2004). The diameter distribution of the trees recorded in the forest inventory was used to select which individuals would be sampled, totaling 50 trees (15% of the total).

In the selected individuals, a 5 mm diameter bark sample (baguettes) was collected 1.30 m from the ground using an increment borer. The instrument was introduced into the trunk of the standing tree to a depth equal to half the diameter. The samples were then stored in plastic bags with water, which were kept in a Styrofoam box to avoid samples being damaged and moisture loss. Each bag was previously marked with the sample number and place and date of collection. After removing the sample, the lesion was sprinkled with Bordeaux syrup to prevent possible contamination of the tree by pathogens. Finally, a piece of wood was inserted into the hole made in the stem.

Basic wood density (WD, Equation 2) was determined in the laboratory for the bored species, by the ratio between dry biomass (DB) and its saturated volume (SV), which was obtained based on Archimedes' Principle. The basic wood density of each species was calculated by the arithmetic mean of the sample densities of the same species.

$$WD = \frac{Dry\ biomass\ (DB)}{Saturated\ volume\ (SV)} \quad (2)$$

in which: WD = basic wood density (g cm^{-3}); DB = dry biomass (g); SV = saturated volume (cm^3).

Wood samples were then packed in paper bags and oven dried at 103 ± 2°C until their dry weight was stabilized. After weighing, the oven dried material was ground, macerated using a pestle, sieved in 60-mesh sieve and the powder retained therein was properly stored and sent for carbon content analysis.

Carbon content was determined using subsamples (3 to 5 mg) packed in tin capsules, which were injected in a furnace at 950 °C for dry combustion in a Vario TOC Cube analyzer. The CO_2 gas emitted by each sample was quantified by an NDIR infrared detector and the carbon generated was related to the evaluated sample mass (mg). The carbon content of each sampled species was calculated by the arithmetic mean of the carbon content of the samples from the same species. For the species for which this information was not available, an average value obtained from the species sampled was used.

2.3. Estimation of carbon stock and increment

Total carbon stock was estimated multiplying the estimated biomass (DB; Equation 1) by the respective sample carbon content obtained in the laboratory. The carbon stock values obtained were extrapolated to the hectare.

Periodic annual carbon stock increment (PAIc) in the study area was also calculated for the periods of 2010 and 2013 (Equation 3).

$$\mathrm{PAIc} = \frac{C_{2013} - C_{2010}}{n} \quad (3)$$

in which: PAIc = periodic annual increment of the carbon stock (t ha^{-1}); C_{2013} = carbon stock (t ha^{-1}) in 2013; C_{2010} = carbon stock (t ha^{-1}) in 2010; n = measurement interval, in this case, 3 years.

PAIc in 2010 and 2013 were obtained according to Equation 4 (Scolforo et al., 2008d), since the carbon stock estimation obtained in 2010 was calculated using this equation (Faria, 2012).

$$\ln(C) = -12.3034390630 + 2.6584231780 \times \ln(\mathrm{DBH}) + 0.5711719721 \times \ln(H) \quad (4)$$

$(\bar{R}^2 = 97.25;\ S_{yx} = 36.40\%)$

in which: C = carbon stock (t ha^{-1}); DBH = diameter at 1.30 m from the ground (cm); H = total height (m).

3. RESULTS AND DISCUSSION

3.1. Characterization of the arboreal stratum

Based on the forest inventory in the Seasonal Semideciduous Forest remnant, 50 tree species were counted, belonging to 26 botanical families. The families with the highest number of species in the survey were Fabaceae (10), Lauraceae (6) and Myrtaceae (4). *Copaifera langsdorffii* (Fabaceae Caesalpinioideae) and *Tapirira obtusa* (Anacardiaceae) presented the highest importance values in the study area (Table 1). Oliveira & Ratter (2000) highlight that these species commonly occur in riparian areas and are considered generalists with a wide distribution.

The average density of individuals per hectare was 1,790 and the mean DBH and basal area values were 12.95cm and 31.85m^2 ha^{-1}, respectively. Other studies carried out on Seasonal Semideciduous Forest fragments (DAP ≥ 5 cm) in Minas Gerais found a basal area ranging from 22.92 to 31.03 m^2 ha^{-1} and density ranging from 322 to 1500 ind ha^{-1} (Vilela et al., 2000; Espírito-Santo et al., 2002; Souza et al., 2003; Scolforo et al., 2008e). Therefore, it seems that there is no uniformity between tree communities, which indicates that the Seasonal Semideciduous Forest fragments of the region can present striking structural differences (Souza et al., 2003).

The diametric distribution presented an inverted J-shaped curve, or negative exponential curve (Figure 2), in which 56% of individuals occur in the first class (5-10 cm). This distribution is characteristic of natural forests, where the frequency of individuals tends to decline with increasing diameter (Souza et al., 2012c; Lima & Leão, 2013; Calixto & Drumond, 2014).

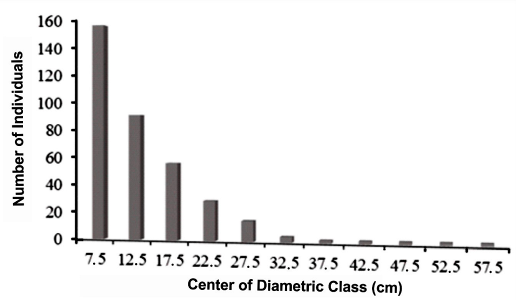

Figure 2. Diametric distribution of individuals sampled in the forest remnant area around the Camargos reservoir, Itutinga, MG.

Table 1. Phytosociological parameters and ecological group of the twenty species with the highest Importance Value in a forest remnant around the Camargos reservoir, Itutinga, MG.

Species	N	RD	RDo	RF	IV	G
Copaifera langsdorffii Desf.	102	28.49	34.06	0.05	62.60	2.17
Tapirira obtusa (Benth.) J.D.Mitch.	41	11.45	12.86	0.05	24.35	0.82
Cryptocarya aschersoniana Mez.	24	6.70	7.91	0.04	14.65	0.50
Protium heptaphyllum (Aubl.) Marchand	31	8.66	5.10	0.05	13.81	0.32
Peltophorum dubium (Spreng.) Taub.	8	2.24	3.21	0.04	5.48	0.20
Dalbergia nigra (Vell.) Allemão ex Benth.	8	2.24	2.51	0.04	4.78	0.16
Persea willdenowii Kosterm.	1	0.28	4.15	0.01	4.43	0.26
Lithraea molleoides (Vell.) Engl.	4	1.12	3.20	0.01	4.32	0.20
Nectandra lanceolata Nees	6	1.68	2.26	0.03	3.96	0.14
Nectandra oppositifolia Nees	6	1.68	1.91	0.02	3.60	0.12
Vismia brasiliensis Choisy	10	2.79	0.68	0.04	3.51	0.04
Protium warmingianum Marchand	8	2.24	1.23	0.05	3.51	0.08
Nectandra nitidula Nees	6	1.68	1.73	0.03	3.43	0.11
Casearia sylvestris Sw.	8	2.24	0.50	0.03	2.76	0.03
Guarea guidonia (L.) Sleumer	6	1.68	0.72	0.03	2.43	0.05
Casearia decandra Jacq.	7	1.96	0.29	0.03	2.28	0.02
Ormosia arborea (Vell.) Harms	4	1.12	1.11	0.02	2.25	0.07
Machaerium villosum Vogel	1	0.28	1.76	0.01	2.04	0.11
Myrcia venulosa DC.	5	1.40	0.56	0.02	1.97	0.04
Guazuma crinita Mart.	2	0.56	1.33	0.01	1.90	0.08

Note: N = number of individuals; RD = relative density (%); RDo = relative dominance (%); RF = relative frequency (%); IV = importance value (%); G = basal area (m^2).

3.2. Biomass, basic wood density and carbon content

Total biomass in the evaluated forest remnant was 126.92 ± 0.09 t ha^{-1}, corresponding to a carbon stock of 55.91 ± 0.05 t ha^{-1}. Basic wood density (Table 2) ranged from 0.38 g cm^{-3} (*Nectandra lanceolata* Nees) to 0.77 g cm^{-3} (*Machaerium villosum* Vogel). Basic wood density (WD) can vary between genera, between species of the same genus and between trees of the same species, besides variation due to edaphoclimatic factors (Latorraca & Albuquerque, 2000). This variation makes WD an important variable to be included in carbon stock prediction models, since it reflects environmental conditions (Chave et al., 2005; Williamson & Wiemann, 2010). Carbon content showed a variation between 41.85% (*Casearia decandra* Jacq) and 46.57% (*Nectandra oppositifolia* Nees). In a study conducted by Watzlawick et al. (2011) in a Mixed Ombrophilous Forest fragment, large stem carbon content variations were also found between species (39.45% to 44.12%). This highlights the importance of determining the carbon content for each species, regardless of the physiognomy to which it belongs. These determinations allow a more reliable estimation of the carbon stored in the forest biomass.

3.3. Carbon stock increment in 2010 and 2013

In this study, the periodic annual carbon stock increment (PAIc) was evaluated for all the species found in the remnant. The five species with the highest IPA_C were: *Copaifera langsdorffii* (7.75 t ha^{-1} year^{-1}), *Tapirira obtusa* (1.29 t ha^{-1} year^{-1}), *Dalbergia nigra* (1.22 t ha^{-1} year^{-1}), *Cryptocarya aschersoniana* (1.21 t ha^{-1} year^{-1}) and *Persea willdenowii* (1.03 t ha^{-1} year^{-1}). These species are among the ten most ecologically important species (Table 1) and made the greatest contribution to the IPA_C of the evaluated forest remnant.

Using the carbon stock increments in the period between 2010 and 2013, we obtained an IPA_C of 3.07 t ha^{-1} year^{-1}, considering all the species present in the remnant. Souza et al. (2011) evaluated the stock and growth in volume, biomass, carbon and carbon

Table 2. Mean values of basic wood density and carbon content of the twenty species sampled in a forest remnant around the Camargos reservoir, Itutinga, MG.

Species	Basic Wood Density (g cm^{-3})	Carbon Content (%)
Casearia decandra Jacq.	0.61	41.85
Casearia sylvestris Sw.	0.56	42.92
Copaifera langsdorffii Desf.	0.68	45.40
Cryptocarya aschersoniana Mez.	0.58	43.44
Dalbergia nigra (Vell.) Allemão ex Benth.	0.75	44.35
Guarea guidonia (L.) Sleumer	0.65	42.14
Guazuma crinita Mart.	0.48	43.77
Lithraea molleoides (Vell.) Engl.	0.69	44.20
Machaerium villosum Vogel	0.77	46.27
Myrcia venulosa DC.	0.64	44.80
Nectandra lanceolata Nees	0.38	42.51
Nectandra nitidula Nees	0.39	45.10
Nectandra oppositifolia Nees	0.53	46.57
Ormosia arborea (Vell.) Harms	0.70	43.40
Peltophorum dubium (Spreng.) Taub.	0.63	44.70
Persea willdenowii Kosterm.	0.60	46.15
Protium heptaphyllum (Aubl.) Marchand	0.52	43.39
Protium warmingianum Marchand	0.53	42.89
Tapirira obtusa (Benth.) J.D.Mitch.	0.47	43.66
Vismia brasiliensis Choisy	0.64	45.04
Mean (Standard Deviation)	0.59 (0.11)	44.13 (1.37)
Confidence interval	0.59 ± 0.05	44.13 ± 0.60

dioxide in a Seasonal Semideciduous Forest in Rio Doce Valley, Minas Gerais. In an advanced succession area, the authors found an IPA_C of 1.19 t ha^{-1} year^{-1} over a period of five years. Souza et al. (2012b) obtained an IPA_C of 0.77 t ha^{-1} year^{-1} (five-year period) in a seasonal semideciduous forest in advanced middle-stage succession in eastern Minas Gerais.

The variation in carbon increment values may be associated with the physiognomy in which the survey was carried out (Gaspar et al., 2016), since the composition of the tree community, disturbance history, successional stage, and climatic and edaphic conditions, influenced the carbon sequestration potential between different tropical forest areas (Ngo et al., 2013).

The determination of IPA_C in tropical forests is of utmost importance given the predictive capacity of this data. From the IPA_C, it is possible to estimate how much carbon will be stored in the forest biomass during a given period. Therefore, the generation of reliable biomass and carbon stock estimates and for their increments in different natural forest physiognomies is of paramount importance. These estimates can increase the quality of the databases and enable the generation of biomass and carbon growth and yield estimates, in addition to allowing a comparison between different studies.

4. CONCLUSIONS

In the Seasonal Semideciduous Forest remnant, a biomass stock of 126.92 ± 0.09 t ha^{-1} was estimated, corresponding to 55.91 ± 0.05 t ha^{-1} of carbon and an IPAc of 3.07 t ha^{-1} year^{-1}. These results indicate that the studied remnant positively contributed to forest carbon storage. This trend can be extended to forests with characteristics similar to those evaluated in the present study. Therefore, the information generated by this study supports the implementation of low carbon policies, since it makes it possible to predict the amount of carbon dioxide that could be emitted into the atmosphere by natural forests in cases of deforestation or fire.

SUBMISSION STATUS

Received: 8 dec., 2015
Accepted: 17 may, 2017

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