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STOCK AND WATER RETENTION CAPACITY OF LITTER ACCUMULATED IN THE ATLANTIC RAINFOREST

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Resumo

Estoque e capacidade de retenção hídrica da serapilheira acumulada na Mata Atlântica. A serapilheira é a camada acima do solo composta por folhas, galhos, material reprodutivo, e miscelânea. É responsável por processos essenciais como a proteção do solo, ciclagem de nutrientes e a retenção de umidade. O objetivo deste trabalho foi quantificar o estoque e a capacidade de retenção hídrica da serapilheira acumulada em áreas com diferentes idades em processo de restauração florestal. Nós conduzimos o estudo no município de Otacílio Costa, Estado de Santa Catarina, Brasil, em uma empresa de silvicultura. A área passou pela extração de *Pinus* spp. e apresenta seis áreas com períodos diferentes em restauração florestal (13, 12, 11, 10, 4 e 3 anos). Em cada idade, nós instalamos quatro parcelas, totalizando 24 parcelas e nós fizemos cinco coletas de serapilheira em cada parcela, totalizando 120 coletas. Nós determinamos a Capacidade de Retenção Hídrica pelo método de Blow (1955) e o estoque de serapilheira na unidade Mg ha^{-1}. Os dados foram submetidos à ANOVA, ao teste Tukey e ao teste de correlação linear de Pearson. A média total de serapilheira acumulada da área foi igual a 4,46 Mg ha^{-1}. Das seis áreas avaliadas, a área mais antiga no processo de restauração florestal, com 13 anos, apresentou o maior estoque de serapilheira e a maior capacidade de retenção hídrica (558,44%). A correlação entre o estoque de serapilheira e a capacidade de retenção de hídrica foi nula, indicando que essa variável não acresce conforme o estoque da serapilheira acumulada aumenta.
Palavras-chave: Restauração Florestal, Floresta Ombrófila Mista, Retenção de umidade.

Abstract

Litter is an above-ground layer which is composed of leaves, twigs, reproductive material, and miscellany. It is responsible for essential processes such as soil protection, nutrient cycling and moisture retention. This study aimed to quantify the stock and water retention capacity of litter accumulated in areas of different ages in a forest restoration process. We conducted the study in the municipality of Otacílio Costa, Santa Catarina State, Brazil, in a forestry company. The area went through the extraction of *Pinus* spp. and displays six areas with different periods in forest restoration (13, 12, 11, 10, 4, and 3 years). At each age, we installed four plots, totaling 24 plots, and we performed five collections of litter in each plot, totaling 120 collections. We determined the Water Retention Capacity by the Blow method, and we determined the litter stock in the unit of Mg ha^{-1}. The data were submitted to ANOVA, Tukey test, and Pearson's Linear Correlation test. The total average litter stock of the area was equal to 4.46 Mg ha^{-1}. From all six areas evaluated, the oldest area in the forest restoration process, with 13 years, showed the highest litter stock and the highest water retention capacity (558.44%). The correlation between the litter stock and the water retention capacity was null, indicating that, as the areas progressed in the restoration process, the increase in accumulated litter did not influence the increase in their water-holding capacity.
Keywords: Forest Restoration, Ombrophilous Mixed Forest, Water retention.

INTRODUCTION

The Atlantic Forest is one of the largest biomes in Brazil, but it has suffered interventions throughout history, actions which were intensified in the 20th century due to anthropic activity (BARBOSA; MANSANO, 2018). Among the phytophysiognomies in the Atlantic Forest in Southern Brazil, the Ombrophylous Mixed Forest (OMF) stands out, whose characteristic species is *Araucaria angustifolia* (Bertol.) Kuntze, which occurs very frequently and has high-quality wood, which is target of excessive logging activity, thus reducing the original occurrence area of this forest formation (MEDEIROS *et al*., 2005). Therefore, actions aimed at ecological restoration in the Atlantic Forest are justified.

Ecological restoration is a purposeful activity that initiates or accelerates the recovery of a given ecosystem, aiming to return its health, integrity, and sustainability (SOCIETY FOR ECOLOGICAL RESTORATION, 2004). The forest restoration process must offer conditions for the restoration of ecological relationships and plant succession in degraded environments (KLIPPEL *et al*., 2016). In other words, it must

reestablish an ecosystem with the capacity to promote ecosystem services such as soil protection and health, organic matter supply, protection of water resources, and wildlife shelter.

Throughout their growth and development, trees add organic matter to the soil via litter deposition and root system renewal, influencing soil physical attributes such as bulk density, porosity, aeration, infiltration and water retention capacity, and aggregate formation and stabilization (NETO *et al*., 2013). Therefore, the establishment of a plant community is desired in forest restoration, since the arboreal individuals play a relevant role in the systems where they are inserted.

The accumulation of litter on the forest floor originates from the plant community in the area, with this layer being composed of leaves, branches, flowers, fruits and miscellaneous matter. According to Scoriza *et al.* (2012), the litter layer is characterized as a compartment in which nutrients will be made available to the surface soil layers throughout the process of this material. Silva *et al*. (2015) state that this layer houses a portion of the seed bank of pioneer species, nutrients, and organic matter; these factors characterize it as an important technique factor for the restoration of degraded areas.

Therefore, it is characterized as an essential agent of forest restoration because its quantification can provide information about the current state of the forest, especially after a disturbance event. Rebêlo *et al.* (2022) state that, in this way, the accumulated litter is characterized as an indicator of environmental quality, because it represents a stock of nutrients for future mineralization and cycling processes in tropical soils, and this stock is important to compensate the loss of organic matter in the soil and provide protection against erosion.

Some factors influence the accumulation of litter on the forest soil, such as soil and climate conditions, site, understorey, and natural disturbances (GODINHO *et al*., 2014) and, subsequently, its accumulation on the forest floor.

Given the importance of this component for forest ecosystems, this study aimed to quantify the stock and water retention capacity of litter accumulated in areas undergoing forest restoration in Otacílio Costa, Santa Catarina State, Brazil. This research aims to answer two main questions: 1) does the advancement of the forest restoration process result in increased soil litter stock? 2) does the water-holding capacity of accumulated litter increase as the stock of this component grows? For each of the questions, we test the following hypothesis: litter stock and water retention capacity increase in areas with more time elapsed in forest restoration processes.

MATERIAL AND METHODS

Study Area

The study was conducted on a Forestry company located in Otacílio Costa city, Santa Catarina State (Figure 1). The site is located at the geographic coordinates 27° 39' 15" S and 49° 48' 26" W and about 850 m altitude (FERREIRA *et al*., 2013).

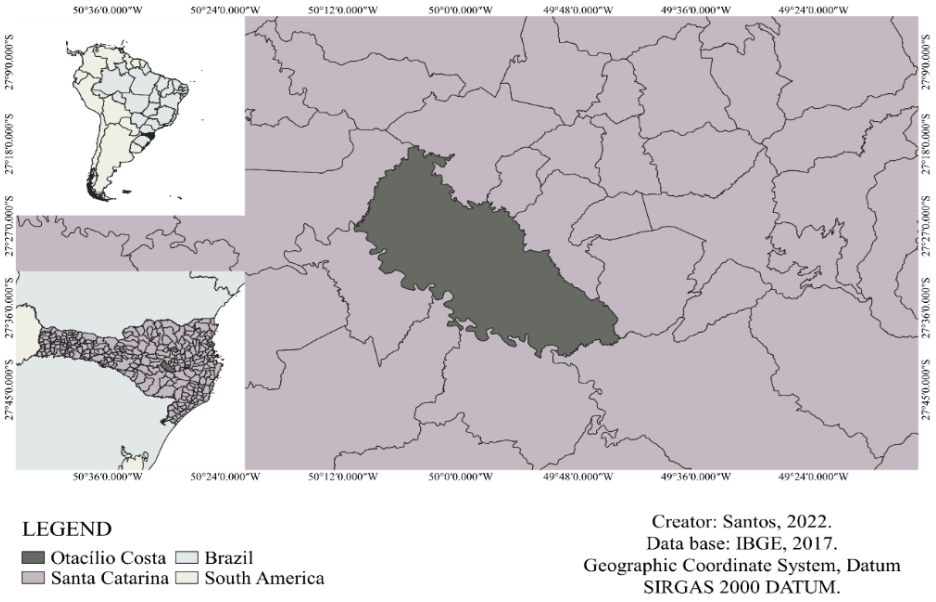

Figure 1: Location of the municipality of Otacílio Costa, Santa Catarina State, Brazil.
Figura 1: Localização do município de Otacílio Costa, Santa Catarina, Brasil.

The municipality of Otacílio Costa is located in the "Planalto Serrano Sul-Catarinense", a microregion of the Lages fields, 49 km from the Lages city and 315 km from the capital Florianópolis and stands out in the forest market due to the extensive planted areas, mainly of *Pinus* spp. According to the Koppen classification, the region's climate is type Cfb, with maximum and minimum temperatures equal to 35 °C and -5 °C, respectively. The area's soil is classified as Humic Clay Cambisol (EMBRAPA, 2013) and the annual pluviometric precipitation can range between 1,360 and 1,600 mm (Figure 2).

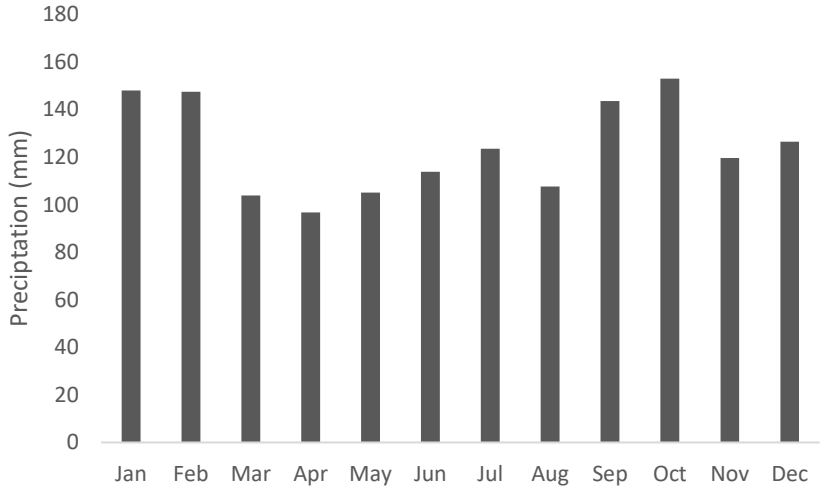

Figure 2: Average monthly precipitation throughout the year in the city of Otacílio Costa, Santa Catarina State, Brazil from a 30-year observed data series.
Figura 2: Precipitação média mensal ao longo do ano na cidade de Otacílio Costa, Santa Catarina, Brasil a partir de uma série de dados de 30 anos observados.
Fonte: CLIMATEMPO (2023)

Before pinus harvesting, the area was covered by fragments of Ombrophylous Mixed Forest (OMF) and after that, there were no forest restoration techniques in the areas, which were left undergoing the process of passive forest restoration. Some of the main tree species in the study area are *Lithraea brasiliensis* Marchand, *Ilex paraguariensis* A.St.-Hil., *Araucaria angustifolia* (Bertol.) Kuntze, *Baccharis dracunculifolia* DC, *Baccharis semiserrata* DC., *Cedrela fissilis* Vell., *Myrsine coriacea* (Sw.) R.Br. ex Roem. & Schult, *Mimosa scabrella* Benth. and *Drimys brasiliensis* Miers.

In "Campo de Dentro" Farm (Figure 3), the extraction of *Pinus* spp. occurred in different periods, characterizing it in different ages of the forest restoration process: 13 years (2008), 12 years (2009), 11 years (2010), ten years (2011), four years (2017), and three years (2018).

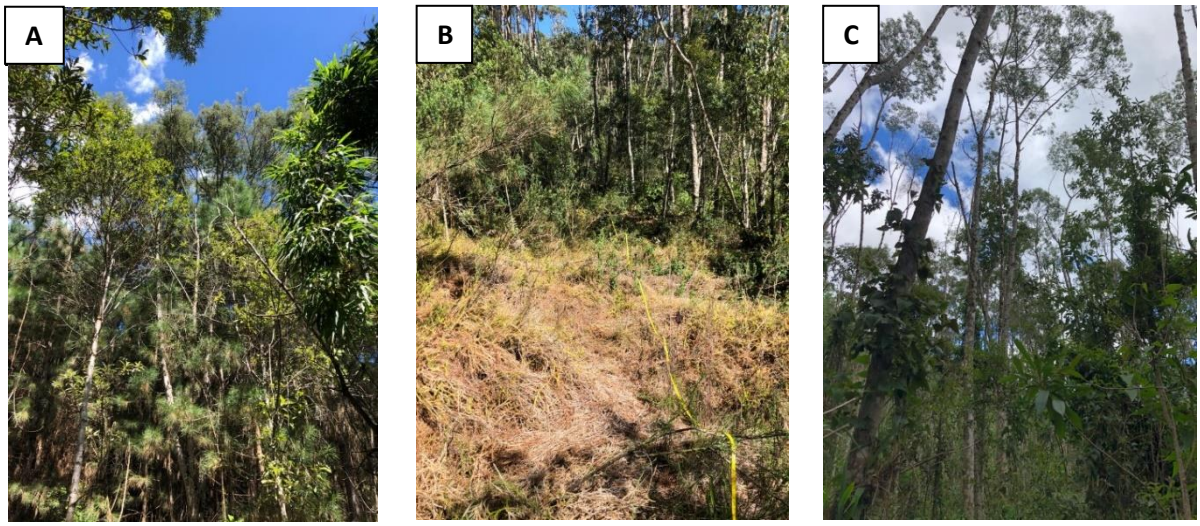

Figure 3 (A, B, C): Study areas in forest restoration process where litter collections occurred.
Figura 3 (A, B, C): Áreas de estudo em processo de restauração florestal onde as coletas de serapilheira aconteceram.

Data Collection

We installed four plots (25 m x 4 m) at each age area of the forest restoration process, totaling twenty-four plots. We collected one sample of the litter monthly in each plot with a 0.5 m x 0.5 m (0.25 m²) template (Figure 4), throughout February, March, April, and June 2021, totaling 120 collections of accumulated material. We conditioned the material in plastic bags adequately identified, and we obtained the litter stock in the unit of grams (g) and converted it from gram to Mg ha^{-1}.

Figure 4: A) Quadrant used for litter collection in the study areas in forest restoration processes; B) Litter collected in the study areas and stored in the laboratory for subsequent determination of its stock.
Figure 4: A) Quadrante utilizado para coleta de serrapilheira nas áres de estudo em processos de restauração florestal; B) Serapilheira coletada nas áreas de estudo e armazenada em laboratório para posterior determinação de seu estoque.

The litter water retention capacity was estimated according to Blow (1955), which consists of immersing the samples in water for 90 minutes; after this period, the excess litter water was removed using sieves for 30 minutes, and then they were weighed on precision scales to determine their moist mass. After the moist mass was determined, the samples were placed in paper bags and taken to the oven at 65 °C for 48 hours to be dried until they reached a constant weight to determine the dry mass. After obtaining the moist and dry mass, the Water Retention Capacity (WRC) was determined according to Equation 1 (Eq 1).

Eq 1:

$$WRC(\%) = \frac{MM-DM}{DM} * 100$$

Which:

WRC (%): Water Retention Capacity;

MM: Moist Mass (g);

DM: Dry Mass (g).

Data analysis

We performed the statistical analyses in Rstudio (Version 4.0.5), where the data were subjected to the Shapiro-Wilk normality test and the Fligner-Killeen test of homogeneity of variances. After this, an Analysis of Variance was performed to determine if there was a significant difference between the averages of the litter stock in areas with different ages in passive restoration. Subsequently, Tukey's test (5%) was applied, and the data of litter stock and WRC (%) were subjected to Pearson's Linear Correlation test (r).

RESULTS

- Litter

The overall average of litter in the study area was 4.46 Mg ha^{-1}, and the highest accumulation of litter was in both the areas with the most advanced age of restoration, with 12 (2009) and 13 years (2008), with an average

stock equal to 5.21 Mg ha^{-1} and 5.30 Mg ha^{-1} (Figure 5). The 3- and 4-years areas showed the lowest stock of this component (respectively 3.29 and 3.59 Mg ha^{-1}). Areas with 10 and 11 years presented average accumulated litter equal to, respectively, 4.79 Mg ha^{-1} and 4.57 Mg ha^{-1}.

The average litter stock of the study areas showed significant differences between them, and the Analysis of Variance accused this statistical difference through the result of the p-value that was lower than the level of significance (p = 0.00001466, at 5% significance).

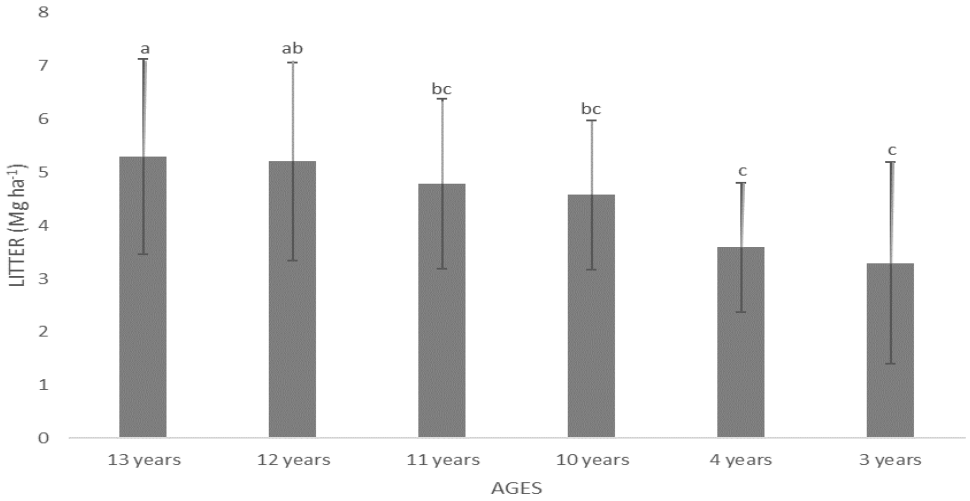

Figure 5: Average litter stock of areas with different ages in forest restoration process. Different letters indicate statistical difference between the study areas.
Figura 5: Média do estoque de serapilheira das áreas com diferentes idades em processo de restauração florestal. Letras diferentes indicam diferença estatística entre as áreas de estudo.

- Water Retention Capacity (WRC %)

The average water retention capacity of the study area was 398.93% (Figure 6). The WRC showed divergent behavior from the litter stock. Analyzing the data by restoration age, there was a significant difference between the means. The p-value reported by the Analysis of Variance was lower than the significance level (p-value = 0.0000 at 5% significance). The highest mean WRC was observed in the 13 years old area, the oldest area in the restoration process, which differed statistically from the other areas. However, the areas with 11 years and 3 years showed high averages of this variable, equal to 535.65% and 433.13%, respectively.

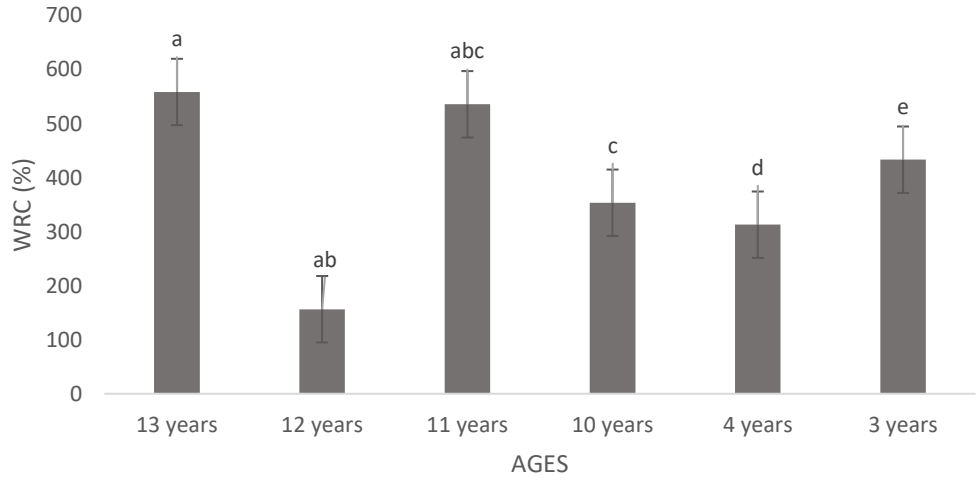

Figure 6: Average water holding capacity of the litter stock of the areas with different ages in forest restoration process. Different letters indicate statistical difference between the study areas.
Figura 6: Média da capacidade de retenção hídrica do estoque de serapilheira das áreas com diferentes idades em processo de restauração florestal. Letras diferentes indicam diferença estatística entre as áreas de estudo.

- Pearson's linear correlation (r)

A null correlation was found between litter and water holding capacity (r = 0.07) (Figure 7). In other words, the increase in litter stock did not influence water retention.

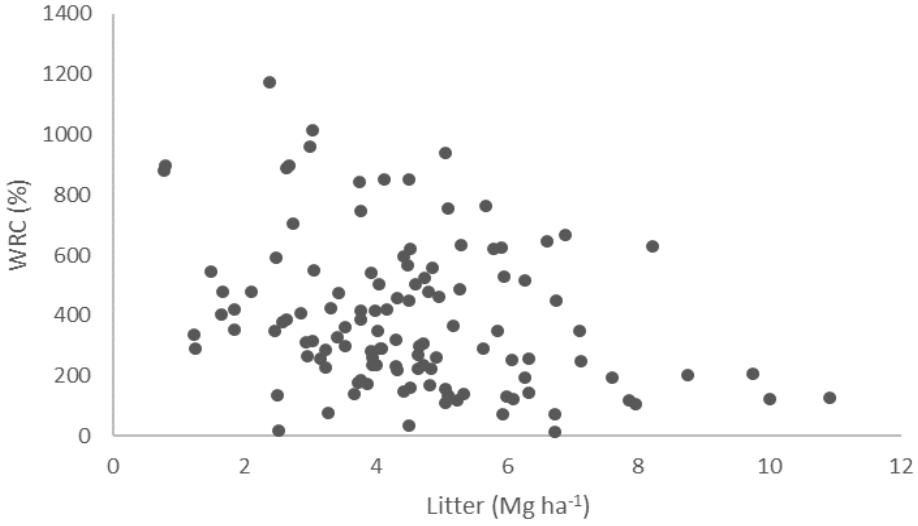

Figure 7: Correlation between the stock and water retention capacity of litter accumulated in areas with different ages in forest restoration process.
Figura 7: Correlação entre o estoque e a capacidade de retenção hídrica da serapilheira acumulada em áreas em com diferentes idades em processo de restauração florestal.

DISCUSSION

We quantified the stock and water retention capacity of litter accumulated in areas with different ages of forest restoration in southern Brazil. We confirm the hypothesis that the older areas have the largest litter stock in relation to the younger areas in the process of passive forest restoration. The 13 years old area differed statistically from the 3, 4, 10, and 11 years old areas. The fact that there was no significant difference with the 12 years old area can be explained by the fact that they are close in age in the passive restoration process. The 12 years old area showed a statistical difference between the 3 and 4 years old accumulated litter averages. The fact cited above and the proximity of the ages of the other areas can be used to explain the lack of significant difference between the averages. Areas which were close in age in the restoration process did not differ significantly from each other.

The overall average of litter found in this study (4.46 Mg ha^{-1}) was lower than other studies conducted in the Atlantic Forest. Sperandio *et al.* (2012) found an average litter equal to 5.61 Mg ha^{-1} in forest restoration areas in the Atlantic Forest in Alegre City, Espírito Santo. Caldeira *et al.* (2007) found an average similar to 7.99 Mg ha^{-1} of accumulated litter in an Ombrophylous Mixed Montane Forest in General Carneiro city with different ages in the successional stage. According to Caldeira *et al.* (2008), the litter stock varies according to the origin, species, forest cover, successional stage, age, time of collection, type of forest, and location, and also undergoes interference from factors such as soil and climate conditions, site, understorey, silvicultural management, crown proportion, decomposition rate, and natural disturbances. The accumulated litter varies according to species occurrence, forest cover, successional stage, age, collection time, forest type, and location (PAULA *et al*., 2022), and the quantity of litter that is deposited on the soil can vary within the same vegetation type (FERREIRA; CATTÂNIO; JARDIM, 2015) so it is expected that there is a difference between the values of this study compared to other sites. It is necessary to consider that the areas in this research are still at an early age in passive restoration. This fact directly influences the litter on the forest soil, especially in the younger areas in the restoration process. The study areas of this research follow the expected behavior for the litter stock, which determines that the older the areas are, the greater the stock of this component on the forest floor is.

Although it was found that the litter stock increases in older areas undergoing passive restoration, this behavior was not observed for water retention, contrary to the hypothesis of the work, that the water retention capacity would increase with the years of restoration. A similar behavior was observed by Oliveira and Braga (2021) in a study of the WRC and litter in forest remnants of the Atlantic Forest, in Capão Bonito, São Paulo, in which the authors observed that the three sites studied, Legal Reserve Area site showed the most outstanding stock of litter with an average equal to 18.8 Mg ha^{-1} and WRC with an average equivalent to 236.1%. However, the

highest WRC of accumulated litter was observed at Permanent Preservation Area site with a mean of 259.2% and mean litter equal to 8.1 Mg ha^{-1}.

Mateus *et al.* (2013) found an average of 290.01% of this variable for the areas studied. The authors evaluated the stock and WRC in four disturbed ecosystems in the Atlantic Forest. The ecosystem with the highest water retention was in the area called "capoeira", with a mean equal to 343.87%, and in the area called "capoeirão", with a mean WRC equal to 339.94%. In the cited study, the WRC was not higher in the area where the litter stock was higher because it was found to have the highest average of litter in the forest fragment area (5.14 Mg ha^{-1}), with lower water retention than in the areas of "capoeira" and "capoeirão". The authors attribute the highest WRC in these areas to the number of leaves of the facilitator species *Clidemia urceolata* DC, present in the areas of "capoeira" and "capoeirão". Araújo *et al.* (2021), researching the water retention capacity in early, late, and primary forests in Belém, Pará, found values equal to 258.46%, 255.15%, and 228.16%, respectively, for each environment in the rainy season. In the dry season, the authors documented values for the same environments similar to 146.01% for the early forest, 82.65% for the late forest, and 155.65% for the primary forest. The authors relate the higher water retention capacity with the low amount of stored material and high decomposition since rainfall and high humidity favor the decomposer fauna. Pereira *et al.* (2021), analyzing the water retention capacity of the litter in forest fragments with different ages in restoration, in Brotas, São Paulo, with 46, 11, and 8 years, found results equal to 394%, 224.6%, and 221.4%, respectively.

The water retention capacity of the accumulated litter reflects the condition that this material presents to absorb and retain moisture, which will be released gradually into the ecological system, allowing the maintenance of the surface moisture (MACEDO *et al*., 2022). However, forest vegetation composition, light, heat, and water conditions have distinct effects on litter accumulation (LI *et al*., 2018), and these factors may influence its water-holding capacity directly. Knowing this variable is fundamental to understanding the importance of litter in forest restoration and the ecological processes that this material can offer.

According to this research and the studies cited, the increase in the water retention capacity of the litter does not depend solely on the rise in its stock; some factors can influence this variable, such as the decomposition of the material forming the litter, the plant typology, the topography and the history of use of the area. This may explain the decreased water retention value in the area with 12 years of passive restoration (2009).

CONCLUSIONS

- The litter stock was higher in the oldest areas (12 and 13 years of age) undergoing restoration and increased as the ages of areas undergoing passive forest restoration increased.
- The water holding capacity values did not follow the increase in litter stock, rejecting the hypothesis that older areas undergoing forest restoration have a higher litter water holding capacity.
- There is no correlation between the values of the variables analyzed, indicating that the increase in litter stock does not influence the increase in water holding capacity.

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