

INFLUENCE OF INTERSPECIFIC VARIATION ON TREE CARBON STOCK OF A BRAZILIAN CERRADO¹

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ABSTRACT – Cerrado is a biodiversity hotspot and possibly the most threatened tropical savanna in the world. Although Cerrado has an important role in the global carbon balance, studies about carbon stock in the biome are rare, especially with estimates per species. Thus, we estimated the carbon content and stock by species in a Cerrado area. We destructively sampled 120 trees from 18 species to determine tree aboveground biomass at a cerrado sensu stricto remnant. The carbon content in dry biomass was determined in laboratory and for the species not sampled an average value was used. The biomass of the remaining inventoried trees was estimated using an allometric equation. The carbon content in dry biomass had mean of $50.5 \pm 0.20\%$ and the carbon stock for the Cerrado remnant accounted for $22,385.46 \text{ kg ha}^{-1}$. Results indicated that some species had higher carbon stock than others. The number of individuals, their size and wood density are key points that need to be considered in the evaluation of carbon stock in forests with large number of species. Maintaining species that contribute to higher carbon stock is essential to keep a positive carbon balance in Cerrado areas

Keywords: Species diversity; Biomass; Carbon storage.

INFLUÊNCIA DA VARIAÇÃO INTERESPECÍFICA NO ESTOQUE DE CARBONO ARBÓREO DE UM CERRADO BRASILEIRO

RESUMO – O Cerrado é um hotspot de biodiversidade e possivelmente a savana tropical mais ameaçada do mundo. Apesar do Cerrado ter um importante papel no balanço de carbono global, estudos sobre o estoque de carbono neste bioma são raros, especialmente com a geração de estimativas por espécie. Dessa forma, neste estudo foi estimado o teor e estoque de carbono por espécie em uma área de Cerrado. Para isso, 120 árvores pertencentes a 18 espécies foram amostradas destrutivamente para se determinar a biomassa acima do solo em um fragmento de cerrado sensu stricto. O teor de carbono na biomassa seca foi determinado em laboratório e para as espécies que não foram amostradas foi usado um valor médio de teor de carbono. A biomassa das demais árvores inventariadas foi estimada usando-se uma equação alométrica. O teor de carbono médio na biomassa seca foi de $50,5 \pm 0,20\%$ e o estoque de carbono para o fragmento de Cerrado avaliado foi de $22.385,46 \text{ kg ha}^{-1}$. Os resultados indicam que algumas espécies tem um estoque de carbono maior que outras. O número de indivíduos, o tamanho e a densidade da madeira são pontos-chave que precisam ser considerados para a avaliação do estoque de carbono em florestas com grande número de espécies. A manutenção das espécies que contribuem com um alto estoque de carbono é essencial para manter um balanço de carbono positivo em áreas de Cerrado.

Palavras-Chave: Diversidade de espécies; Biomassa; Estoque de carbono.



1. INTRODUCTION

Forests are large carbon reservoirs that play an important role in the context of climate change. The capacity of trees to absorb carbon dioxide from the atmosphere and store it as biomass can mitigate global CO₂ emissions. However, disturbances such as fire or land use change alter forest structure and, therefore, forest carbon stock. This fact can be explained by interspecific differences in carbon storage. Considering identical biomass volumes, trees with high wood density store more carbon per unit volume than trees with lower wood density. Pioneer species tolerate a lower wood density than late-successional ones. Therefore, in a heterogeneous forest, species that occupy different ecological niches will complement each other comprising a total carbon stock that is usually higher than that of pure stands (Pretzsch, 2005; Jandl et al., 2007).

Forest carbon stock assessments are a way to detect interspecific differences in carbon storage. Based on data collected in forest inventories, the carbon stock is determined per species using direct (harvesting and weighing trees) or indirect measurements (biomass expansion factors or allometric equations). Understanding the role of each species in carbon storage is fundamental in the context of climate change, especially in managed forests. Forest management practices can balance the harvesting of species with high economic value and the maintenance of species that efficiently sequester and store carbon in biomass. This is one of the most cost-effective options to mitigate climate change (Intergovernmental Panel on Climate Change, 2007, 2014). However, because different species have distinct strategies to capture and store carbon, it is important to know which species are the major drivers of carbon storage in an area (Conti and Díaz, 2013). Studies that link tree species diversity with forest productivity (and therefore carbon stock) are more frequent in temperate and boreal forests (Caspersen and Pacala, 2001; Vilà et al., 2007; Paquette and Messier, 2011) than in highly diverse tropical forests (Cavanaugh et al., 2014). Moreover, most studies present productivity estimates by forest type and not by species. In savanna ecosystems this is also the case, as species-specific carbon stock data is scarce in the literature.

Savannas cover approximately 20% of the land area of terrestrial vegetation and are discontinuous landscapes formed by a prevailing grass layer and scattered trees (Gwenzi and Lefsky, 2014). In woodland

savannas, trees occur throughout the landscape and play an important role, as a keystone component for carbon sequestration and stocks in these ecosystems (San Jose et al., 1998; Tilman et al., 2000; Barbosa and Fearnside, 2004, 2005). Tropical savannas have a high species diversity when compared with temperate grassland and dry forests (Solbrig et al., 1996). Because 0.05 ha of tropical savanna may contain more than 30 different tree species (Ribeiro et al., 2011), including many endemic ones, it is a challenge to determine which tree species are more efficient in storing carbon as biomass. The Cerrado is a neotropical moist savanna located in central Brazil encompassing 204.7 million hectares, making it the largest savanna in South America (Silva and Bates, 2002). It is a biodiversity hotspot; however it is possibly most threatened tropical savanna in the world, with ~48.5% of its original cover cleared (Silva and Bates, 2002; Myers et al., 2000; Mittermeier et al., 2005; Sano et al., 2010). Despite the importance of Cerrado in the global carbon balance (Brasil, 2010), few studies have assessed carbon stock in Cerrado areas. Most of the published studies focus on biomass quantification (an extensive review is provided by Miranda et al., 2014) and the few that are dedicated to estimating Cerrado carbon stock have assumed that 50% of tree biomass is carbon (e.g. Grace et al., 2006; Rezende et al., 2006). To our knowledge, there is no published study that has quantified carbon stock by species in a Cerrado area using carbon content in dry biomass determined in the laboratory.

In this study we use biomass field data, allometric relationships and laboratory-determined carbon content to estimate the aboveground carbon stock by species in an area of Brazilian Cerrado. We address the following questions: (1) do Cerrado species have significantly different capacities to store carbon? (2) what are the key factors that determine carbon storage in Cerrado species?.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in a protected Cerrado remnant located in the municipality of Curvelo, in the state of Minas Gerais, in southeast of Brazil (18°48'39"S; 44°33'53"W). The 35 hectare fragment was located inside an area of Eucalyptus plantation owned by Plantar S/A, a privately owned pig-iron company.

Red latosols underlie the study area which has an elevation of about 600m. The average annual temperature in Curvelo is 23°C. The rainy season stretches from January to February, with a mean annual precipitation of 1200 mm.

The vegetation of the study site was classified as “cerrado sensu stricto típico” (cerrado s.s. hereafter) and is characterized by high species richness of shrubs and trees with 3-6 m in height. The tree cover is around 20-50% (Ribeiro and Walter, 1998). The studied cerrado s.s. comprises one of many Cerrado remnants in Curvelo, where anthropic interventions have occurred mainly in the past 4-5 decades for the establishment of cash-crop agriculture and eucalyptus monocultures (Klink and Machado, 2005). As result, the region is heavily fragmented, with scattered fragments in different stages of degradation. Despite this, the study site had no clear evidence of any recent human intervention.

2.2. Floristic and structure of the Cerrado remnant

The data were collected in October 2009 in ten 20 m x 25 m (0.05 ha) plots, systematically distributed along two transect lines. The distance between plots and between each plot and the border of the remnant was 200 m and 75 m, respectively. All living trees with diameter at breast height (DBH) > 5 cm were measured for diameter and height was visually estimated by experienced field crews in 0.5 m classes. All measured individuals were botanically identified by specialists. The confirmation of current scientific names and author’s abbreviations was performed through consultation (Jardim Botânico do Rio de Janeiro, 2014). The importance value (IV) was used as an indicator of the overall importance of each species in the community structure and was calculated as the average of the phytosociological parameters relative abundance (RA), relative frequency (RF) and relative prominence (basal area; RP; Moro and Martins, 2013).

2.3. Quantification of biomass and carbon stock

To estimate the carbon stock of the study site and of individual species we used previously collected samples of total above ground biomass (AGB) to estimate carbon stock; a detailed description of the methods used to collect these samples can be found in Ribeiro et al. (2011). Briefly, the aboveground biomass (bole + branches + leaves) was quantified by destructive sampling of 120 trees from 18 species. Bole, branches

and leaves were separately weighed in the field and samples of each tree component were oven dried to determine dry weight. We also determined basic wood density and determined carbon content in dry biomass of individual species. Samples of bole, branches and leaves were ground in a knife mill to pass through a 100 mesh sieve. The carbon content of the re-dried regrind samples was determined using a continuous-flow isotope ratio mass spectrometry (ANCA-GLS). Carbon stock per species was estimated multiplying dry weight by average carbon content per species.

The biomass of species that were not harvested was estimated using an allometric equation developed for the study area (Ribeiro et al., 2011).

$$\ln B = -3.3520 + 2.9853 \ln D + 1.1855 \ln WD$$

$$(R^2 = 0.898; \text{SEE} = 0.371; \text{CF} = 1.071)$$

where B = aboveground biomass in kg; D = diameter at breast height in cm and WD = wood density in g cm⁻³.

The wood density of the unharvested species was obtained in literature (Vale et al., 2002; Paula and Alves, 2007; Lorenzi, 2009; Zanne et al., 2009; Jati et al., 2014) and an average carbon content was calculated to estimate carbon stock using the mean values found for sampled species.

3. RESULTS

3.1. Floristic and carbon density of the dominant species in the Cerrado remnant

A total of 47 species were recorded, belonging to 40 genera and 29 families (Table 1). The best-represented families were Vochysiaceae (42.3% individuals), Erythroxylaceae (11.4%), Papilionoideae (5.6%), Malpighiaceae (4.5%), Caryocaraceae (3.7%) and Lythraceae (2.9%); two families were represented by only one species (Ochnaceae and Loganiaceae).

The 15 most common species accounted for approximately 78% of trees per hectare and ~41% of total carbon stock in the study area. A high importance value did not necessarily mean a high carbon stock for the most common species in the remnant.

3.2. Carbon storage

We determined the carbon content for the 18 species harvested in the study site. There was a slight difference

Table 1 – Carbon stock of the 15 species with highest importance values (in descending order of IV).
Tabela 1 – Estoque de carbono das 15 espécies com maior valor de importância (em ordem decrescente de IV).

Species	IV (%)	Basal area (m ² ha ⁻¹)	Carbon stock (kg ha ⁻¹)	% of the total carbon stock
<i>Qualea parviflora</i> Mart.	19.86	4.53	22.87	2.53
<i>Qualea grandiflora</i> Mart.	9.67	1.85	18.5	2.05
<i>Erythroxylum suberosum</i> A.St.-Hil.	7.32	1.07	9.7	1.07
<i>Caryocar brasiliense</i> Cambess.	5.29	1.42	154.76	17.12
<i>Eriotheca gracilipes</i> (K.Schum.) A.Robyns	3.25	0.54	23.67	2.62
<i>Lafoensia pacari</i> A.St.-Hil.	3.03	0.25	7.05	0.78
<i>Byrsonima coccolobifolia</i> Kunth	2.82	0.23	6.34	0.70
<i>Kielmeyera coriacea</i> Mart. & Zucc.	2.68	0.23	5.32	0.59
<i>Astronium fraxinifolium</i> Schott	2.64	0.21	8.7	0.96
<i>Acosmium</i> sp.	2.63	0.28	11.86	1.31
<i>Solanum</i> sp.	2.55	0.54	35.09	3.88
<i>Tachigali</i> sp.	2.26	0.33	32.28	3.57
<i>Piptocarpha rotundifolia</i> (Less.) Baker	2.22	0.15	5.11	0.57
<i>Acosmium dasycarpum</i> (Vogel) Yakovlev	2.15	0.19	14.02	1.55
<i>Terminalia argentea</i> Mart.	2.00	0.22	18.17	2.01
Other species in total (32 species)	29.63	2.88	530.52	58.69

among carbon content in dry biomass of leaves and bole+branches, but the mean carbon content of both tree compartments was similar (Table 2).

The tree carbon stock for the Cerrado study site was estimated to be 22,385.5 kg ha⁻¹ (SE% = 35.4%). The distribution of trees by 5 cm diameter classes revealed that 57.0% of carbon storage occurred in trees 40-45 cm DBH, while 25.5% and 17.5% was stored in trees 30-35 cm DBH and 25-30 cm DBH, respectively. There were no trees in 35-40 cm diameter class. However, when the number of trees per ha in each diameter class is contrasted with the average carbon storage, we realize the role of larger trees in determining the carbon storage in the area is very important (Figure 1).

3.3. Average carbon stock per species

We found that Cerrado species have different capacities to store carbon and this varies according to the number of individuals, their size and wood density. For example, *Caryocar brasiliense* had the highest relative contribution to carbon stock, while also having a high number of individuals per hectare (Figure 2). Further, only this species had individuals larger than 30 cm DBH. It had wood density of 0.61 g cm⁻³ and accounted for more than 80% of the carbon storage in the area.

Qualea grandiflora (262 trees ha⁻¹) and *Qualea parviflora* (526 trees ha⁻¹) are examples of species with

high number of trees per hectare, medium wood density and a low carbon stock. Together they accounted for almost 40% of all inventoried trees (*Q. grandiflora* – 12.6% and *Q. parviflora* – 25.2%). Nonetheless, their carbon stock (< 23 kg ha⁻¹) was among the lowest of the top ranked carbon storing species. On a smaller scale, this trend is also noticed for *Solanum* sp., *Tachigali* sp. and *Eriotheca gracilipes*.

Pouteria ramiflora and *Curatella americana* showed a great potential for carbon storage. Despite having low numbers of individuals (< 9 trees ha⁻¹), these species hold the second and third largest carbon stock in the area (*P. ramiflora* – 82.5 kg ha⁻¹ and *C. americana* – 48.5 kg ha⁻¹). *P. ramiflora* had trees equally distributed in small and medium size diameter classes (5-20 cm DBH), while 75% of *C. americana* trees were between 20 and 30 cm DBH. The wood density was 0.70 g cm⁻³ for *P. ramiflora* and 0.51 g cm⁻³ for *C. americana*. Other species presented carbon stocks relatively consistent with their abundance.

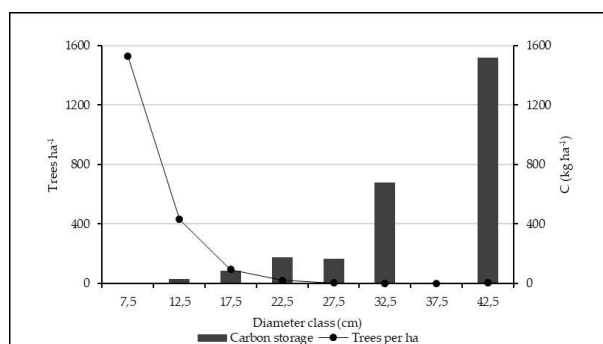
4. DISCUSSION

4.1. Carbon storage in the Cerrado remnant

The carbon content in dry biomass of 18 species of cerrado *sensu stricto* that are among the most common and widespread woody species for the Cerrado region was determined to be between 47.7% and 54.6% (Ratter et al., 2003; Table 2). Kauffman et al. (1994), Barbosa

Table 2 – Mean carbon content in dry biomass of leaves and bole+branches by species (only harvested species).**Tabela 2** – Teor de carbono médio na biomassa seca de folhas e tronco+galhos por espécie (apenas espécies abatidas).

Species	Carbon content (%)	
	Leaves	Wood
<i>Acosmium</i> sp.	49.0	50.2
<i>Astronium fraxinifolium</i> Schott	51.6	48.8
<i>Byrsonima coccolobifolia</i> Kunth	48.9	52.2
<i>Curatella americana</i> L.	47.7	49.2
<i>Eriotheca gracilipes</i> (K.Schum.) A.Robyns	49.2	47.9
<i>Erythroxylum suberosum</i> A.St.-Hil.	49.5	50.3
<i>Lafoensia pacari</i> A.St.-Hil.	50.2	51.9
<i>Piptocarpha rotundifolia</i> (Less.) Baker	53.1	52.8
<i>Plathymenia reticulata</i> Benth.	50.5	47.9
<i>Pouteria torta</i> (Mart.) Radlk.	52.7	50.7
<i>Pterodon emarginatus</i> Vogel	54.6	51.8
<i>Qualea grandiflora</i> Mart.	48.9	50.5
<i>Qualea parviflora</i> Mart.	48.1	49.3
<i>Tachigali</i> sp.	53.2	51.1
<i>Solanum</i> sp.	51.5	51.8
<i>Strychnos pseudoquina</i> A.St.-Hil.	47.8	51.0
<i>Stryphnodendron adstringens</i> (Mart.) Coville	54.3	53.3
<i>Terminalia argentea</i> Mart.	50.6	47.7
Mean ± CI ¹	50.6 ± 0.26	50.5 ± 0.20

¹ Confidence interval**Figure 1** – Average carbon storage and number of trees in a Cerrado remnant in Minas Gerais, Brazil.**Figura 1** – Estoque de carbono médio e número de árvores em um remanescente de Cerrado em Minas Gerais, Brasil.

and Fearnside (2005) and Scolforo et al. (2008) found a carbon content for cerrado s.s areas ranging from 46.1% to 52%, values that are comparable to the ones we found (47.7-54.6% – leaves; 47.7-50.5% – wood; Table 2). Nevertheless, none these studies showed species-specific carbon content values, but only an average value for the physiognomy.

We calculated the carbon stock for all the species registered in a Cerrado remnant and found that 15 species

accounted for ~41% of total carbon stock in the study area. This means that the remaining 32 species (59% of total carbon stock) had only a small amount of influence on the carbon stock of the Cerrado remnant, indicating the key role these 15 species play as primary contributors to carbon stock in the area. Similarly, the study by Lung and Espira (2015) pointed out that a select group of 10 species was the major contributors to aboveground biomass, hence affecting the local carbon stock variability. We also noticed that species with higher carbon stock did not necessarily have a high importance value (Table 1 and Figure 2a), i.e. a broad distribution and large size did not solely explain the influence of a species on the carbon stock of the Cerrado remnant.

With respect to size, the distribution of carbon stock in diameter size classes emphasized the importance of larger trees in composing the remnant's carbon stock. Despite trees with DBH > 40 cm representing only 0.2% of trees in the study area, they were responsible for more than half of carbon stock estimated in the study site. The influence of large trees in the forest biomass (and therefore carbon) is also reported in other studies (e.g. Kirby and Potvin, 2007; Slik et al., 2013; Sist et al., 2014).

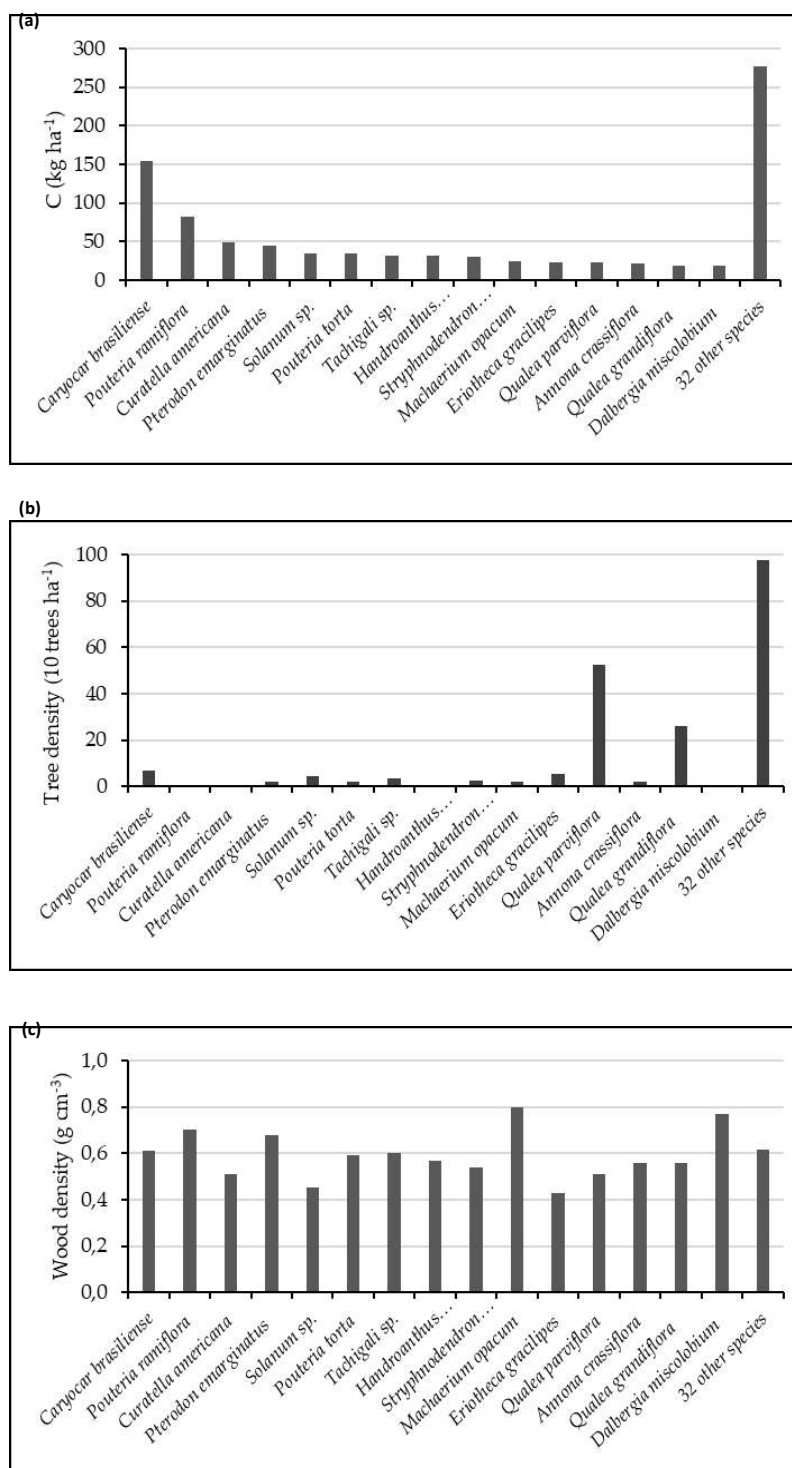


Figure 2 – Carbon stock (a), tree density (b) and wood density (c) of 15 top ranked carbon storing species.

Figura 2 – Estoque de carbono (a), densidade de árvores (b) e densidade da madeira (c) das 15 espécies com maior estoque de carbono.

4.2. Average carbon stock per species

We found that some species are able to more efficiently stock carbon than others, which strengthens the need for determination of carbon content in dry biomass per species in laboratory. The number of individuals, their size and wood density are key factors that determine carbon storage in the species sampled. For instance, *Caryocar brasiliense* had the highest carbon stock among all the species sampled. The presence of some large individuals (DBH > 30 cm) was a major factor contributing to the high carbon stock of this species, as the large trees accounted for 16.6% of total carbon stock in the area. Baker et al. (2004), Slik et al. (2010) and Cavanaugh et al. (2014) also found a positive relationship between higher diameters and aboveground carbon stock in tropical forests. Moreover, *C. brasiliense* wood density (0.61 g cm^{-3}) is above average for the study area (0.57 g cm^{-3}). This species is widely distributed in Cerrado areas and can have densities of up to 180 trees per hectare (Brandão and Gavilanes, 1992; Almeida et al., 1998).

Qualea grandiflora and *Qualea parviflora* also have a broad distribution in Cerrado vegetation (Ratter et al., 2003). However, in the study area most of individuals from these species were small (almost 90% had DBH < 15 cm) and had a medium wood density (*Q. grandiflora* – 0.56 g cm^{-3} and *Q. parviflora* – 0.51 g cm^{-3}), which led to lower carbon stock totals for both species.

Pouteria ramiflora and *Curatella americana* presented a high carbon stock despite having a low number of individuals (Table 1). In the case of both species, the presence of large trees is not solely enough to explain the carbon stock differences. Tree carbon stock may vary with site conditions (e.g. climate, soil) and species features, like growth pattern and wood density. For example, *Pouteria ramiflora* and *Curatella americana* have wood densities of 0.70 and 0.51 g cm^{-3} , respectively (Ribeiro et al., 2011). Therefore, in the case of *Pouteria ramiflora*, the high wood density plays a major role in defining carbon stock. *Curatella americana* has a wood density similar to *Qualea grandiflora* (0.56 g cm^{-3}) and *Q. parviflora* (0.51 g cm^{-3} ; Ribeiro et al., 2011), however higher diameter sizes compensated for lower numbers of these species.

Key factors that determined carbon storage in the species sampled included number of individuals, their size and wood density, nonetheless it is important to

consider forest age. Aboveground biomass and carbon stock are largely affected by tree age (Pregitzer and Euskirchen, 2004; Wei et al., 2013), which indicates the growing stage of a species and its potential to sequester and stock carbon in biomass (Dube and Mutanga, 2015). This means that if one species has a higher carbon stock than another, it may be that this species is older. We do not have any reliable information about the species age of the studied Cerrado remnant however, which hampers any attempt to make inferences regarding this issue. In the literature, studies that correlate biomass or carbon stock with age in Cerrado areas are also scarce, which calls for the development of further studies to fill this knowledge gap.

Considering our case study, we believe that the logging of some species will affect the carbon stock of the area. The selective logging of *Caryocar brasiliense*, for example, would deplete the carbon stock in the landscape. Fortunately, Brazilian legislation protects this species from unlawful harvest (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, 1996). However, species like *Pouteria ramiflora* and *Curatella americana* are less protected. The logging of these species would have a negative impact in the carbon balance of an area. Therefore, maintaining species that stock carbon more efficiently is essential to keep a positive carbon balance in Cerrado areas.

Nonetheless, more than 48% of Cerrado original cover has already been cleared for the establishment of agricultural and cattle ranching activities (Brannstrom et al., 2008; Brasil, 2011). In addition to illegal harvesting, climate change is also a threat to the Cerrado biome as elevated temperatures may lead to increased fire events reducing biomass and nutrients stock, in addition to diversity loss (Painel Brasileiro de Mudanças Climáticas, 2013). The growing emphasis on adaptation to climate change and the provision of ecosystem services highlight the need to shift Cerrado land use patterns before it is too late.

5. CONCLUSIONS

In this study, we investigated whether Cerrado species have different capacities to store carbon and which are the factors that determine carbon storage in those species. Our results have showed that 15 species play as primary contributors to carbon stock in the study area, indicating that some species are able to more efficiently stock carbon than others. The capacity

of each species to stock carbon will depend on the number of individuals, their size and wood density. Therefore, harvesting species that stock carbon efficiently may negatively affect the carbon balance of Cerrado areas.

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