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Artigos

Carbon stock and horizontal structure in riparian forest fragments

Estoque de carbono e estrutura horizontal em fragmentos de Mata Ciliar

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ABSTRACT

Research that aims to quantify the carbon stock in riparian forests underscores the environmental services of these forests to minimize the effects of climate change. The objective of this work was to i) quantify the carbon stock present in the above-ground biomass of the species present in areas of riparian forest and ii) rank species by the expanded importance value index (IVIA) in relation to a standard phytosociological analysis by the importance value index (IVI). The data used in the study were taken from an inventory conducted in areas of riparian vegetation in the southwestern region of the state of Goiás. The wood biomass of each tree was estimated for all species, with a later estimate of carbon stock (Mg.ha^{-1}) per hectare in the phytophysiognomy. The riparian forest has a high capacity to store carbon. Incorporation of this variable and ranking of species by the expanded importance index can be a reason to conserve and preserve riparian forests, as well as a criterion in the choice of species with greater potential to stock carbon for the recovery of degraded areas.

Keywords: Carbon sequestration; Above-ground biomass; Cerrado; Riparian forests

RESUMO

Pesquisas que quantificam o estoque de carbono em matas ciliares destacam-se pela apresentação de serviços ambientais que essas florestas oferecem e assim minimizam os efeitos das mudanças climáticas. Objetivou-se com a realização deste trabalho: i) quantificar o estoque de carbono presente na biomassa acima do solo das espécies presentes em áreas de mata ciliar; ii) ranquear as espécies pelo índice de valor de importância ampliado (IVIA) em relação à análise fitossociológica padrão, pelo índice de valor de importância (IVI). Os dados utilizados no estudo foram obtidos a partir de um inventário realizado em áreas de vegetação ripária, região sudoeste do estado de Goiás. Estimou-se a biomassa da madeira de cada árvore para todas as espécies e posteriormente a estimativa de estoque de carbono ($Mg.ha^{-1}$) por hectare na fitofisionomia. A mata ciliar possui alta capacidade de estocar carbono e a incorporação dessa variável e o ranqueamento das espécies pelo índice de importância ampliado pode ser utilizado como razão para conservação e preservação das matas ciliares, bem como um critério na escolha de espécies com maior potencial de estoque de carbono para recuperação de áreas degradadas.

Palavras-chave: Sequestro de carbono; Biomassa acima do solo; Cerrado; Florestas ripárias

1 INTRODUCTION

Forests are one of the main sinks of atmospheric carbon (CO_2), one of the main greenhouse gases (GHG). Tropical forests maintain large above-ground carbon (AGB) reserves, exceeding 200 x 10^9 Mg C (Saatchi; Harris; Brown; Lefsky; Mitchard; Salas; Zutta; Buermann; Lewis; Hagen; Petrova; White; Silman; Morel, 2011; Baccini; Goetz; Walker; Laporte; Sun; Sulla-Menashe; Hackler; Beck; Dubayah; Friedl; Samanta; Houghton, 2012). Considering the above and below-ground carbon estimates, the total exceeds 500 x 10^9 Mg C (Houghton; Byers; Nassikas, 2015). Brazilian tropical forests alone are estimated to maintain a stock of 53.2 x 10^9 Mg C above the ground (Baccini; Goetz; Walker; Laporte; Sun; Sulla-Menashe; Hackler; Beck; Dubayah; Friedl; Samanta; Houghton, 2012). However, deforestation and forest degradation in tropical regions emit between 1 and 2 x 10^9 Mg $C.year^{-1}$ (Houghton; Byers; Nassikas, 2015), which causes great concern and puts Brazil in a central position for emission reduction programs due to deforestation and forest degradation (Corte; Sanquetta; Kirchner; Rosot, 2012).

The quantification of carbon stock is important to promote actions to mitigate the effects of climate change and must be carried out in several phytophysiognomies to understand the dynamics of C in a wide and accurate way. Preserving the Cerrado is very important, as it is the second-largest Brazilian biome in extent, and 48% of the area is deforested (Inpe, 2018). Despite its importance, studies that estimate the biomass and quantify the carbon concentration of the biome are still required. In the Cerrado Biome, the phytophysiognomies are distributed in forest, savanna, and grassland formations (Ribeiro; Walter, 2008).

In forest formations, riparian forests stand out as a phytophysiognomy associated with watercourses and have different widths, floristic compositions, and structures. These forests are important and protected by Brazilian legislation as permanent preservation areas (app), as they are fundamental to maintain water resources, soil, and biodiversity (Brasil, 2012). Furthermore, due to climate change, studies are required to highlight the potential carbon sinks of riparian forests (Melo; Durigan, 2006).

In recent studies that estimated the biomass and carbon of individual trees in riparian forests in the Cerrado, Melo and Durigan (2006) found 99 $Mg.ha^{-1}$ of biomass above ground and 50 $Mg.ha^{-1}$ of carbon. Nunes, Terra, Oliveira and Van Den Berg (2018), studying a fragment of riparian forest in southern Minas Gerais, found that carbon stocks increased by 70% in the areas near the stream, ranging on average from 44.4 $Mg.ha^{-1}$ at the edges of the forest to 75.3 $Mg.ha^{-1}$ in the areas along the stream. However, little information about biomass and carbon stock is available at the family and species level. Therefore, studies are needed to support better strategies to recover degraded areas and projects to Reduce Emissions from Deforestation and Forest Degradation (REDD+).

Thus, the objective of this work was to i) quantify the carbon stock present in the above-ground biomass of species present in riparian forest areas in the state of Goiás; ii) rank the species by the expanded importance value index (IVIA) in relation to the standard phytosociological analysis using the importance value index (IVI).

2 MATERIALS AND METHODS

2.1 Study and sampling area

The study area is located near the Verdão River, which is in the Paranaíba River Basin, in the municipality of Santa Helena de Goiás, in the southwestern region of the state of Goiás, at geographical coordinates latitude 17º45'05.4" S and longitude 50º27'05.3" W. The studied area has fragments of intact vegetation and fragments in restoration process due to previous anthropogenic degradation, which have been stopped because of the law regulation, since they are located in a Permanent Preservation Area (APP).

The altitude of the region is 584 m, and the climatic type is Aw, characterized by a rainy season in summer and a dry season in winter. The average annual temperature is between 22 and 24°C, and the average annual rainfall is 1600 to 1900 mm (Alvares; Stape; Sentelhas; Gonçalves; Sparovek, 2013). According to the Brazilian Soil Classification System (Embrapa, 2018), the soil is the Red-Yellow Latosol. According to Ribeiro and Walter (2008), the vegetation of the study area is characterized as riparian forest. The forest vegetation accompanies the medium-sized rivers of the Cerrado region, in which the arboreal vegetation does not form galleries.

Fourteen sections of 2000 m^2 were plotted for sampling the shrub-tree stratum, totaling 2.8 hectares of sample area in a total area of 64.5 ha of riparian forest. The plots were distributed systematically in a rectangular grid of 20 m x 100 m. All individuals with a diameter 1.3 m from the ground (DBH) greater than or equal to 5 cm were identified. Their respective DBH was measured by a caliper, and their height was visually estimated, using a rod of known height as a reference. During the measurement of the individuals in the plots, they were identified in the field by a botanist. From unidentified ones, botanical material was collected, pressed, and taken for identification in the herbarium of the Federal University of Jataí, Goiás. Botanical identification of the sampled individuals was performed according to the system of the Angiosperm Phylogeny Group (Apg III, 2009).

2.2 Data analysis

2.2.1 Quantification of biomass and carbon

Biomass and carbon were estimated using the non-destructive method. To estimate the total biomass, an equation adjusted for the same phytophysiognomy was used, as described in Equation (1) (Cetec, 1995):

$$TVWB = 0.000066 \cdot DBH^{2.084676} \cdot Ht^{0.752177} \quad (1)$$

In where: TVWB = total volume with bark; DBH = diameter measured at 1.3 m from the ground (cm); Ht = total height (m).

By estimating the volume for each sampled species, the basic wood density value was attributed, according to Lorenzi (2002), Carvalho (2003), Lorenzi (2009a), Lorenzi (2009b) and Silva Júnior (2012). Thus, the wood biomass of each tree was estimated by multiplying the average basic wood density per species by the total volume observed, according to Ribeiro, Jacovine, Soares, Martins, Nardelli and Souza (2010). For individuals identified only at the genus or family level, the average basic density of wood with bark ($kg.m^{-3}$) of the respective taxonomic group was used.

The estimate of carbon stored in dry biomass was obtained by multiplying the factor 0.5, considering that dry biomass contains on average 50% of mass represented by carbon as described in the studies by Fukuda, Lehara and Matsumoto (2003) and Ribeiro, Jacovine, Soares, Martins, Nardelli and Souza (2010). Totaling the amount of carbon from all individuals per species allowed estimation of the carbon stock per hectare ($Mg.ha^{-1}$).

2.2.2 Phytosociological parameters

The density, dominance, frequency, and importance value index (IVI) were calculated in absolute and relative forms for each species to characterize the phytosociological structure (Table 1). The IVI is obtained by the sum of three components: i) abundance – the density of individuals; ii) dominance – the basal area occupied by each species; and iii) frequency – based on the presence/absence of the species or family in each sample unit and representing its spatial distribution (Müeller-Dombois; Ellemberg, 1974).

Table 1 – The phytosociological parameters of forest horizontal structure

Phytosociological variables	Unit	Formula
Absolute Frequency of species *i*	%	$FA_i = \frac{P_i}{\sum_{i=1}^{n} P_i} * 100$
Relative Frequency of species *i*	%	$FR_i = \frac{FA_i}{\sum_{i=1}^{n} FA_i} * 100$
Absolute Density of species *i*	ind.ha^{-1}	$DA_i = \frac{N_i}{A}$
Relative Density of species *i*	%	$DR_i = \frac{DA_i}{\sum_{i=1}^{n} DA_i} * 100$
Absolute Dominance of species *i*	m^{2}ha^{-1}	$DoA_i = \frac{G_i}{A}$
Relative Dominance of species *i*	%	$DoR_i = \frac{DoA_i}{\sum_{i=1}^{n} DoA_i} * 100$
Importance Value Index of species *i*	%	$IVI_i = DR_i + DoR_i + FR_i$

Source: Authors (2023)

In where: G_i = Basal area of species i; F_i = Number of plots where species i occurred; A = Total area sampled.

The variable carbon by species (CA, in Mg.ha^{-1}) and its relative value (CR) were inserted in the calculation of the importance value index, to evaluate the effect of this inclusion on the valuation of species, compared to the traditional method Gaspar, Castro, Del Peloso, Souza and Martins (2014). Thus, the expanded importance value index (IVIA) was obtained by averaging all relative values, including the relative carbon value of species in the community. Then, species rankings were done based on IVI and IVIA, in ascending order, and their positioning among rankings was compared.

3 RESULTS AND DISCUSSIONS

We measured 2,095 individuals from 118 species belonging to 41 botanical families. The families Fabaceae, Anacardiaceae, Myrtaceae, Chrysobalanaceae, and Malvaceae had the largest number of individuals in the sample, with 100 or more individuals.

Licania humilis, *Chrysophyllum marginatum*, *Cecropia pachystachya*, *Myrcia* sp., *Guazuma ulmifolia*, *Zanthoxylum riedelianum*, *Tapirira guianensis*, *Copaifera langsdorffii*, *Luehea divaricata,* and *Hirtella gracilipes* were the species with the highest frequency values (Table 2), thus being the species with the highest distribution in the study area. *Licania humilis*, *Myracrodruon urundeuva*, *Protium heptaphyllum*, *Myrcia* sp., *Tapirira guianensis*, *Rhamnidium elaeocarpum*, *Inga vera*, *Psidium laruotteanum*, *Chrysophyllum marginatum*, and *Hirtella gracilipes* were the species with the highest absolute density (Table 2).

The most dominant species were *Ficus guaranitica*, *Hymenaea courbaril*, *Copaifera langsdorffii*, *Anadenanthera colubrina*, *Myracrodruon urundeuva*, *Myrcia* sp., *Tapirira guianensis*, *Licania humilis,* and *Dilodendron bipinnatum*, which together accounted for more than 50% of relative dominance. Among the previously mentioned ten species, *Ficus guaranitica* had the lowest number of individuals and, therefore, the large size of most of its individuals contributed to its dominance. *Licania humilis* was the species that presented the highest number of individuals, which was why it was among those with the highest relative dominance value.

The species *Ficus guaranitica*, *Licania humilis*, *Myracrodruon urundeuva*, *Myrcia* sp., *Tapirira guianensis*, *Copaifera langsdorffii*, *Anadenanthera colubrina*, *Hymenaea courbaril*, *Protium heptaphyllum,* and *Inga vera* were the ones with the highest IVI values (Table 2; Figure 1).

Table 2 – The horizontal structure parameters of a riparian forest area from the state of Goiás

Scientific name	FA	FR	DA	DR	DoA	DoR	CA	CR	VC	IVI	IVIA	Ranking
Ficus guaranitica Chodat	42,9	1,25	10,7	1,43	3,698	17,707	6,857	16,338	9,569	6,797	9,182	=
Licania humilis Cham. & Schltdl.	85,7	2,51	46,1	6,16	0,647	3,097	0,651	1,551	4,627	3,920	3,328	↓5
Myracrodruon urundeuva Allemão	50,0	1,46	41,4	5,54	0,720	3,449	2,161	5,148	4,493	3,483	3,899	↓1
Myrcia sp.	78,6	2,30	27,9	3,72	0,679	3,251	1,740	4,145	3,487	3,090	3,354	↓2
Tapirira guianensis Aubl.	71,4	2,09	27,5	3,68	0,648	3,104	0,730	1,740	3,390	2,956	2,652	↓3
Copaifera langsdorffii Desf.	71,4	2,09	13,6	1,81	1,023	4,900	2,372	5,651	3,357	2,934	3,613	↑1
Anadenanthera colubrina (Vell.) Brenan	42,9	1,25	16,8	2,24	1,009	4,829	3,175	7,564	3,536	2,775	3,972	↑5
Hymenaea courbaril L.	50,0	1,46	13,6	1,81	1,026	4,913	3,195	7,611	3,363	2,729	3,950	↑5
Protium heptaphyllum (Aubl.) Marchand	57,1	1,67	29,6	3,96	0,435	2,081	0,685	1,631	3,021	2,571	2,336	↓2
Inga vera Willd.	35,7	1,04	22,5	3,01	0,760	3,640	1,164	2,774	3,323	2,564	2,616	↑1
Dilodendron bipinnatum Radlk.	57,1	1,67	16,8	2,24	0,604	2,893	1,189	2,833	2,568	2,269	2,410	↑1
Rhamnidium elaeocarpum Reissek	64,3	1,88	24,3	3,25	0,314	1,502	0,565	1,347	2,374	2,209	1,994	↓1
Luehea divaricata Mart. & Zucc.	71,4	2,09	16,1	2,15	0,469	2,248	0,722	1,720	2,198	2,161	2,051	↑1
Guazuma ulmifolia Lam.	78,6	2,30	18,2	2,43	0,308	1,475	0,419	0,997	1,955	2,069	1,801	↓2
Chrysophyllum marginatum (Hook. & Arn.) Radlk.	85,7	2,51	19,3	2,58	0,173	0,831	0,271	0,647	1,704	1,971	1,640	↓3
Cecropia pachystachya Trécul	85,7	2,51	18,9	2,53	0,180	0,864	0,171	0,407	1,697	1,966	1,576	↓7
Hirtella gracilipes (Hook.f.) Prance	71,4	2,09	19,3	2,58	0,214	1,027	0,303	0,722	1,802	1,897	1,604	↓4
Psidium laruotteanum Cambess.	28,6	0,84	22,1	2,96	0,372	1,780	0,765	1,823	2,369	1,858	1,849	↑3
Zanthoxylum riedelianum Engl.	78,6	2,30	13,6	1,81	0,278	1,330	0,347	0,826	1,572	1,813	1,567	↓5
Platypodium elegans Vogel	42,9	1,25	15,4	2,05	0,303	1,451	0,674	1,606	1,752	1,586	1,591	↓2
Cassia ferruginea (Schrad.) Schrad. ex DC.	64,3	1,88	11,4	1,53	0,274	1,311	0,401	0,955	1,419	1,572	1,418	↓4
Calophyllum brasiliense Cambess.	42,9	1,25	8,9	1,19	0,451	2,162	0,764	1,821	1,677	1,536	1,607	↑2
Terminalia brasiliensis (Cambess.) Eichler	50,0	1,46	8,6	1,15	0,398	1,907	1,007	2,399	1,526	1,505	1,728	↑6

To be continued ...

Table 2 – Continuation

Scientific name	FA	FR	DA	DR	DoA	DoR	CA	CR	VC	IVI	IVIA	Ranking
Astronium fraxinifolium Schott	42,9	1,25	10,0	1,34	0,380	1,820	1,352	3,221	1,578	1,470	1,907	↑10
Ormosia arborea (Vell.) Harms	64,3	1,88	9,3	1,24	0,248	1,186	0,452	1,076	1,214	1,435	1,346	↓3
Andira sp.	57,1	1,67	7,9	1,05	0,317	1,520	0,601	1,432	1,285	1,414	1,418	=
Myrcia tomentosa (Aubl.) DC.	64,3	1,88	13,9	1,86	0,072	0,343	0,108	0,256	1,103	1,361	1,085	↓3
Guarea guidonia (L.) Sleumer	42,9	1,25	14,6	1,96	0,161	0,772	0,194	0,463	1,365	1,327	1,111	↓1
Ficus sp.	28,6	0,84	6,1	0,81	0,449	2,151	0,732	1,744	1,481	1,266	1,386	↑2
Lonchocarpus sp.	7,1	0,21	5,4	0,72	0,585	2,802	1,174	2,796	1,759	1,242	1,631	↑11
Matayba guianensis Aubl.	64,3	1,88	11,1	1,48	0,075	0,361	0,133	0,317	0,920	1,240	1,009	↓1
Xylopia aromatica (Lam.) Mart.	42,9	1,25	12,9	1,72	0,133	0,638	0,178	0,423	1,178	1,203	1,008	↓1
Croton urucurana Baill.	35,7	1,04	11,8	1,58	0,156	0,745	0,342	0,815	1,160	1,121	1,045	↑2
Coccoloba mollis Casar.	57,1	1,67	6,1	0,81	0,069	0,330	0,111	0,265	0,571	0,937	0,769	↓6
Tabebuia roseoalba (Ridl.) Sandwith	42,9	1,25	8,9	1,19	0,072	0,347	0,127	0,303	0,770	0,931	0,774	↓4
Curatella americana L.	28,6	0,84	6,1	0,81	0,197	0,945	0,309	0,736	0,878	0,864	0,832	↓1
Mauritia flexuosa L.f.	35,7	1,04	1,8	0,24	0,253	1,214	0,360	0,857	0,726	0,832	0,838	↑1
Apuleia leiocarpa (Vogel) J.F.Macbr.	35,7	1,04	2,5	0,33	0,215	1,029	0,599	1,426	0,681	0,802	0,958	↑4
Ixora sp.	21,4	0,63	7,9	1,05	0,128	0,611	0,347	0,826	0,831	0,763	0,778	↑1
Handroanthus serratifolius (Vahl) S.Grose	21,4	0,63	4,3	0,57	0,214	1,027	0,655	1,560	0,800	0,742	0,947	↑5
Genipa americana L.	28,6	0,84	4,6	0,62	0,146	0,699	0,269	0,641	0,660	0,718	0,699	↓1
Alibertia edulis (Rich.) A.Rich.	50,0	1,46	3,9	0,53	0,023	0,108	0,032	0,076	0,316	0,698	0,543	↓2
Terminalia argentea Mart.	28,6	0,84	4,3	0,57	0,129	0,619	0,327	0,778	0,596	0,676	0,701	↑2
Agonandra brasiliensis Miers ex Benth. & Hook.f.	21,4	0,63	7,1	0,95	0,085	0,408	0,161	0,384	0,681	0,663	0,593	↑1
Casearia gossypiosperma Briq.	35,7	1,04	5,4	0,72	0,036	0,174	0,047	0,112	0,445	0,645	0,511	↓1
Ouratea castaneifolia (DC.) Engl.	42,9	1,25	3,9	0,53	0,032	0,154	0,040	0,096	0,339	0,644	0,507	↓1
Coussarea hydrangeifolia (Benth.) Müll.Arg.	28,6	0,84	6,4	0,86	0,041	0,197	0,047	0,112	0,528	0,631	0,501	↓1
Handroanthus impetiginosus (Mart. ex DC.) Matto	35,7	1,04	3,2	0,43	0,059	0,284	0,166	0,394	0,357	0,586	0,538	↑3

To be continued ...

Table 2 – Continuation

Scientific name	FA	FR	DA	DR	DoA	DoR	CA	CR	VC	IVI	IVIA	Ranking
Sorocea bonplandii (Baill.) W.C.Burger et al.	42,9	1,25	3,2	0,43	0,015	0,073	0,015	0,035	0,251	0,585	0,448	↓2
Machaerium acutifolium Vogel	35,7	1,04	3,2	0,43	0,048	0,232	0,123	0,293	0,331	0,569	0,500	↑1
Bauhinia rufa (Bong.) Steud.	35,7	1,04	3,9	0,53	0,025	0,118	0,032	0,075	0,321	0,562	0,440	↓2
Guettarda viburnoides Cham. & Schltdl.	35,7	1,04	3,2	0,43	0,036	0,170	0,052	0,125	0,300	0,548	0,442	=
Blepharocalyx salicifolius (Kunth) O.Berg	35,7	1,04	2,1	0,29	0,053	0,254	0,114	0,271	0,270	0,528	0,464	↑3
Casearia sylvestris Sw.	28,6	0,84	3,2	0,43	0,024	0,115	0,041	0,098	0,272	0,460	0,369	↓1
Inga marginata Willd.	21,4	0,63	2,1	0,29	0,095	0,457	0,141	0,336	0,371	0,456	0,426	↑1
Psidium sp.	28,6	0,84	3,2	0,43	0,018	0,087	0,030	0,071	0,258	0,451	0,356	↓1
Erythroxylum suberosum A.St.-Hil.	21,4	0,63	4,3	0,57	0,029	0,138	0,041	0,098	0,355	0,446	0,359	↑1
Diospyros sp.	28,6	0,84	2,1	0,29	0,022	0,107	0,033	0,078	0,197	0,410	0,327	↓4
Pseudobombax tomentosum (Mart. & Zucc.) A.Robyns	21,4	0,63	1,4	0,19	0,074	0,353	0,065	0,156	0,272	0,390	0,332	↓2
Erythroxylum argentinum O.E.Schulz	21,4	0,63	2,5	0,33	0,044	0,208	0,072	0,170	0,271	0,390	0,335	=
Bauhinia sp.	14,3	0,42	3,9	0,53	0,041	0,195	0,043	0,103	0,360	0,379	0,310	↓4
Unonopsis guatterioides (A.DC.) R.E.Fr.	21,4	0,63	2,9	0,38	0,025	0,119	0,021	0,049	0,251	0,376	0,294	↓5
Trema micrantha (L.) Blume	28,6	0,84	1,4	0,19	0,014	0,069	0,007	0,016	0,130	0,365	0,278	↓5
Inga sessilis (Vell.) Mart.	7,1	0,21	2,5	0,33	0,113	0,540	0,122	0,291	0,437	0,361	0,344	↑6
Pouteria sp.	21,4	0,63	1,1	0,14	0,059	0,282	0,123	0,294	0,213	0,351	0,336	↑6
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	21,4	0,63	1,8	0,24	0,029	0,137	0,043	0,102	0,188	0,334	0,276	↓3
Dipteryx alata Vogel	21,4	0,63	1,1	0,14	0,044	0,212	0,117	0,279	0,178	0,327	0,315	↑3
Siparuna guianensis Aubl.	14,3	0,42	3,6	0,48	0,017	0,082	0,020	0,048	0,280	0,326	0,256	↓4
Casearia decandra Jacq.	21,4	0,63	2,1	0,29	0,012	0,060	0,019	0,044	0,173	0,324	0,254	↓4
Maclura tinctoria (L.) D.Don ex Steud.	7,1	0,21	4,3	0,57	0,033	0,156	0,058	0,137	0,364	0,312	0,269	↓1
Bactris setosa Mart.	7,1	0,21	4,3	0,57	0,032	0,156	0,025	0,060	0,364	0,312	0,249	↓3
Aspidosperma sp.	21,4	0,63	1,8	0,24	0,010	0,046	0,016	0,039	0,142	0,304	0,237	↓3
Roupala montana Aubl.	21,4	0,63	1,4	0,19	0,008	0,036	0,008	0,019	0,114	0,285	0,218	↓8
Erythroxylum sp.	21,4	0,63	1,4	0,19	0,007	0,031	0,009	0,021	0,111	0,283	0,217	↓8
Cassia sp.	14,3	0,42	1,4	0,19	0,046	0,220	0,106	0,253	0,205	0,276	0,270	↑5
Persea sp.	14,3	0,42	1,8	0,24	0,033	0,157	0,044	0,106	0,198	0,271	0,230	=

To be continued ...

Table 2 – Continuation

Scientific name	FA	FR	DA	DR	DoA	DoR	CA	CR	VC	IVI	IVIA	Ranking
Sweetia fruticosa Spreng.	14,3	0,42	2,1	0,29	0,020	0,094	0,045	0,107	0,190	0,266	0,226	↓1
Aspidosperma subincanum Mart.	21,4	0,63	1,1	0,14	0,006	0,028	0,008	0,019	0,085	0,266	0,204	↓5
Myrcia rostrata DC.	21,4	0,63	1,1	0,14	0,003	0,014	0,004	0,010	0,079	0,261	0,199	↓6
Senna alata (L.) Roxb.	7,1	0,21	2,9	0,38	0,038	0,181	0,046	0,109	0,281	0,257	0,220	=
Machaerium hirtum (Vell.) Stellfeld	7,1	0,21	2,5	0,33	0,044	0,213	0,054	0,129	0,273	0,252	0,221	↑2
Bathysa sp.	14,3	0,42	1,8	0,24	0,019	0,093	0,023	0,054	0,166	0,250	0,201	↓2
Albizia polycephala (Benth.) Killip ex Record	7,1	0,21	1,4	0,19	0,067	0,320	0,194	0,462	0,256	0,240	0,296	↑17
Cupania vernalis Cambess.	14,3	0,42	1,4	0,19	0,013	0,064	0,021	0,049	0,128	0,224	0,180	↓3
Annona sp.	14,3	0,42	1,1	0,14	0,019	0,092	0,014	0,034	0,118	0,218	0,172	↓3
Virola sebifera Aubl.	14,3	0,42	0,7	0,10	0,026	0,125	0,037	0,087	0,110	0,213	0,181	=
Aegiphila integrifolia (Jacq.) Moldenke	14,3	0,42	1,4	0,19	0,006	0,028	0,011	0,025	0,109	0,212	0,165	↓3
Aspidosperma parvifolium A.DC.	14,3	0,42	1,1	0,14	0,013	0,063	0,023	0,055	0,103	0,208	0,170	↓1
Rheedia gardneriana Planch. & Triana	7,1	0,21	0,4	0,05	0,074	0,356	0,291	0,693	0,202	0,204	0,326	↑26
Cordia sellowiana Cham.	14,3	0,42	1,1	0,14	0,008	0,039	0,010	0,023	0,091	0,200	0,156	↓1
Trichilia casaretti C.DC.	14,3	0,42	1,1	0,14	0,007	0,034	0,011	0,027	0,089	0,198	0,156	↓1
Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl.	14,3	0,42	1,1	0,14	0,004	0,020	0,005	0,011	0,081	0,193	0,148	↓2
Lithraea molleoides (Vell.) Engl.	14,3	0,42	0,7	0,10	0,014	0,066	0,015	0,035	0,081	0,193	0,154	=
Terminalia sp.	7,1	0,21	0,4	0,05	0,060	0,285	0,158	0,376	0,167	0,181	0,229	↑17
Maytenus floribunda Reissek	14,3	0,42	0,7	0,10	0,003	0,012	0,003	0,008	0,054	0,175	0,133	=
Syagrus oleracea (Mart.) Becc.	7,1	0,21	1,8	0,24	0,005	0,023	0,004	0,009	0,131	0,157	0,120	=
Erythroxylum deciduum A.St.-Hil.	7,1	0,21	0,7	0,10	0,014	0,066	0,018	0,043	0,081	0,123	0,103	↓1
Myrsine guianensis (Aubl.) Kuntze	7,1	0,21	0,4	0,05	0,022	0,108	0,042	0,101	0,078	0,121	0,116	↑1
Aspidosperma cuspa (Kunth) Blake	7,1	0,21	0,7	0,10	0,011	0,050	0,018	0,043	0,073	0,118	0,099	=
Nectandra lanceolata Nees	7,1	0,21	0,4	0,05	0,016	0,077	0,024	0,057	0,063	0,111	0,098	=
Trichilia pallens C.DC.	7,1	0,21	0,7	0,10	0,004	0,020	0,005	0,013	0,058	0,108	0,084	↓5

To be continued ...

Table 2 – Conclusion

Scientific name	FA	FR	DA	DR	DoA	DoR	CA	CR	VC	IVI	IVIA	Ranking
Pseudobombax longiflorum (Mart. & Zucc.) A.Robyns	7,1	0,21	0,4	0,05	0,013	0,064	0,013	0,031	0,056	0,107	0,088	↓2
Byrsonima intermedia A.Juss.	7,1	0,21	0,4	0,05	0,013	0,061	0,017	0,040	0,054	0,106	0,089	=
Rubiaceae spp.	7,1	0,21	0,7	0,10	0,002	0,011	0,002	0,005	0,053	0,105	0,080	↓3
Anadenanthera peregrina (L.) Speg.	7,1	0,21	0,4	0,05	0,012	0,056	0,032	0,075	0,052	0,104	0,097	↑4
Aspidosperma polyneuron Müll.Arg.	7,1	0,21	0,4	0,05	0,011	0,051	0,030	0,070	0,049	0,103	0,094	↑4
Xylopia emarginata Mart.	7,1	0,21	0,4	0,05	0,009	0,044	0,018	0,043	0,046	0,100	0,086	↑2
Byrsonima laxiflora Griseb.	7,1	0,21	0,4	0,05	0,008	0,039	0,008	0,019	0,043	0,098	0,078	↓1
Asteraceae spp.	7,1	0,21	0,4	0,05	0,008	0,038	0,010	0,024	0,043	0,098	0,080	↑1
Byrsonima sericea DC.	7,1	0,21	0,4	0,05	0,005	0,024	0,006	0,014	0,036	0,093	0,074	=
Myrsine tomentosa C. Presl	7,1	0,21	0,4	0,05	0,004	0,018	0,005	0,012	0,033	0,091	0,072	=
Hancornia speciosa Gomes	7,1	0,21	0,4	0,05	0,004	0,017	0,005	0,011	0,033	0,091	0,071	=
Aspidosperma discolor A.DC.	7,1	0,21	0,4	0,05	0,003	0,013	0,005	0,011	0,031	0,090	0,070	=
Piptadenia gonoacantha (Mart.) J.F.Macbr.	7,1	0,21	0,4	0,05	0,003	0,013	0,004	0,009	0,031	0,090	0,070	=
Brosimum gaudichaudii Trécul	7,1	0,21	0,4	0,05	0,003	0,013	0,003	0,008	0,031	0,090	0,069	=
Emmotum nitens (Benth.) Miers	7,1	0,21	0,4	0,05	0,002	0,009	0,003	0,008	0,028	0,088	0,068	=
Cordiera sessilis (Vell.) Kuntze	7,1	0,21	0,4	0,05	0,001	0,007	0,002	0,004	0,027	0,088	0,067	=
Alchornea glandulosa Poepp. & Endl.	7,1	0,21	0,4	0,05	0,001	0,004	0,000	0,001	0,026	0,087	0,065	=
Total	3421,4	100,00	748,2	100,00	20,883	100,00	41,972	100,00	100,00	100,00	100,00	

Source: Authors (2023)

In where: FA = absolute frequency; FR = relative frequency (%); DA = absolute density (individuals.ha^{-1}); DR = relative density (%); DoA = absolute dominance; DoR = relative dominance (%); CA = absolute carbon stock (Mg.ha^{-1}); CR = relative carbon stock (%); IVI = importance value index (%); IVIA = expanded importance value index (%); Δ Rank = change of species position when classified by VIA in relation to classification by VI.

The average carbon stock estimated in the shrub-tree stratum was 41.77 Mg.ha^{-1} for riparian forest, higher than those estimated by Rezende, Vale, Sanquetta, Figueiredo Filho and Felfili (2006) in the Cerrado *sensu stricto* area in Brasília, DF (4.93 Mg.ha^{-1}) and by Pereira Júnior, Andrade, Palácio, Raymer, Ribeiro Filho and Pereira, (2016) in the Dry Tropical Forest in Iguatú, CE (19.27 Mg.ha^{-1}). Note that the aforementioned authors adopted more comprehensive inclusion criteria than those adopted in this study. However, the carbon stock estimated here is lower than that observed by Amaro, Soares, Souza, Leite and Silva (2013) and Torres, Jacovine, Soares, Oliveira Neto, Santos and Castro Neto (2013) in studies carried out in a Semideciduous Seasonal Forest in Viçosa, MG, in which the authors adopted inclusion criteria similar to this study and estimated 56.31 and 48.70 Mg.ha^{-1} and 108.98 Mg.ha^{-1}, respectively.

The highest relative carbon stocks (CR) were observed for the species *Ficus guaranitica* (16.3%), *Hymenaea courbaril* (7.6%), *Anadenanthera colubrina* (7.5%), *Copaifera langsdorffii* (5.6%), *Myracrodruon urundeuva* (5.1%), *Myrcia* sp. (4.1%), *Astronium fraxinifolium* (3.2%), *Dilodendron bipinnatum* (2.8%), *Lonchocarpus* sp. (2.7%), and *Inga vera* (2.7%) (Table 2). These species represented 58.1% of the total carbon stored in the region's riparian forest and resembled the situation observed by Gaspar, Castro, Del Peloso, Souza and Martins (2014), in which nine species accounted for more than 50% of the carbon stored.

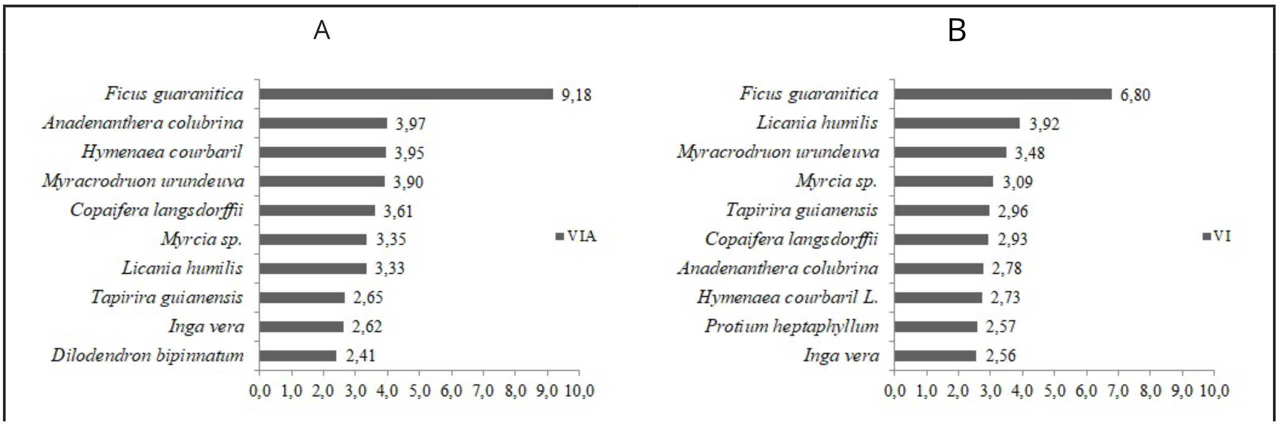
Among the ten species with the highest carbon stocks are *Myracrodruon urundeuva* and *Astronium fraxinifolium*, which were at risk of extinction until 2008 (Brasil, 2008). Thus, efforts to preserving these species must be pursued not only due to their ecological function but also because their carbon stock capacity in riparian vegetation areas.

From the inclusion of the relative carbon variable to compose the IVIA, the species with the highest values also stood out for the IVI, except for the species *Dilodendron bipinnatum* (Table 2).

In general, 81.4% of the sampled species underwent some type of change in this ranking. Some species were not among the ten best ranked; however, they presented great changes in position, such as *Astronium fraxinifolium*, *Lonchocarpus* sp., *Albizia polycephala*, *Terminalia* sp. and *Rheedia gardneriana* that rose 10, 11, 17, 17, and 26 positions, respectively, and the species *Cecropia pachystachya*, *Erythroxylum* sp., and *Roupala Montana* that fell 7, 8, and 8 positions, respectively (Table 2).

These changes indicate that incorporating a new variable, in this case, the carbon stock, to characterize the importance of the species contributes to the knowledge of the specific function of each species in the environment that it is found. Gaspar, Castro, Del Peloso, Souza and Martins (2014), studying a fragment of a Semideciduous Seasonal Forest, also observed that most species rose or fell in the ranking when considering the expanded importance value index in relation to the standard phytosociological analysis by the importance value index. As highlighted by those authors for the fragment studied, the ranking of species considering their ability to store carbon can support the restoration of riparian forests, which would increase the range of environmental services of this vegetation.

Figure 1 - Representation of the ten species with the highest importance value (IV, %) (A) and the increased importance value (VIA, %) (B) in riparian forest fragments



Source: Authors (2023)

When considering the percentage of total carbon per family, the order of importance changes, with the first five families (Fabaceae, Moraceae, Anacardiaceae, Myrtaceae, and Combretaceae) responsible for more than 75% of the stored carbon (Table 3). For the botanical families Fabaceae, Anacardiaceae, and Myrtaceae, a large number of individuals were sampled in the plant formation studied. Furthermore, most individuals cataloged in these families (86.1%) have medium to high-density wood, which facilitates greater carbon stock. Although the Moraceae family had fewer individuals than the previously mentioned families and most individuals (68.1%) with low-density wood, it has large individuals. Low-density woods have values below 0.550 g.cm^{-3}, medium-density woods are between 0.550 and 0.720 g.cm^{-3}, and high-density woods have densities greater than 0.720 g.cm^{-3} (Vale; Brasil; Leão, 2002).

Table 3 – Botanical families and their respective number of individuals and percentage of total carbon stored by individuals from each family, sampled in the arboreal stratum of riparian forest

Family	Number of individuals	% Total Carbon
Anacardiaceae	223	10.14
Annonaceae	48	0.55
Apocynaceae	16	0.25
Arecaceae	22	0.93
Asteraceae	1	0.02
Bignoniaceae	51	2.36
Boraginaceae	3	0.02
Burseraceae	83	1.63
Calophyllaceae	25	1.82
Cannabaceae	4	0.02
Celastraceae	2	0.01
Chrysobalanaceae	183	2.27
Clusiaceae	1	0.69
Combretaceae	37	3.55
Dilleniaceae	17	0.74
Ebenaceae	6	0.08
Erythroxylaceae	25	0.33
Euphorbiaceae	34	0.82
Fabaceae	477	36.76
Icacinaceae	1	0.01
Lamiaceae	4	0.03
Lauraceae	6	0.16
Malpighiaceae	3	0.07

Table 3 – Conclusion

Family	Number of individuals	% Total Carbon
Malvaceae	101	2.90
Meliaceae	46	0.50
Moraceae	69	18.26
Myristicaceae	2	0.09
Myrsinaceae	1	0.01
Myrtaceae	195	6.56
Ochnaceae	11	0.10
Opiliaceae	21	0.40
Polygonaceae	17	0.26
Primulaceae	1	0.10
Proteaceae	4	0.02
Rubiaceae	81	1.84
Rutaceae	38	0.83
Salicaceae	30	0.25
Sapindaceae	86	3.21
Sapotaceae	57	0.94
Siparunaceae	10	0.05
Urticaceae	53	0.41

Source: Authors (2023)

The estimated carbon stock corroborates the theory that forests behave as an important carbon sink (Saatchi; Harris; Brown; Lefsky; Mitchard; Salas; Zutta; Buermann; Lewis; Hagen; Petrova; White; Silman; Morel, 2011; Baccini; Goetz; Walker; Laporte; Sun; Sulla-Menashe; Hackler; Beck; Dubayah; Friedl; Samanta; Houghton, 2012) and indicates the importance of their conservation and preservation. The riparian forests are essential for maintaining the water quality of rivers and ichthyological fauna; however, they are fragile systems in the face of impacts caused by man. Therefore, when these areas are restored, in addition to the ecological factors, the capacity of the possible planted species to store carbon in their biomass should be considered; thus, the vegetation could provide several functions.

According to Ipcc (2014), the most cost-effective carbon sequestration alternatives in the forest area are the reduction of deforestation, sustainable forest management, and reforestation. Natural forests are a low-cost solution to reduce carbon dioxide concentrations because different formations and forest species play a vital role in removing it from the atmosphere and converting it into biomass. The importance of these forests increases as concentrations of carbon dioxide in the atmosphere also increase, increasing discussions of their potential effect on the climate and possible solutions.

Restoration of riparian forests is a particularly valuable strategy because it has the potential for rapid carbon sequestration, is a focus of biodiversity, and offers numerous valuable ecosystem services (Dybala; Matzek; Gardali; Seavy, 2019).

4 CONCLUSIONS

The riparian forest has a high capacity to store carbon. Incorporating this variable by obtaining the expanded value index of importance changes the positioning of the species when ranked by value of importance.

The ranking of species by the expanded importance index (IVIA) can be used as part of a basis for the conservation and preservation of riparian forests, as well as one of the criteria in the choice of species with the greatest potential for carbon stock in restoring degraded areas.

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