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ASSESSING GALLERY FOREST ECOSYSTEMS - CASE STUDY OF THE PAJEÚ GALLERY FOREST

AVALIAÇÃO DE ECOSSISTEMAS FLORESTAIS – ESTUDO DE CASO DA MATA CILIAR DO PAJEÚ

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ABSTRACT

There is a lack of basic information about the Caatinga gallery forests. The aim of the study was to obtain basic information of the Pajeú gallery forest (Pernambuco, Brazil) and offer different ways to restore and conserve it. A characterization of the conservation status and its seed bank was made. The characterization was done using a quality index (QBR index) and an evaluation of land use through satellite images. Research was then conducted on the native plants of the Caatinga riparian forests in order to test active restoration methods in the field. To do so, a multi-criterion analysis was constructed and included all tree and shrub species based on previous local researches and found in literature. After this analysis, some species were grown in a plant nursery to test their germination, survival and growth rates for different soils and irrigation frequencies. Finally, transplantation in the gallery forest was evaluated by observing survival and growth rates of different native species that were directly planted in the forest. Our results show that the global QBR was 43.73 and that 73% of lands had either an insufficient (64%) or bad (9%) quality. However, some areas maintained a high biodiversity. We observed 23,651 seed germinations from the seed bank, where most germinations (53%) came from preserved site. Soils collected during the dry season also offered more seedlings (60%) than their rainy season counterparts (40%). As for active restoration, it was observed that some plants are better suited for tree nurseries and transplantation such as *Sapindus saponaria*, *Vitex gardneriana*, *Celtis iguanaea* and that by selecting the correct plants and techniques, the ecosystem can be restored. There is still a long way to restore Pajeú's gallery forest. But studies like this are essential to increase knowledge of the ecosystem. This study could serve as a reference to design management/restoration strategies, prioritize actions and develop public policies that ensure integrity and long-term conservation of the ecosystem and their functions.

Keywords: tropical dry forest; soil seed banks; restoration; tree nursery; seedlings recruitment; ecosystem integrity; gallery forest quality index.

RESUMO

Faltam informações básicas sobre as florestas de galeria da Caatinga. Os objetivos do estudo foram obter informações básicas da floresta de galeria do Pajeú (Pernambuco, Brasil) e oferecer diferentes maneiras de restaurá-las e conservá-las. Foi realizada a caracterização do estado de conservação e seu banco de sementes. A caracterização foi feita usando um índice de qualidade (índice QBR) e uma avaliação do uso do solo por meio de imagens de satélite. Em seguida, foi realizado um inventário sobre as plantas nativas das matas ciliares da caatinga, a fim de testar métodos ativos de restauração no campo. Para isso, foi construída uma análise multicritério que incluiu todas as espécies de árvores e arbustos, com base em pesquisas prévias locais e citadas na literatura. Após essa análise, algumas espécies foram cultivadas em um viveiro de plantas para testar sua germinação, sobrevivência e taxas de crescimento para diferentes solos e frequências de irrigação. Finalmente, o transplante na floresta de galeria foi avaliado mediante a observação das taxas de sobrevivência e crescimento de diferentes espécies nativas que foram plantadas diretamente na floresta. Nossos resultados mostram que o QBR global foi de 43,73 e que 73% das terras tinham qualidade insuficiente (64%) ou ruim (9%), no entanto algumas áreas mantiveram alta biodiversidade. Foram observadas 23.651 sementes germinadas no banco de sementes, em que a maioria das germinações (53%) veio do local preservado. Os solos recolhidos durante a estação seca também ofereceram mais plântulas (60%) do que os seus homólogos da estação chuvosa (40%). Quanto à restauração ativa, observou-se que algumas plantas são mais adequadas para viveiros e transplantes de árvores como *Sapindus saponaria*, *Vitex gardneriana* e *Celtis iguanaea* e que, selecionando as plantas e técnicas corretas, o ecossistema pode ser restaurado. Há ainda um longo caminho para a restauração da floresta de galeria do Pajeú. Estudos como este são essenciais para aumentar o conhecimento desse ecossistema. Esta pesquisa servirá como referência para orientar estratégias de manejo/restauração, priorizando ações e o desenvolvimento de políticas públicas de conservação a longo termo que garantam a integridade do ecossistema e suas funções.

Palavras-chave: floresta tropical seca; bancos de sementes de solo; restauração; estufa de árvores; recrutamento de mudas; integridade do ecossistema; índice de qualidade da floresta de galeria.

INTRODUCTION

Tropical dry forests are characterized for having a dry season that lasts at least three to four months, an average annual temperature greater than 25°C, and an average annual rainfall of 250–2000 mm (PORTILLO-QUINTERO; SÁNCHEZ-AZOFEIFA, 2010). They represent about 40% of the world's tropical forests, where more than half occur in the Americas (PORTILLO-QUINTERO; SÁNCHEZ-AZOFEIFA, 2010). In Brazil, this ecosystem is known as Caatinga.

The Caatinga is located in the northeast of Brazil and covers more than 735,000 km^2, which represents almost 10% of the country's territory (SANTOS *et al*., 2011; KOCH; Almeida-Cortez; KLEINSCHMIT, 2017). It is recognized as having one of the greatest biological diversity for a semi-arid region in the world (SANTOS *et al.*, 2014), including more than 1,000 plant species (SANTOS *et al*., 2011), of which at least 19.7% are endemic (SOUZA; RODAL, 2010; QUEIROZ *et al*., 2017). This ecosystem has experienced an intense degradation of its habitat (SANTOS *et al.*, 2011), mainly due to human activities (ANTONGIOVANNI; VENTICINQUE; FONSECA, 2018; KOCH; Almeida-Cortez; KLEINSCHMIT, 2017), and projections show that precipitation will be reduced with climate change (HOEGH-GULDBERG *et al*., 2018). It is estimated that around 80% of the vegetation has been modified (RIBEIRO-NETO *et al*., 2016), including gallery forests.

Gallery forests occur adjacent to waterways, comprising both terrestrial and aquatic components as well as the interface between them (NASCIMENTO, 2001; MARUANI; AMIT-COHEN, 2009; MOURA *et al*., 2018). Due to water availability, these ecosystems are different from the rest of Caatinga, being more productive, rich, and diverse (FERRAZ; ALBUQUERQUE; MEUNIER, 2006; DIAS; BOCCHIGLIERI, 2016; LAKE; BOND; REICH, 2017). Their importance lies within the ecosystem services they provide. These services may include the recharge of groundwater through rainwater absorption, prevention of floods, maintenance of water quality, formation of ecological corridors that allow gene flow, prevention of erosion, and siltation of riverbanks. They may also offer shelter and food for animals (PRICE; LOVETT, 2002). Furthermore, they provide benefits to local communities, particularly for the use of medicinal plants, fruits, and wood for construction or cooking (ARAÚJO; CASTRO; ALBURQUERQUE, 2007; ANTONGIOVANNI; VENTICINQUE; FONSECA, 2018).

Despite their importance, these ecosystems are seriously degraded as a result of anthropic activities. Due to their closeness to watercourses and their fertility, the soils of gallery forests are particularly attractive for farmers seeking ground for agricultural practices and livestock activities (PRICE; LOVETT, 2002; FERRAZ; AL-

BUQUERQUE; MEUNIER, 2006). Usually, the land is first deforested for agriculture activities and later is used as grazing sites for livestock (SANTOS *et al*., 2014; SCHULZ *et al*., 2016). These two activities have a high impact on vegetal communities (RIBEIRO-NETO *et al*., 2016; SCHULZ *et al*., 2018; 2019), resulting in loss and fragmentation of the gallery forests (NASCIMENTO, 2001).

In addition, a high number of exotic species have been introduced to improve productivity of livestock (NASCIMENTO *et al*., 2014; SCHULZ *et al*., 2016) and agriculture-based activities (DÍAZ-PASCACIO *et al*., 2018), which threaten native plant populations (NASCIMENTO *et al*., 2014; SCHULZ *et al*., 2019). This situation has resulted in the loss of native biodiversity. Santos *et al*. (2011) have reported that there has been an almost total loss of native biodiversity in the tributaries of São Francisco River. This severely alters the landscape and ecosystem integrity (SOUZA *et al*., 2013). As a result, the soils have eroded, the fauna has lost habitat, and the watercourses have experienced pollution, siltation, and even river death (PRICE; LOVETT, 2002; RAFFERTY; PIMM, 2018; TROVÃO; FREIRE; MELO, 2010). Nevertheless, there is a lack of specific information about the species, composition, and structure of Caatinga gallery forests (SILVA *et al*., 2015; SOUZA *et al*., 2013), as well as its state of conservation (NASCIMENTO, 2001).

These disturbances also have an effect on the soil seed bank (SSB), which is important for the regeneration of the forest and secondary succession. It has been reported that an increase in degradation level results in a decrease of seed density and species richness of the SSB (KASSAHUN; SNYMAN; SMIT, 2009; MENDES *et al*., 2015). When SSB is insufficient for forest regeneration, other measures have to be taken in order to restore gallery forest (BRAGA *et al*., 2008; REIS; Davide; Ferreira, 2014). This is called active or assisted restoration (HOLL; AIDE, 2011).

To perform an effective restoration, it is indispensable to know and understand the status and characteristics of the site. The first step is to know the ecosystem damage and then identify the system characteristics that are important in determining the ecosystem recovery. Therefore, we can determine realistic and effective goals for restoration (HOBBS, 2007). There are different variables that can be identified directly, like soil characteristics (SOUZA *et al*., 2018a), or indirectly, by GIS tools (DIAS *et al*., 2014). Combining direct and indirect methods, we intend to have a better understanding of the situation in the Pajeú river and so put into place effective restoration actions that are adequate for the ecosystem and population requirements.

The goals of this paper are:

- to characterize the ecosystem integrity of the gallery forest;
- to compare the soil seed bank in areas with different conservation levels;
- to evaluate different plants species and methods of production and transplantation for an active restoration.

METHODOLOGY

Study area

The study was held in the municipality of Floresta, PE, Brazil (8º35’60” S, 38º34’05” W), in the basin of the Pajeú River (Figure 1), an affluent of the São Francisco River, the most important river in the northeast region. The Pajeú is an intermittent river that starts in the municipality of Brejinho and runs for 350 km. The climate in this region is classified as “BSHW”, which means a hot and semi-arid region, with a defined dry season and rains in the summer. The annual mean precipitation is around 500 mm, and the temperature is about 25°C.

Ecosystem Integrity

The quality of the riverbank was evaluated according to its morphological conditions. To do so, there were two protocols applied: the gallery forest quality index—QBR (MUNNÉ *et al*., 2003) and an evaluation of the quality of the riverbank according to its land use (ACA, 2006). These protocols were applied on the Pajeú river, on a length of 76.17 km, starting from the last dam with high capacity and ending on the influx of the São Francisco River.

Quality index

Based on an analysis of satellite images, 33 sections of homogeneous vegetation were found along the waterway. In each of these sections, the QBR index was applied, as proposed by Munné *et al*. (2003). Both riverbanks were considered to determine the quality of the riparian habitat.

The QBR index assesses four components of the riparian vegetation:

- vegetal coverage (1);
- vegetal structure (2);
- quality of the vegetal coverage (3);
- naturalness of the river channel (4).

Due to the characteristics of the ecosystem, the index was modified according to the suggestions made by ACA (2006) and Sirombra and Mesa (2012). Each component has a value between 0 and 25, and the sum of the four components determine the QBR value (Table 1).

Spearman correlation analyses were made among the components of the QBR index, the QBR value, and the altitude in order to know the influence and relations between them. Once the QBR for each section was obtained, the global QBR value for the entire water body was evaluated, according to the following formula (ACA, 2006):

$$QBR_{WB} = \sum \frac{QBR_i x \left(section\ length\ QBR_i \right)}{total\ length\ WB}$$

In which:
QBR_{WB} = integrated QBR value for the entire water body evaluated;
QBR_i = QBR value obtained for the representative section *I*;
Section length QBR_i = length of the water body represented by QBR_i. Not the length of the section where the index was applied, but the length of the homogeneous area of which QBR_i is representative;
Total length WB = total length of the water body.

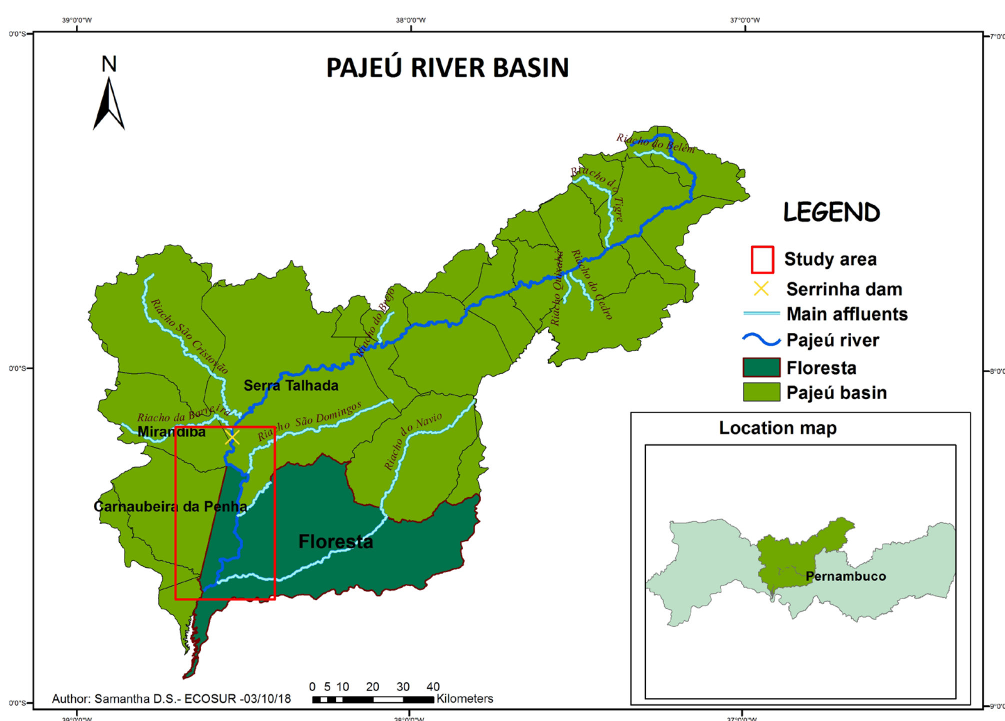


Figure 1 – Study area. Pajeú river basin and Floresta municipality, Pernambuco, Brazil.

Quality of the riverbank according to its land use

The naturalness of the floodplain land use was evaluated according to the protocol established by ACA (2006). The analyzed sites were 187.6 m from the riverbanks on either side. Satellite images were analyzed using Google Earth Pro 7.3.2.5491 (64-bit) and ArcGis 10.5. The land use was classified as agricultural soils/degraded soils, natural areas or urban areas, and the percentage of each land use was calculated. With the percentages obtained, an assessment of the quality of the riverbank was based on the information contained in Table 2.

Combining the results obtained by these protocols, we can obtain the quality of the riverbank based on its morphological conditions according to the Table 3 (ACA, 2006).

Table 1 – Quality of the riparian habitat obtained by the quality (QBR) index.

Quality of riparian habitat	QBR	Quality level
Riparian habitat in natural conditions.	≥ 95	Very good
Slightly disturbed forest	75–90	Good
Forest with major disturbance	55–70	Moderate
Strong alteration, bad quality	30–50	Deficient
Extreme degradation	≤ 25	Bad

Source: modified from Munné *et al*. (2003) and ACA (2006).

Table 2 – Quality of the riverbank according to land uses.

		Quality level		
		Very good	Good	Less than good
% Use	Natural	≥ 85	60	<60
	Agricultural	≤ 15*	40*	>40*
	Urban	0	5	>5

*Agricultural + Urban.
Source: ACA (2006).

Table 3 – Quality of the riverbank according to its morphological conditions.

		QBR index				
		Very good	Good	Moderate	Deficient	Bad
Land use quality	Very good	Very good	Good	Good	Moderate	Deficient
	Good	Good	Good	Moderate	Deficient	Bad
	Less than good	Moderate	Moderate	Moderate	Deficient	Bad

Source: ACA (2006).

Soil seed bank

Three sites were selected for the characterization of soil seed bank (SSB), all of them in Pajeú riverbanks. The first site was situated in a degraded area, where the native vegetation was removed. Historically, the land was used for conventional agriculture and livestock. The second was a semi-degraded area, used for livestock but at a low intensity, according to Schulz *et al*. (2019). And the third one was a well-conserved area without any historical record of vegetation removal or important disturbances in the past 70 years. The sites were considered as a gradient of perturbation from strongly degraded (site one) to preserved (site three).

Two periods of sample collection were done in 2015: one at the end of the dry season (January) and the other one at the end of the rainy season (July). In each site, 40 samples were collected randomly at least 10 m from the river. The soil was saved in bags and carried to the greenhouse of the Universidade Federal de Pernambuco (UFPE). The analysis of the seed bank was done using the germination method (BROWN, 1992). The soil was laid in polystyrene trays (29 × 29 × 5 cm). The soil was watered every day for three months. All germinated plants were counted and identified. If no germinations happened within a week, the soil was churned.

The seedlings were identified using specialized guides, through comparison with records from the Herbarium Dárdano de Andrade-Lima (IPA — Instituto Agronômico de Pernambuco), and expert consultations. The classification system APG III (2009) was followed.

The habit and dispersion syndrome of each species were recorded (RICHTER; STROMBERG, 2005). Relative frequency, abundance, and density were calculated. As for biodiversity, the species richness (S), Shannon diversity index (H'), Pielou equitability index (J'), and Sorensen similarity index (Ss) were calculated.

Active restoration

Active restoration was divided in three parts: the first was *Plant selection,* the second was *plant production*, and the third was *transplantation*.

Plant selection was based on a multicriteria analysis carried out in 2018. This analysis was based on previous local researches and the information available in literature. One list of all the trees/shrubs present in the gallery forest was elaborated based on Maia (2004) and Souza and Rodal (2010) and non-published data from the authors. Plant selection was also based on seed availability at the time of the experiment, either directly from the trees or shrubs or previously collected by locals.

Only native plants were considered for this forest restoration because it's the most certain way to obtain structure and function recovery in the ecosystem. A grid was elaborated considering four dimensions: adaptation to the environment (endemic from Brazil, drought tolerance, exclusive of gallery forest or occurs also in the caatinga *sensu stricto*). Ecological interest (quick growth, nitrogen fixer, erosion control, shade, fruit or flower visited or used by animals). Anthropogenic interest (used for the local population as food, fodder, wood, medicine, etc.) as described by Josélia and Tatiane Menezes from SOS Caatinga NGO and production feasibility (high germination rate, seed dormancy).

Plant production

The tree nursery was a relatively square structure with a shade canvas that blocked 50% of the light, an essential element for seedling survival where the sun shines about 2,800 hours a year (MOURA; MALHADO; LADLE, 2013; PORTILLO-QUINTERO; SÁNCHEZ-AZOFEIFA, 2010). This canvas was supported by wooden beams. Inside the tree nursery, wood pallets separated the area in four zones. These four zones were used to separate the treatment combinations that were applied to the seedlings. Each combination contained one of two levels of each treatment applied. These treatments were soil type and frequency of irrigation. For the soil type, half the seeds were planted in sand (S) and the other half were planted in a mixture of equal parts sand, goat manure, and clay (A). These plants were initially watered every day, then either every day (1) or every three days (3) when they reached a fourth leaf stage. Five species were used in this experiment; their selection was based on seed availability and nativeness. The species were *Mimosa pigra* (Fabaceae, Calumbi), *Vitex gardneriana* (Lamiaceae, Salgueiro), *Triplaris gardneriana* (Polygonaceae, Pajeuzeiro), *Celtis iguanaea* (Cannabaceae, Jamerim), and *Sapindus saponaria* (Sapindaceae, Saboneteiro). With these different combinations, S3 was used as the reference point because its conditions were most similar to the plants' natural habitat. In the tree nursery experiment, 1,000 seedling bags were used in total, therefore 200 bags were used per treatment combination, meaning every species inside a zone had 50 bags. In each bag, two seeds were planted and watered every day until the seedling had four leaves. If more than one seed germinated per bag, the weaker plant was removed. Four measurements were taken the day of emergence (germination), the survival, the height, and the number of leaves. The first two were taken on a daily basis for approximately 12 weeks whereas the other two were taken weekly for 10 consecutive weeks. This experiment focused on four variables: the percentage of germination at 10 weeks, the percentage of survival at 10 weeks, the maximum height at 10 weeks, and the maximum number of leaves per plant at 10 weeks. Germination is based on the 100 seeds that have been planted for each combination of treatments for each species, so a total of 400 seeds per species and 2,000 seeds in total. However, survival is based on the number of living plants compared to the number of plants saved for the experiment.

A secondary experiment was conducted alongside the first one. In this study, the same five species were submitted to pre-treatments of germination. The pre-treatments were the control, meaning no treatment at all (1), a cold-water submersion for 24 hours (2), a warm water submersion for 15 minutes, immediately followed by 30 minutes in the refrigerator (3), and a mechanical scarification using sandpaper (4). Each pre-treatment was applied to 150 seeds for each species. In total, 3,000 seeds were treated, planted, and watered daily. Germination and day of emergence were recorded. In both experiments, most of the data was modelled according to a generalized linear model (GLM), then ANOVAs were applied to the GLM to determine the effects of the treatments, species, or a combination of those factors on germination, emergence, survival, and growth (height and leaves). All data pertaining to germination and survival are based on a binomial distribution. On the other hand, data applied to growth rates were modelled by a linear model with a Gaussian distribution. ANOVAs were also applied to these linear models.

Transplantation

For an exploratory experiment, 120 plants of five species were transplanted at the end of the 2019 rainy season on Pajeú's riverbanks. The selected species were produced in a tree nursery in 2018: *Schinopsis brasiliensis* Engl., *Tabebuia aurea* (Silva Manso) Benth. & Hook. F. ex S. Moore), *Spondias tuberosa* Arruda, *Albizia inundata* (Mart.) Barneby & J.W. Grimes, and *Lonchocarpus sericeus* (Poir.) Kunth ex DC.

The treatments consisted of a bifactorial model of two and three levels. The *microenvironment* was the first factor, where reforestation taking place in sunny and shaded areas were evaluated. *Mulching* was the second factor, where the control had no mulch and other plants has either straw or coconut fibre at the base.

Transplantation design followed the Food and Agriculture Organization (FAO, 2017) recommendations. The trees were planted in 40 cm^3 holes and each tree was at least 3 m from each other. Irrigation was automatic, using hoses and a water pump. This system delivered 2 L of water a week to each plant. The transplantation was conducted on July 2019.

Height, basal diameter, and leaf number were recorded weekly, as well as survival status. Initial measures were taken after transplantation, and plants were monitored for three months. Survival was evaluated categorically as alive or apparently dead. Relative growth rate (RGR) was estimated as (log [final measure]—log [initial measure])/time in days. When performing the statistical analysis, all distributions were normal. ANOVAs were used to compare the RGR between treatments, and chi-square to compare survival. A GLM Logit was used to relate the initial measure with the probability of survival.

RESULTS

Ecosystem integrity

The global QBR value was 43.73, indicating a conservation status considered as deficient for the gallery forest: 64% of the sites were evaluated as having a deficient quality, 27% a moderate quality, and 9% a bad quality (Figure 2). The QBR index is negatively affected by small dams in 60% of dams the QBR index was worst downstream and 66.66% of sites with the worst quality were close to a dam.

Among the components of the QBR index, the one related to *naturalness* of the river channel was the one with the highest and most constant values in all the sections evaluated, where 42.4% of the sections have a value of 15. This is followed by the component *vegetal structure* with 27.3% of the data having a value of 10. The components of *vegetal coverage* and *quality of the vegetation* were the ones with the lowest values, 32.8% and 61.6% of the data, respectively, had a value of 0.

The Spearman correlation analysis showed that the variables that had a greater influence to determine QBR index were *vegetal coverage* (0.809) and *vegetal structure* (0.674), while the variables *naturalness*

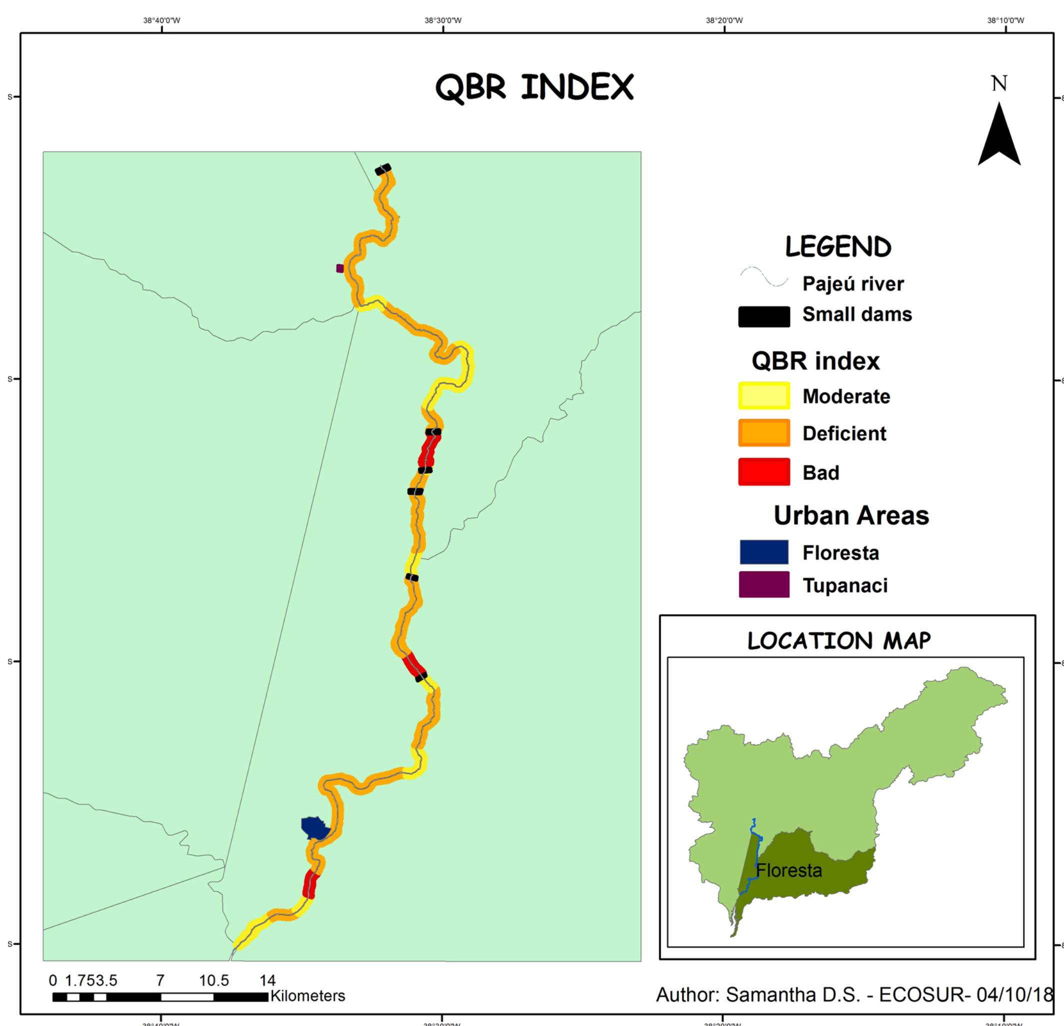


Figure 2 – Quality (QBR) index for Pajeú River, Floresta, Pernambuco, Brazil.

of the river channel (0.404) and *quality of vegetation* (0.273) had a low influence. The *altitude* variable was not correlated with the QBR index but had a positive correlation with *quality of vegetation* (0.403) and a negative correlation with *naturalness of the river channel* (-0.330). Among these variables, there was just one strong correlation (0.517) between *vegetal coverage* and *structure*. Nevertheless, it was interesting to note the negative correlation (-0.156) between *quality of vegetation* and *vegetal structure*.

Quality of the riverbank according to its land use

We evaluated 2,883 hectares of land to determine the quality of the riverbank according to land uses. It was found that only 40% of the area had natural land use, while 46% of the area had agricultural use, 13% were degraded soils, and 1% were urban areas (Figure 3). According to these percentages, the quality of the riverbank is *less than good*. Based on the results obtained, we found that the quality of the riverbank based on the morphological conditions of this section of the Pajeú river is *deficient*, indicating an important series of alterations which have modified its natural state.

Soil seed bank

Germination and density

A total of 23,651 germinated seeds were found for the three sites for both seasons. In accordance to the level of degradation, 53% were found in the preserved site, 26.2% in the degraded site, and 20.8% in the intermediate site. According to seasons, the dry season presented 14,315 (60%) seedlings, with 10,285 germi-

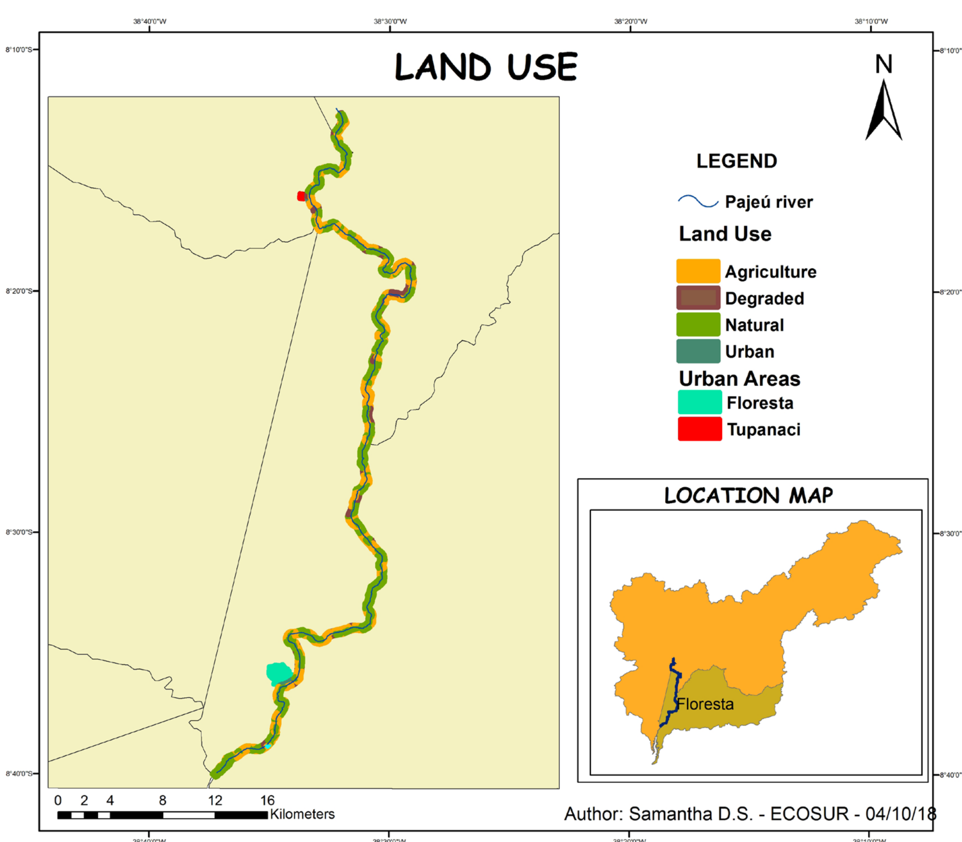


Figure 3 – Land use of the Pajeú basin, Floresta, Pernambuco, Brazil.

nating within the first four weeks and the rainy season presented 9,336 seedlings (40%), with 8,753 germinating in the first four weeks.

Seed density show significant differences between the preserved site and the intermediate as well as the degraded site, but only for the dry season. Comparing between seasons, the dry season presents higher density in preserved and degraded site than during the rainy season (Figure 4). The intermediate site's density did not differ statistically between seasons.

Floristic composition

A total of 89 species of 31 families were found in the SSB, whereof 74.1% were herbs and the rest were trees, shrubs/sub shrubs, or lianas. Adding both season samplings, the richness of the preserved site was 64 species, whereas the intermediate and disturbed site had 53 and 39, respectively.

For the preserved site, the families with the highest numbers, in both seasons, were Poaceae and Cyperaceae (Table 4). More morphospecies were found in the dry season (50) than in the rainy season (39), whereof 25 were common for both seasons.

In the intermediate site, 46 species of 22 families were found for the dry season and 25 species of 11 families for the rainy season, with only 18 species in common. Poaceae was the most represented family in both seasons. For the dry season, the next families with the highest abundance were Cypereceae, then Solanaceae and Rubiaceae. As for the rainy season, it was Portulacaceae and Rubiaceae (Table 4).

In the degraded site, Poaceae was the richest family in both seasons. In the dry season, the following families were Amaranthaceae, Cyperaceae, and Rubiaceae. While in the rainy season, the next family was Amaranthaceae (Table 4). A total of 34 species were found in the dry season and 20 in the rainy season, with 15 species in common.

Floristic diversity and similarity

The Shannon diversity index (H) was calculated for all three sites, preserved site (dry: 1.54, rainy: 1.17), intermediate (dry: 1.30, rainy: 0.85), and degraded (dry: 1.42, rainy: 1). In the dry season, there was no statistical difference between sites. In contrast, in the rainy season, the intermediate site shows statistical difference to the other two sites. Pielou's evenness index (J') did not show any statistical difference between sites nor seasons.

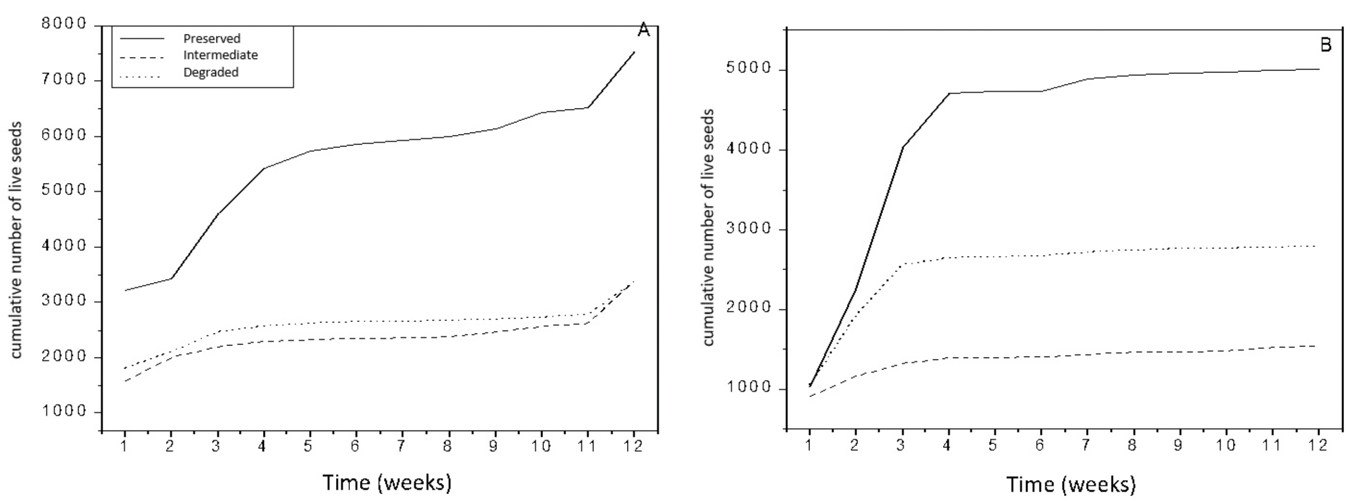


Figure 4 – Cumulative number of viable seeds from the seed bank of three riparian areas of the Pajeú River in a region of the Caatinga in the municipality of Floresta, PE, to (A) end of the dry season and (B) end of the rainy season, in the year 2015.

Species composition similarity between sites was evaluated through Sorensen. In the dry season, the higher similarity (63%) is between intermediate and degraded site; conserved and intermediate sites show 56% similarity, while conserved and degraded 48%. Rainy season keep the same tendency, but with a lower score (53, 44, and 41% respectively). Contrasting between seasons, a conserved area showed a similarity of 57%, intermediate 48%, and degraded 56%.

Plant selection

A total of 68 species (trees and shrubs) were evaluated with the multicriteria grid. Among these, 61 can be found in the gallery forest of Pajeú river and 14 of them are exclusive of this type of ecosystem (they cannot be found in the Caatinga vegetation *sensu stricto*). The other ones can be found both in gallery forest and in caatinga vegetation. Fifteen of the registered plants are endemic of Brazil (REFLORA, 2020), and three of them are in IUCN red list: *Myracrodruon urundeuva* and *Schinopsis brasiliensis* are endangered, and *Amburana cearensis* is considered in danger of extinction.

Each specie was scored by the multicriteria grid. The scores ranged from 2 to 25 (the maximum was 30). Only 22 species got score equal or higher than 15 (Figure 5). Whereof, five were selected, according to seed

Table 4 – Floristic composition by environment and season. Only families with more than one species are shown.

Families	Preserved		Intermediate		Degraded		Total spp.
	Dry	Rainy	Dry	Rainy	Dry	Rainy	
Amaranthaceae	2	2	2	1	3	2	3
Asteraceae	3	2	2	0	1	1	3
Cactaceae	0	2	1	0	0	0	3
Convolvulaceae	2	1	2	0	0	0	4
Cyperaceae	4	3	4	1	3	3	6
Euphorbiaceae	3	1	1	0	2	0	5
Fabaceae	4	0	3	0	2	1	6
Lamiaceae	2	3	2	2	1	0	3
Malvaceae	3	0	0	0	1	0	3
Phytollaccacea	1	1	1	0	1	0	2
Plantaginaceae	2	1	1	0	0	0	2
Poaceae	7	4	7	9	9	6	14
Portulacaceae	2	2	2	2	1	2	2
Rubiaceae	3	3	3	2	3	1	4
Solanaceae	2	1	3	1	0	1	3

availability, for exploring their production in greenhouses. *Albizia inundata, Licania rigida, Spondias tuberosa, Tabebuia aurea and Schinopsis brasiliensis*. *L. rigida*, and *S. tuberosa* are endemic to Brazil. *S. brasiliensis, S. tuberosa*, and *T. aurea* are present exclusively in gallery forest (REFLORA, 2020).

Plant production

The pre-treatment germination experiment/exit of dormancy

This experiment was carried out on four species: *Mimosa pigra*, *Celtis iguanaea*, *Triplaris gardneriana*, and *Sapindus saponaria* (*saboneteiro*). The results of the germination percentage and days of emergence by treatment are shown on Figures 6 and 7, respectively.

The statistical analyses show that, for *Mimosa pigra*, only hot water treatments had a significantly positive effect on the germination rate compared to other treatments. However, pre-treatments did not have an effect on the emerging time of the seedlings. For *Celtis iguanaea*, the best germination rate comes from the control treatment, being significantly better than hot water and sandpaper. In terms of emergence time, all treatments had a similar effect on this species, with an average emergence between 20 days (control and sandpaper) and 21 days (cold and hot water). For *Triplaris gardneriana*, hot water treatment is significantly worse in terms of germination rate than other treatments. This treatment also has the longest emergence time compared to other treatments. Finally, for *Sapindus saponaria* seeds, the sandpaper treatment favoured the germination rate compared to the other treatments. For this species, the sandpaper treatment also significantly reduced the time it takes for seeds to emerge.

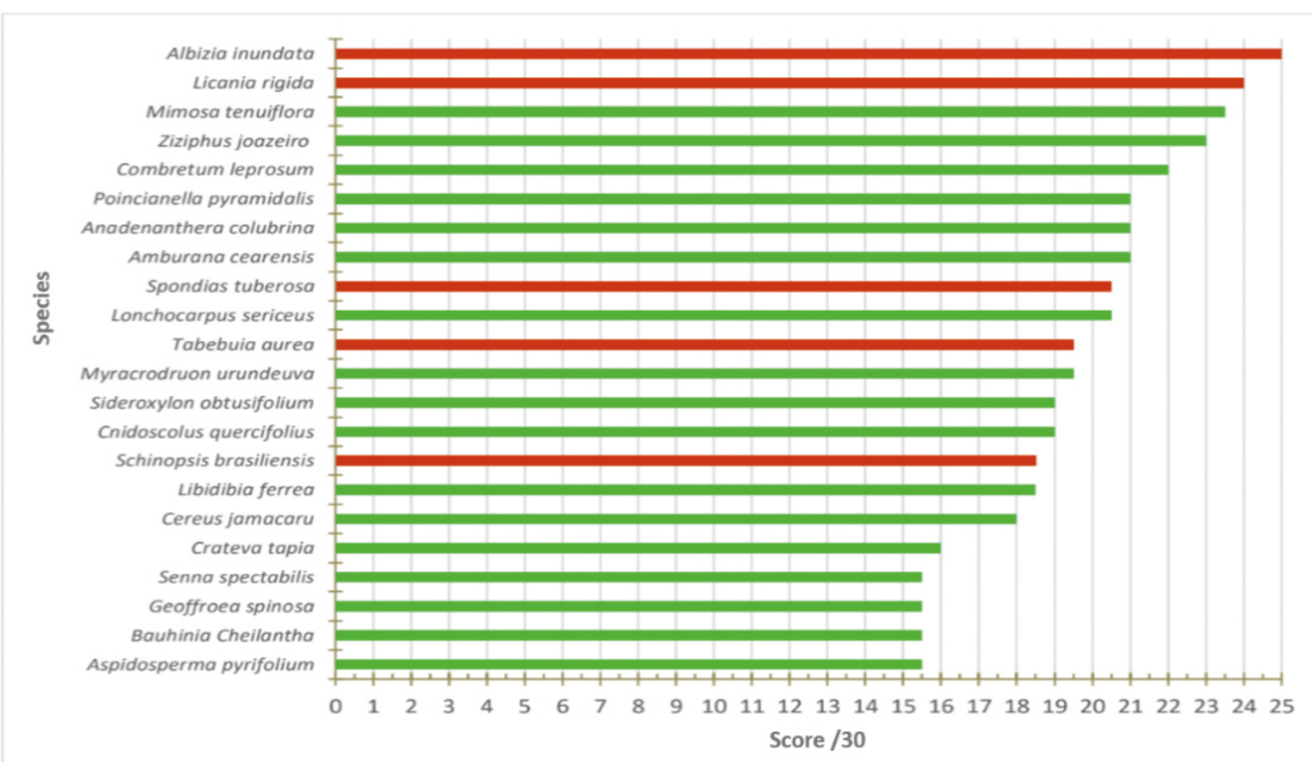
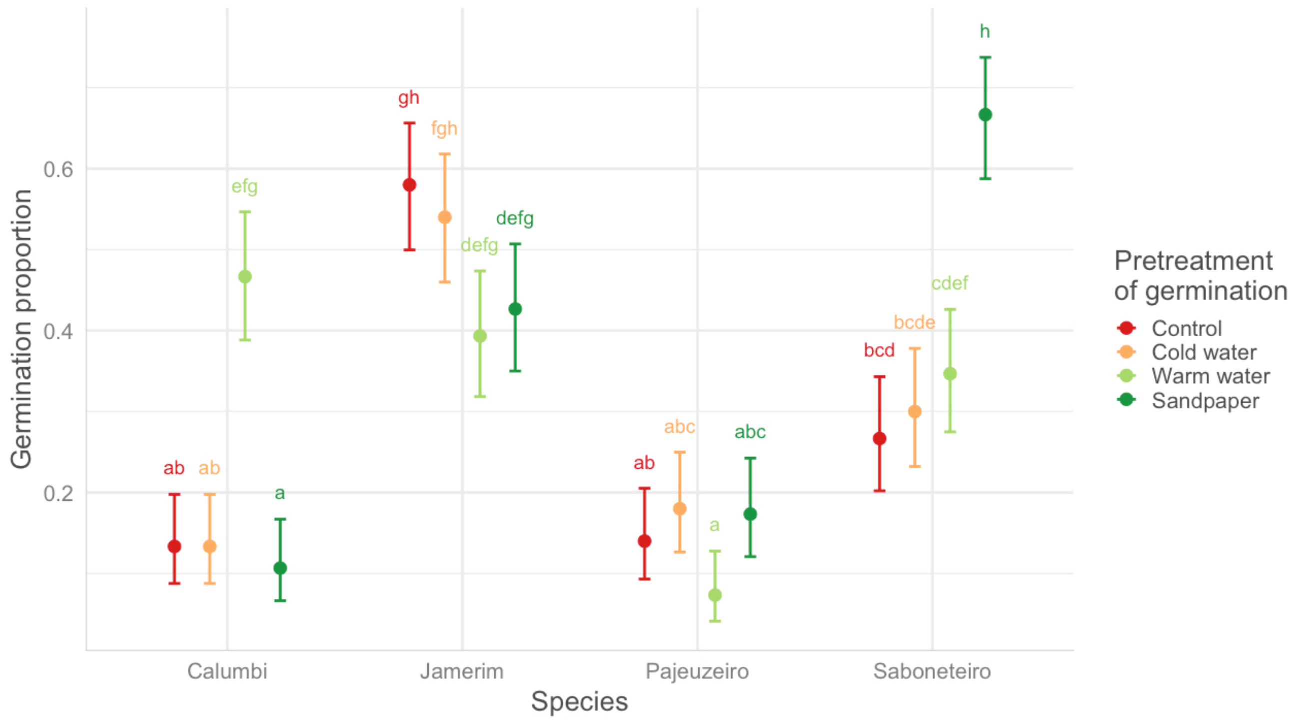
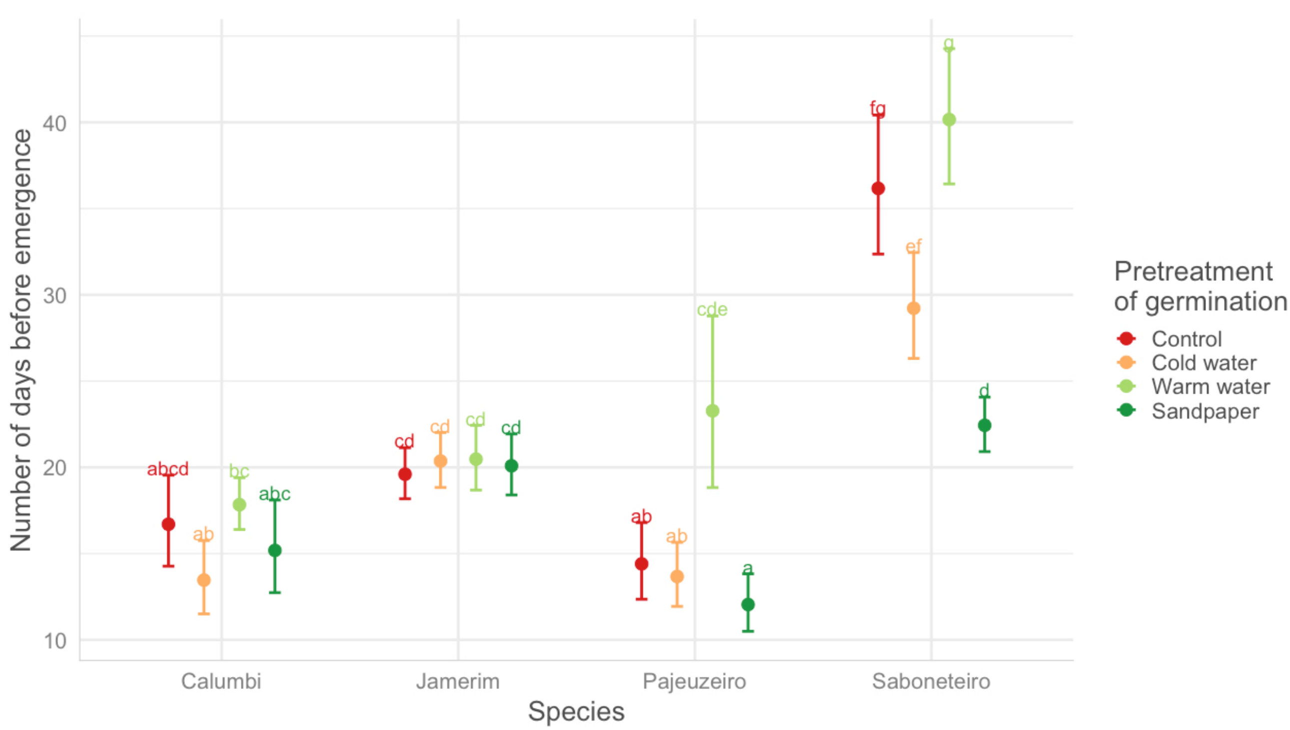


Figure 5 – Total scores obtained for native woody species following multi-criterion analysis; only species with a score above 15/30 are presented. The species in red are those that have been selected for the production of nursery plant.



*Letters represent statistically significate differences between treatments within the same species, as well as among different species.

Figure 6 – Comparison of the germination percentage by treatment and among species: *Mimosa pigra*, *Celtis iguanaea*, *Triplaris gardneriana*, and *Sapindus saponaria*.



*Letters represent statistically significate differences between treatments within the same species, as well as among different species.

Figure 7 – Comparison of the time of emergence of the seeds by treatment and among species: *Mimosa pigra*, *Celtis iguanaea*, *Triplaris gardneriana*, and *Sapindus saponaria.*

Effect of treatments on germination rate, survival rate and plant growth

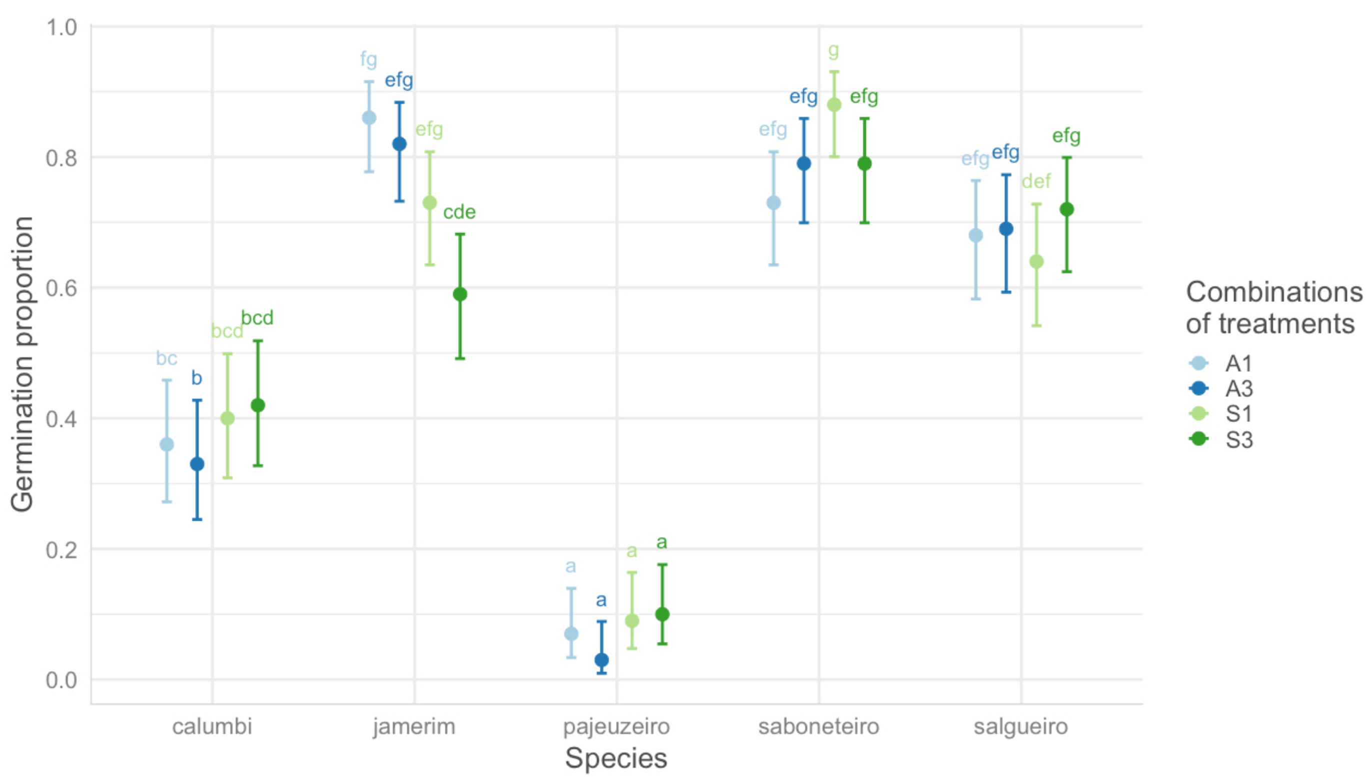
Germination rate and survival rate

Statistical analyses show that none of the treatment combinations have a distinct effect on plant germination for *Mimosa pigra* (33 to 42%), *Triplaris gardneriana* (3 to 10%), and *Vitex gardneriana* (63 to 70%). In the case of the *Celtis iguanaea*, germination is significantly favoured by the amended soils (A1 = 86% and A3 = 82%) compared to the plants in the S3 combination (59%). On the other hand, the combinations in amended soil are not statistically different from the S1 combination (73%). In the case of *Sapindus saponaria*, the proportion of seedlings watered daily is higher in sand (87%) than in the amended soil (72%), but the germination rates of combinations with 3-day watering (S3 = 78% and A3 = 79%) are not statistically different from those of combinations with daily watering (Figure 8). Finally, there is no difference between treatment combinations for plant survival rates for all species tested.

Growth rate

In general, combinations of amended soil treatments significantly improved the height growth of all species (Figure 9). A similar case arises for the growth rate of leaves per plant (Figure 10).

In general, combinations of amended soil treatments appear to significantly improve height growth of all species. The same is true for growth by the number of leaves per plant (Table 5). However, these differences



*Letters represent statistically significate differences between treatments within the same species, as well as among different species.

Figure 8. Comparison of germination proportions by combination of treatments (A1, A3, S1, and S3 in which S = sand and A = mixture of equal parts sand, goat manure, and clay; the numbers 1 and 3 mean watered frequencies: 1 = watered every day; 3 = every three days) and among species: *Mimosa pigra*, *Celtis iguanaea*, *Vitex gardneriana*, *Triplaris gardneriana*, and *Sapindus saponaria*.

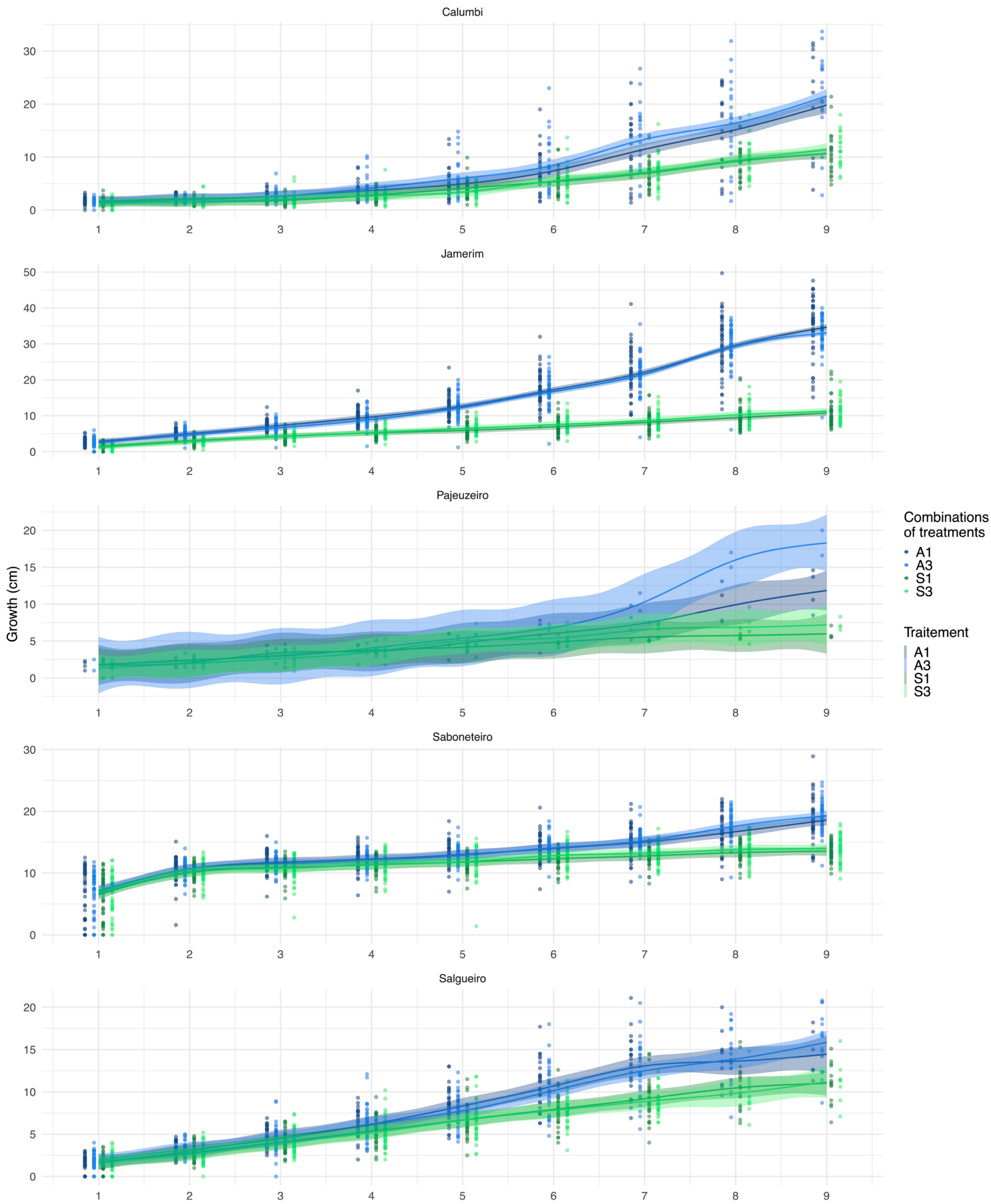


Figure 9 – Growth rates (height in centimetres) for nine weeks with a comparison of different combination of treatments (Soil types: S = sand and A = mixture of equal parts sand, goat manure, and clay; watered frequencies: 1 = watered every day; 3 = every three days) in and between the species: *Mimosa pigra*, *Celtis iguanaea*, *Vitex gardneriana*, *Triplaris gardneriana*, and *Sapindus Saponaria*.

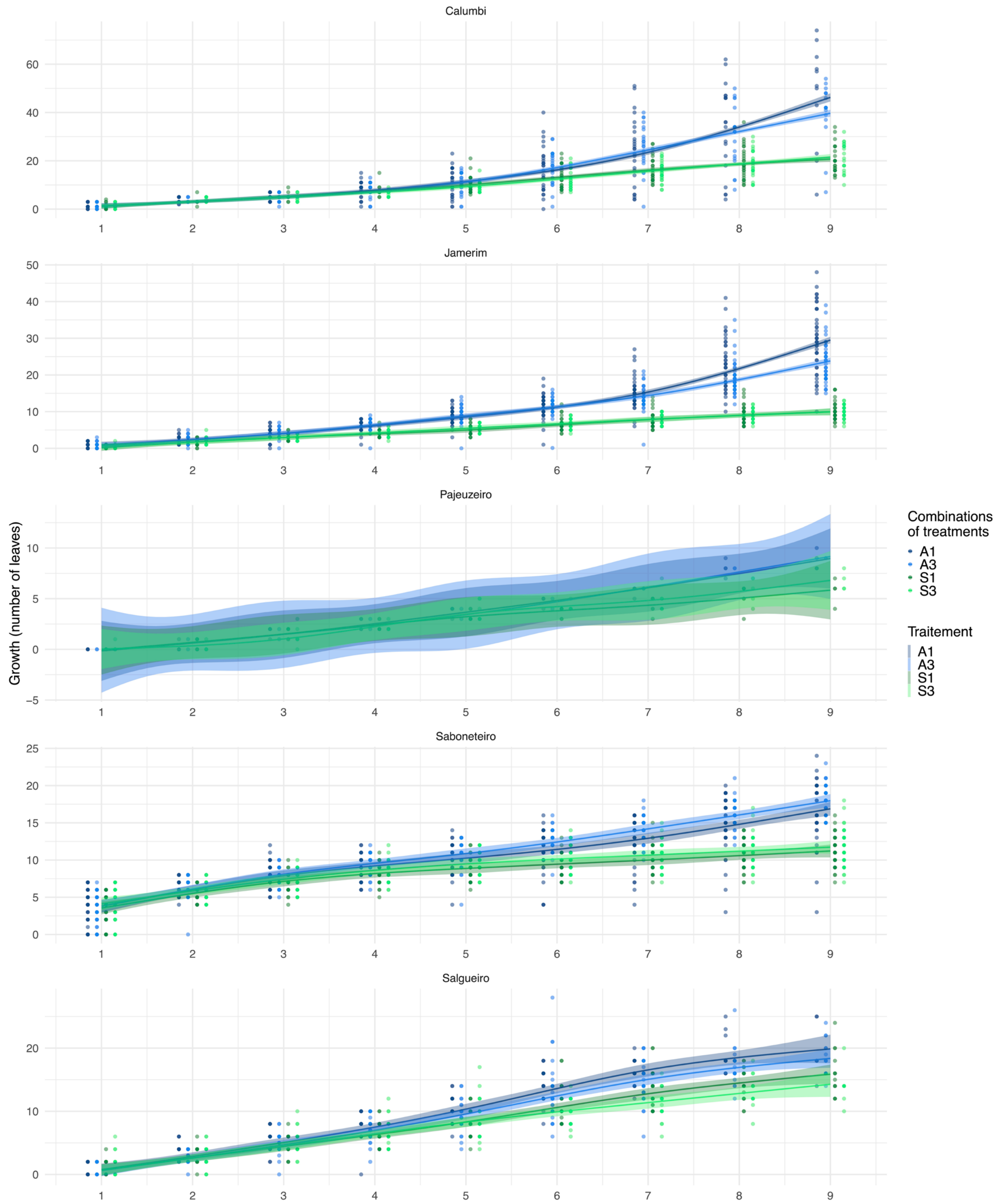


Figure 10 – Growth rates (number of leaves) for nine weeks with a comparison of different combination of treatments (Soil types: S = sand and A = mixture of equal parts sand, goat manure, and clay; Watered frequencies: 1 = watered every day; 3 = every three days) in and between the species: Mimosa pigra, Celtis iguanaea, Vitex gardneriana, Triplaris gardneriana, and Sapindus Saponaria.

are not always significant, such as *Triplaris gardneriana*, who shows no difference between treatment combinations for growth analysis. For *Mimosa pigra* (2.19 cm/wk) and *Sapindus saponaria* (1.32 cm/wk) species, the A3 treatment combination obtained the highest height growth rates while *Celtis iguanaea* (4.02 cm/wk) and *Vitex gardneriana* (1.94 cm/wk) obtained better growth under A1. On the other hand, the differences between the A1 and A3 combinations are not significant. The species follow the same trend with leaf count, where *Mimosa pigra* (4.23 leaves/wk), *Celtis iguanaea* (3.30 leaves/wk), and *Vitex gardneriana* (2.72 leaves/wk) have a faster increase in leaf count under the combination of A1 and *Sapindus saponaria* (1.69 leaves/wk) treatments under A3.

In the case of height growth, the combination of A3 treatments improves growth up to 1.9 times for *Mimosa pigra* and *Sapindus Saponaria*, while the combination of A1 treatments improves growth 3.8 times for *Celtis iguanaea* and 1.5 times for *Vitex gardneriana*. For growth with the number of leaves, an increase of 1.7 times can be observed in *Mimosa pigra*, 2.7 times in *Celtis iguanaea*, and 1.4 times in *Vitex gardneriana* under the combination of treatments A1. Finally, *Sapindus saponaria* sees an increase in leaf count up to 1.9 times higher with the A3 combination.

Transplantation

From the five selected species to transplantation produced in a tree nursery in 2018: *Schinopsis brasiliensis* Engl., *Tabebuia aurea* (Silva Manso) Benth. & Hook. F. ex S. Moore), *Spondias tuberosa* Arruda, *Albizia inundata* (Mart.) Barneby & J.W. Grimes, and *Lonchocarpus sericeus* (Poir.) Kunth ex DC; only *Lochocarpus sericeus* showed statistical difference for the microenvironmental factor, but just for the RGR-Height, being the shade environment where the plants grew more (p-value < 0.01). For basal diameter and leaf number, there were no statistical differences between treatments.

Mulching did not have any effect on growth (height, diameter, nor number of leaves) for any species. However, the interaction between microenvironment and mulching for *L. sericeus* showed effect for the RGR-Height, being sunny-straw lower than all the three shade treatments (shade-coconut, shade-straw, and shade-uncovered); sunny-coconut and sunny-uncovered (control) reported a growth between the other treatments with no statistical difference.

Final apparent survival was 95.8%, but there were any statistical differences between species nor microenvironment nor mulching. For *L. sericeus,* the final apparent survival was 96%, but with some regrowth plants. Initial measures did not have any effect on survival or on growth.

Table 5 – Growth rates by height and number of leaves for all five species by their combination of treatments.

	Height (cm/wk)				Number of leaves (#leaves/wk)			
	S3*	S1	A3	A1	S3	S1	A3	A1
Triplaris gardneriana	0.88	0.56	2.07	1.24	0.92	0.74	1.52	1.14
Mimosa pigra	1.31	1.16	2.19	1.81	2.44	2.50	3.89	4.23
Vitex gardneriana	1.28	1.39	1.90	1.94	1.99	2.05	2.46	2.72
Sapindus saponaria	0.77	0.71	1.32	1.20	0.91	0.88	1.69	1.52
Celtis iguanaea	1.21	1.07	3.82	4.02	1.22	1.21	2.72	3.30

*Soil types: S = sand and A = mixture of equal parts sand, goat manure, and clay; watered frequencies: 1 = watered every day; 3 = every three days.

DISCUSSION

Ecosystem integrity

The quality of the Pajeú riverbank, as measured by the QBR index and the land use, indicates a strong alteration of the habitat. Alterations in the Caatinga have occurred for a long time (SANTOS *et al*., 2014). Specifically, in the riverbanks, land use change is common due to their favourable characteristics for agriculture and livestock (VALERO; PICOS; ÁLVAREZ, 2014), resulting in habitat loss and affecting the species composition of a community (VALERO; PICOS; ÁLVAREZ, 2014).

In the Pajeú River, these are the two main anthropic activities, and so, they have caused a decrease in native vegetation and the invasion of exotic plants, particularly the algaroba (*Prosopis juliflora*) (NASCIMENTO *et al*., 2014), which was introduced to Brazil in 1942, with the intention of providing a supplement for livestock feed (BURNETT, 2017; CUNHA; SILVA, 2012; GOMES; BARBOSA, 2008; SANTOS; DIODATO, 2016, 2017; SCHULZ *et al*., 2016). This invasive plant has resulted in a change in the composition and abundance of species (ARAÚJO *et al*., 2018; RIBEIRO-NETO *et al*., 2016). Allelopathic effects have been reported for this species (CABI, 2020), as well as an increase in soil acidity (SOUZA *et al*., 2018b). Areas with a good arboreal component dominated by this exotic species, and so, the areas with a greater proportion of native species are those with fewer trees. This explains the negative correlation found between vegetation structure and quality of vegetation.

As reported by Souza *et al*. (2013), vegetal coverture was the main variable that determines the quality of the gallery forest. In this case, the fact that the variables naturalness of the river channel and quality of vegetation had almost no influence over the QBR index is due to their low variability among the different sites studied. On the other hand, altitude did not have influence on QBR index, probably because the altitude difference is relatively small (100 metres). Nevertheless, it had a positive influence on the quality of vegetation. This may be due to the difficult access conditions found in the upstream parts of the river that makes difficult to modify native vegetation. This coincides with other studies, where it has been reported that inaccessibility positively influences the conservation of the sites (REIS; DAVIDE; FERREIRA, 2014; VALERO *et al*., 2014; LAKE; BOND; REICH, 2017).

The bad conservation status found in our days on the Pajeú River is the result of several factors that have caused strong alterations to the riverbank components. Agricultural land use leads to deforestation (VALERO; PICOS; ÁLVAREZ, 2014), less species diversity (DÍAZ-PASCACIO *et al*., 2018), and decrease connectivity between the riverbank and adjacent natural vegetation (RODRÍGUEZ-TÉLLEZ *et al*., 2016). This provides ideal conditions for the establishment of *P. juliflora* (SANTOS; DIODATO, 2016), which is then disseminated by goats and bovine, facilitating the process of invasion (SCHULZ *et al*., 2016). Once established, the *P. juliflora* prevents the establishment of native species, affecting the function of the ecosystem (NASCIMENTO *et al*., 2014).

Soil seed bank

Germination and density

After the first month in the greenhouse, 71.8% (dry season) and 93.7% (rainy season) of seeds germinated. This high percentage of germination may indicate a quick response of seeds to water. The herb predominance can explain this response, since they need to germinate as soon as possible after the rain season starts to ensure a new seed generation because of their short life cycle (COSTA; ARAÚJO, 2003). By doing that, the herbs are advantaged in environments like the Caatinga, where the annual precipitation is low and irregular (SANTOS *et al.*, 2011). This pattern of germination has been reported by Costa and Araújo (2003), Mamede and Araújo (2008). The observed density values (except for conserved site at end the of the dry season) are consistent with the reported by Garwood (1989) for tropical forest, lower than 500 seeds/m^2. However, they are higher than the values reported by Santos *et al*. (2010) and Mamede and Araújo (2008), but lower than the published in others works for arid or semi-arid ecosystems (COSTA; ARAÚJO, 2003; KASSAHUN; SNYMAN; SMIT, 2009; SILVA *et al.*, 2015).

While dry season, the effect of anthropocentric disturb reducing the SSB was evident, and it may be related not only with the kind of impact, but its intensity (KASSAHUN; SNYMAN; SMIT, 2009). At the end of the rainy season, lower values were recorded perhaps because the seeds were recruited as a seedling while the rainy season (SILVA *et al*., 2013). Santos *et al*. (2011) suggest that seed diminution may be related to the irregular rain pattern, which affects the flowering and fructification, and by consequence, the seed production, concluding that the number of seeds is directly proportional to the amount of rain. Silva *et al*. (2013) also support that total precipitation determine the seed production but suggest that years of high precipitation are required to keep the seed stock on soil.

Floristic composition

Found richness is higher than reported by other works on dry forests (COSTA; ARAÚJO, 2003; MAMEDE; ARAÚJO, 2008; KASSAHUN; SNYMAN; SMIT, 2009), and in others works on caatinga's gallery forest (SANTOS *et al*., 2011; SANTOS *et al*., 2013).

The most abundant families, both in sites and seasons, are herbs. Poaceae was the most represented family, with a total of 14 species. This family is known by dominate some ecosystems and adapt to them. Moreover, it has a good development in sunny places.

Fabaceae was the only family with tree seeds in this study, *P. juliflora* and *L. leucocephala*, both exotic and invasive. Even though *P. juliflora* was reported as invasive of degraded areas, it has an important abundance in the SSB of the conserved area, maybe because the conserved site is surrounded by disturbed areas and also because the site is visited by caprine livestock, which is raised free on the caatinga vegetation. *L. leucocephala* was the third most abundant species of the degraded site and be considered one of the 100 worst invasive species of the world, to which the loss of biodiversity is attributed (NASCIMENTO *et al*., 2014).

Herbs predominance may be related to a life cycle, the high seed production, and their capacity to bear adverse conditions such as high temperatures and droughts. Another factor that contributes to the high number of herbs is that all the sites are surrounded by crop and grazing fields, and not by areas with trees that could be a propagules source. According to Braga *et al*. (2008), a seed bank dominated by herbs proof the bank is ready to start a successional process in a disturbed area.

Santos *et al.* (2013) suggest that the high number of herbs is due to a continuous herb seed production that contrasts with the lower seed production of trees or shrubs. Furthermore, because of the lower viability, bigger seeds vulnerable to an intense depredation and fungi attacks. Shannon values are lower than the ones reported in other works about caatinga seed bank (MAMEDE; ARAÚJO, 2008).

Plant selection

The Multicriteria grid developed for the project allows us to compare and classify tree and shrub species in a pondered scale easy to interpret. Ecological and social criteria were established in order to maintain biodiversity and maximize ecosystem services. Nevertheless, the score of one species may be determined by the availability of information; therefore, species poorly known or studied have lower scores. It was a challenge to find trustable and complete information for planting and cultivating the plants. Some of the species are barely mentioned in literature, and some of the data (such as germination rate or methods to break dormancy) are contradictory. Even if there is focus on the plantation and culture of native species of Caatinga and gallery forest (MAIA, 2004; CARRIÓN *et al.*, 2017), it is still necessary to continue to develop knowledge about the plants and its culture.

Pre-treatment germination

In preliminary research on germination pre-treatments, which aim to bring seeds out of their dormancy, the most recurrent treatments were hot or boiling water and sulphuric acid (NASR; SAVADKOOHI; AHMADI, 2013;

RASEBEKA; MATHOWA; MOJEREMANE, 2014). Since the current experiment wanted to make the manipulations accessible to everyone, sulphuric acid was not used. However, it was anticipated that hot water treatment would be the most effective way to bring the seeds out of their dormancy. In fact, only *M. pigra* germination was improved by hot water. For its part, mechanical scarification had a positive effect on germination and emergence of *S. saponaria*, information already available in the literature (SAUTU *et al*., 2006). Finally, *T. gardneriana* and *C. iguanaea* did not see any difference between treatments. It is difficult to determine why these two species did not respond to the dormancy release methods, since there is no information in the literature. However, in the case of *T. gardneriana*, it is possible that the seed does not have exogenous dormancy, but rather endogenous dormancy (GENEVE, 2003). Indeed, this rather delicate seed, found inside a samara, does not have the hard exterior of the other species tested. Consequently, the treatments applied did not have the desired effect. It is even possible that the hot water damaged the seeds, since the germination rate for this treatment is significantly lower than for the other treatments. A review of the scientific literature indicates that endogenous dormancy can be lifted by constant temperature, alternating hot and cold temperatures, potassium nitrate or gibberellic acid treatments (GENEVE, 2003). These treatments could therefore be tested at a later stage. In the case of *C. iguanaea*, the seeds are covered with a harder outer layer. However, the control treatment showed a better germination rate than hot water and scarification. Therefore, the hypothesis put forward here is that the treatments selected for the experiment were ineffective in bringing the seeds out of their dormancy and that no treatment is needed for the germination rates were high.

Growth and sustainability

After a thorough analysis of the results, I recommend growing *Sapindus saponaria*, *Celtis iguanaea* and potentially *Vitex gardneriana* in amended soils, and watering every two days.

As a first step, we suggest growing *V. gardneriana*, since it has very good growth rates in amended soils (4.02 and 3.82 cm/week) as well as good germination rates (86 and 82%) and excellent survival rates (98 and 94%). Among the species studied, it was the easiest to grow. It has a simple dormancy, or even no dormancy at all, and its maintenance requires daily or bi-daily watering. Irrigation frequencies should be closer together, since the amended soils seem to dry out more quickly. Indeed, this soil has allowed for superior plant growth and therefore requires more water. During the nursery experiment, *V. gardneriana* was the first species to show symptoms of water deficit; wilted leaves, lack of turgidity, dry and cracked soil. More frequent watering is therefore recommended. This species is also a good choice for self-cultivation and forest restoration since it has a good regeneration capacity. In fact, several plants had been injured or cut by an animal, but they all reformed apical buds and restarted their growth.

Secondly, we believe that *S. saponaria* would be a good candidate for nursery culture and gallery forest reforestation. Although it has low growth rates compared to the other species tested (0.71 to 1.32 cm/week), it is a species with good germination rates (73 to 88%) and excellent survival rates (98 to 100%). This secondary succession species (ROMÁN-DAÑOBEYTIA *et al*., 2012) is very easy to grow under any conditions tested and regenerates after injury. Despite lower growth rates, this species has a rapid initial growth rate, reaching 10 cm in height after only 2 weeks. This height is not reached until 5 weeks for *C. iguanaea* and 6 weeks for *V. gardneriana*. In addition, *S. saponaria* had the lowest emergence time in the nursery experiment, with an average of 16 days before germination compared to 17 days for *C. iguanaea* and 31 days for *V. gardneriana*. Ultimately, the pre-treatments applied to the latter two species were not ideal, but this reinforces the idea of simplicity in the cultivation of *S. saponaria*. This species has an easier and more feasible dormancy exit than the other two. In addition, it has many uses and economic benefits for the local population. Indeed, *S. saponaria* already has a recognized role in the recovery of degraded areas, in addition to its medicinal role against ulcers, inflammation, and skin lesions (PELEGRINI *et al.*, 2008; NEVES *et al*., 2018). Furthermore, the fruit is used for the extraction of saponin, used in soap (RIBEIRO *et al.*, 1999 *apud* NEVES *et al.*, 2018), and for its insecticidal properties (PREVIERO *et al*., 2010 *apud* NEVES *et al.*, 2018). Lastly, its heavy, hard, and compact wood is used for construction and the manufacture of tools and toys (LORENZI, 1998).

Finally, the last species recommended for home cultivation and reforestation of the Caatinga is *V. gardneriana*. This specie has germination rates of 64 to 72% and survival rates of 84 to 95%. In addition, it has some of the highest growth rates in the nursery experiment, 1.90 and 1.94 cm/wk. This species is recommended primarily for cultivation and forest restoration for two reasons. The first is the particularity of *V. gardneriana* seeds, which contain several embryos that have the possibility to germinate. This is a particularly interesting feature for reforestation efforts. It is also an interesting feature for other types of reforestation than transplantation, including direct sowing. Possibly, the seeds will improve the germination rate in direct sowing and intraspecific competition may force natural selection of the most suitable individuals to survive. Furthermore, according to Josélia Menezes (SOS Caatinga NGO), *V. gardneriana* is a shrub specie found on the banks of the gallery forests of the Caatinga. Menezes argues that *V. gardneriana* is a very important species for gallery forests, particularly for its role in maintaining the banks and thereby limiting erosion (Josélia Menezes, pers. comm., September 2019). However, this could not be verified in the literature, which does not address the ecological services played by this species. Finally, the species also has an economic role. Its leaves contain compounds used for pharmaceutical and insecticidal purposes (RANI; SHARMA, 2013; SENA FILHO *et al.*, 2017) and its wood is used in the manufacture of poles and tools (TPD, 2019).

Transplantation

Difference in growth in shaded areas may be explained by the nurse effect. The nursing plants benefit the growth of seedlings because of the reduction of stressful factors, both biotic (as herbivory) and abiotic (as high temperature, reducing evapotranspiration, and increasing nutrients in soil) (MOURA; MALHADO; LADLE, 2013; CARRIÓN *et al.*, 2017). Literature reported that seedlings from some species are only founded under the canopy of nursing plants (PATERNO; SIQUEIRA-FILHO; GANADE, 2016; CARRIÓN *et al*., 2017). Competition for water in seasonal dry forest may affect growth, but relation benefits-competition depends on species and their ontogeny (TROVÃO; FREIRE; MELO, 2010).

Mulching did not show either any statistical difference between treatments neither for species nor growth measure. However, in other seasonal dry forest had been reported that mulching increase 65% survival and the plants grow nine times faster (BARAJAS-GUZMÁN; CAMPO; BARRADAS, 2006). The final apparent survival was more than 95%, which is high compared with others seasonally dry forest and other gallery forests (HOLANDA *et al*., 2010; REIS; DAVIDE; FERREIRA, 2014; TORRES; RENISON, 2015). All the apparent dead plants were in the sunny treatment, however there was any statistical difference on microenvironment, nor mulching nor factor-interaction for any species.

Contrasting with another species in dry forests (VEGA-RAMOS, 2016), initial measures had no effect on survival or growth for any neither treatment nor species. That may be explained because it has been documented that the root development is more important than aerial part (DAMASCENO, 2016), but it was not evaluated on this project because it is a destructive measure.

A long-term monitoring to evaluate the ecosystem attributes (such as diversity, management, and functionality) and comparison with attributes of the reference ecosystem to assess the effectiveness of the restoration is essential (FERNANDES; FREITAS; PIÑA-RODRIGUES, 2017; GALETTI *et al*., 2018).

CONCLUSION

Gallery forest of Pajeú river showed high degradation and a low ecosystem integrity, only the areas of more difficult access were little more conserved. This degradation has affected the soil seed bank, and now, even in conserved sites, the proportion of seeds of native trees and shrubs is low. Those conditions had facilitated the establishment of invasive alien species, which makes even more difficult the secondary succession. For that reason, active restoration is necessary. Selecting the species and developing a plan for seedlings production are some of the first steps. Local people have shown they have much knowledge about native species, their uses and management. Seedlings production using native and local seed is possible, with a high rate of growth and germination. And the transplantation to a natural area seems to be effective in the short term.

There is still a long way to restore Pajeú's gallery forest, but studies like this are essential to increase knowledge of the ecosystem. This study could serve as a reference to design management/restoration strategies, prioritize actions, and develop public policies that ensure integrity and long-term conservation of the ecosystem and their functions.

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