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DIRECT SEEDING FOR RESTORATION IN TABULEIRO FORESTS: EVALUATION 16 YEARS AFTER IMPLEMENTATION

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Resumo

Semeadura direta para restauração florestal em Tabuleiros: Avaliação após 16 anos de implantação. Este estudo foi desenvolvido na Reserva Natural Vale, em Linhares, Espírito Santo, Brasil, com o objetivo de testar o uso da semeadura direta como método de restauração florestal em Floresta de Tabuleiros após 16 anos da sua implantação. Foram avaliados 3 diferentes tratamentos, onde em cada um foram utilizadas 29 espécies nativas com diferentes preparos da área, sendo eles: Roçada manual total + queima do resíduo + herbicida (T1); Roçada manual total + queima de resíduo (T2) e Roçada manual total (T3). Cada tratamento apresentou área de 100 m² (10x10 m) e intervalo entre parcelas de 2 m. Foi avaliada a sobrevivência dos indivíduos implantados na semeadura direta bem como a regeneração natural dos indivíduos ingressantes com Diâmetro à Altura do Peito (DAP) ≥ 15 cm. Como resultados, após 16 anos pode-se observar a presença de 16 espécies e 106 indivíduos, assim como índice de diversidade de Shannon (H') = 1,917 e equabilidade (P) = 0,691, demonstrando uma baixa diversidade florística na área. As espécies que mais se destacaram (maior número de indivíduos), foram: *Joannesia princeps* Vell. L.C.; *Spondias venulosa* (Engl.) Engl e *Peltophorum dubium* (Spreng.) Taub. Como sugestão, recomenda-se a utilização da semeadura direta de maneira complementar à outras técnicas de restauração, devendo haver o monitoramento da área a fim de avaliar a evolução do processo e a necessidade de eventuais intervenções para auxiliar de forma assertiva, todo o processo.
Palavras-chave: Reflorestamento; áreas degradadas; sementes florestais, monitoramento.

Abstract

This study was carried out at the Vale Natural Reserve in Linhares, Espírito Santo, Brazil, with the objective of testing the use of direct seeding as a forest restoration method in Tabuleiro Forest (also called Tableland Forest outside of Brazil) 16 years after its implantation. Three different treatments were evaluated in which 29 native species with different area preparations were used, namely: Total manual mowing + residue burning + herbicide (T1); Total manual mowing + residue burning (T2); and Total manual mowing (T3). Each treatment had an area of 100m² (10x10m) and an interval between plots of 2 m. The survival of the individuals implanted in the direct seeding was evaluated, as well as the natural regeneration of the new individuals with Diameter at Breast Height (DBH) = 15 cm. As a result, after 16 years we can see the presence of 16 species and 106 individuals, as well as a Shannon's diversity index of (H') = 1.917 and Pielou's index (P) = 0.691, demonstrating a low floristic diversity in the area. The species which stood out the most (most individuals) were: *Joannesia princeps* Vell. L.C.; *Spondias venulosa* (Engl.) Engl.; and *Peltophorum dubium* (Spreng.) Taub. As a suggestion, it is recommended to use direct seeding in a complementary manner to other restoration techniques, and there should be monitoring of the area in order to assess the evolution of the process and the need for any interventions to assertively assist the entire process.
Keywords: Reforestation; degraded areas; forest seeds, monitoring.

INTRODUCTION

It is estimated that there are between 1 and 6 billion hectares of degraded areas in the world, which correspond to respectively 22 and 66% of the world area. The estimated value in Brazil according to information from the Ministry of the Environment (MMA, 2015) is approximately 140 million ha, which corresponds to 16.5% of the territory.

Within this context, the Atlantic Forest biome, which originally occupied 1.2 million km² in 17 Brazilian states, currently has approximately 29% of its original coverage as a result of occupation and development of unsustainable anthropic activities, such as the use of non-conservationist soil and deforestation techniques (MMA, 2015). In view of this scenario, an advancement of actions which make it possible to leverage/accelerate the restoration process, as well as identify species which have greater potential for use in each technique and region is fundamental for the restoration success of altered areas and thus enable a gain of scale in restoration.

In this sense, in an attempt to "imitate" the natural regeneration process that occurs in the environment, direct seeding can have great potential for application due to the positive results, lower costs and often greater effectiveness than active actions such as planting seedlings, mainly for establishing the initial phase of the restoration (CHAZDON, 2012; FERREIRA *et al*., 2015; FREITAS *et al*., 2019). Thus, the advantages of seeding in relation to planting seedlings are the ease of implantation (lower cost of transport and labor), higher performance and the possibility of forming mixtures containing a high diversity of species from different ecological groups (ISA 2009; CHAZDON, 2012).

However, it is worth noting that numerous issues can influence the success of using this technique, including: type of impact and disturbance intensity suffered in the area (CHAZDON, 2012), the surrounding site/landscape conditions (SANTOS *et al*., 2012), soil conditions (GONÇALVES *et al*., 2020), luminosity, climate and local precipitation conditions (LIMA *et al*., 2014), mix of species used in the seed mix and density (ISA, 2009), seed quality (viability/germination rate), storage and seeding depth (LESSA *et al*., 2013), need to break dormancy (PEREIRA *et al*., 2013), among others. Thus, as addressed by the authors, this technique has great potential for application, but the characteristics of the area and environmental conditions can significantly affect the results produced.

In this sense, one of the main problems faced in the use of the direct seeding technique (in addition to the reduced number of studies with long-term monitoring), is the low germination rate and field survival presented by some species, which may be directly related with the quality of the seeds used (CECCON *et al*., 2015). In view of this, numerous issues need to be better understood in order to fill in the existing gaps and direct actions to advance restorations in a more effective way.

In view of the above, this work sought to evaluate the efficiency of restoration by direct seeding under different soil preparations after 16 years of its implementation, in addition to the floristic dynamics of the shrub and tree community and to identify species with the greatest potential for use in restoration via direct seeding of the area.

MATERIAL AND METHODS

The study was conducted at the Vale Natural Reserve, located in the municipality of Linhares, Espírito Santo, Brazil, with a conservation area of approximately 23,000 hectares (Figure 1). Together with the Sooretama Biological Reserve, both add up to approximately 46,000 ha, representing the largest forest massif in the entire state.

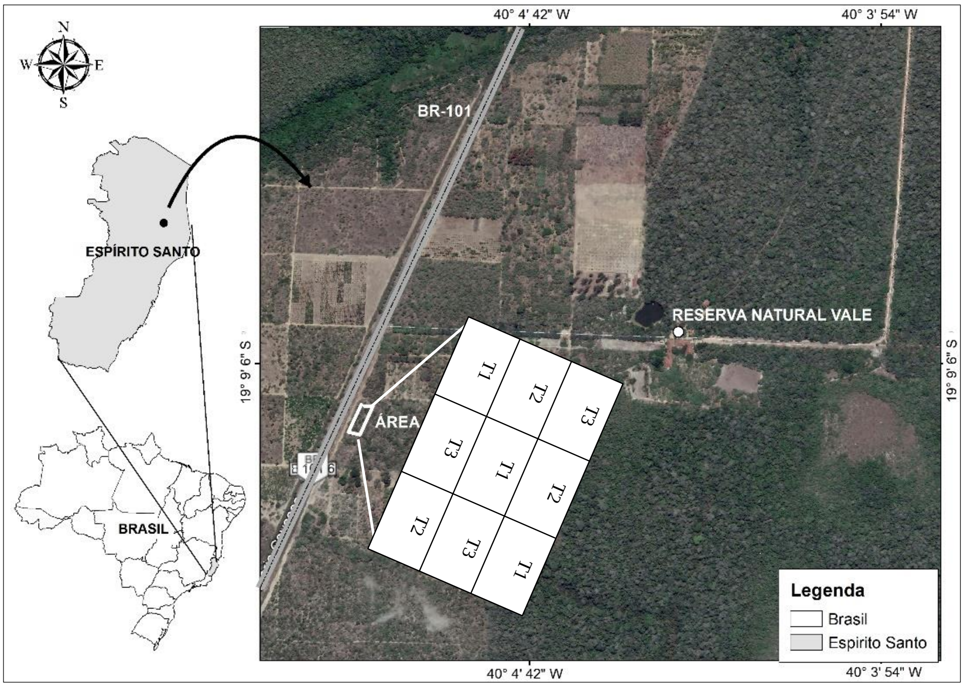

Figure 1. Study area location and design.
Figura 1. Localização e croqui da área de estudo.

The area's vegetation is classified as Dense Ombrophylous Lowland or Tabuleiro Forest (IBGE, 2012) and the region's climate is Aw type according to the Köppen classification, with rainy summers and dry winters (KOPPEN, 1984). The average annual temperature (measured from 1975 to 2019) is approximately 23.4 ºC and the average annual precipitation is 1184 mm (RNV, 2019). The relief is flat, with well-drained soils classified as

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Yellow Dystrocohesive Argisol, with sandy texture in the A horizon and clayey in the B horizon (EMBRAPA, 2018).

The study area was previously used for a silvopastoral experiment (*Eucalyptus* spp. and *Brachiaria decumbens*), being inserted in an area which borders an area of altered native forest and research plots in different stages of development, in addition to being close to an area with invasion of *Acacia mangium* (separated by the highway). The experiment in question was implemented in May 2003, in which the direct seeding technique was tested under different preparations (ROLIM *et al*., 2007). The experiment was set up in 3 randomized blocks, with 3 treatments referring to different site preparations, namely: T1: Total manual mowing + residue burning after 13 days + herbicide application after another 13 days (10 ml of glyphosate/ha); T2: Total manual mowing + residue burning after 13 days; and T3: Total manual mowing.

Next, three plots of 10 x 10 m were established for each treatment (totaling 9 plots), which are separated by a border of 2 m between plots and 5 meters between blocks. Then, 29 species were selected for seeding with the same number of seeds, totaling 35,510 seeds (Table 1). Thus, the total seed density used per plot was 39.5 seeds/linear meter, or 394,555 seeds/ha. The seeds were mixed and the sowing was done in a row, inside furrows 5 cm deep and separated by 1 m.

Table 1. List of species used in direct seeding.
Tabela 1. Lista de espécies utilizadas na semeadura direta.

Ind.	**Specie**	**Family**	**EG**
1	*Abarema cochliacarpos* (Gomes) Barneby & J.W.Grimes	Fabaceae	IS
2	*Andira fraxinifolia* Benth.	Fabaceae	IS
3	*Apuleia leiocarpa* (Vogel) J.F. Macbr.	Fabaceae	LS
4	*Bauhinia forficata* Link subsp. forficata	Fabaceae	IS
5	*Bixa arborea* Huber	Bixaceae	PI
6	*Bowdichia virgilioides* Kunth	Fabaceae	IS
7	*Byrsonima sericea* DC.	Malpighiaceae	IS
8	*Cecropia hololeuca* Miq.	Urticaceae	PI
9	*Coccoloba alnifolia* Casar.	Polygonaceae	IS
10	*Deguelia negrensis* (Benth.) Taub.	Fabaceae	IS
11	*Dimorphandra jorgei* M.F. Silva	Fabaceae	IS
12	*Jacaratia spinosa* (Aubl.) A. DC.	Caricaceae	IS
13	*Joannesia princeps* Vell.	Euphorbiaceae	PI
14	*Lonchocarpus cultratus* (Vell.) A.M.G. Azevedo & H.C. Lima	Fabaceae	IS
15	*Senna multijuga var. verrucosa* (Vogel) H.S. Irwin & R.C. Barneby	Fabaceae	PI
16	*Melanoxylon brauna* Schott	Fabaceae	CL
17	*Moldenhawera papillanthera* L.P.Queiroz, G.P.Lewis & R.Allkin	Fabaceae	IS
18	*Parkia pendula* (Willd.) Benth. ex Walp.	Fabaceae	IS
19	*Peltophorum dubium* (Spreng.) Taub.	Fabaceae	IS
20	*Poeppigia procera* C. Presl.	Fabaceae	IS
21	*Pterogyne nitens* Tul.	Fabaceae	IS
22	*Rollinia laurifolia* Schltdl.	Annonaceae	IS
23	*Schinus terebinthifolius* Raddi	Anacardiaceae	IS
24	*Senna multijuga* (Rich.) H.S.Irwin & Barneby	Fabaceae	IS
25	*Sesbania grandiflora* (L.) Pers.	Fabaceae	LS
26	*Spondias macrocarpa* Engl.	Anacardiaceae	IS
27	*Spondias venulosa* (Engl.) Engl	Anacardiaceae	IS
28	*Vitex cf. montevidensis* Cham.	Verbenaceae	IS
29	*Xylopia sericea* A.St.-Hil.	Annonaceae	IS

Where: EG = Ecological Group; PI = Pioneers; IS = Initial Secondary; LS = Late Secondary; CL = Climax.
Onde: GE = Grupo Ecológico; PI = Pioneiras; SI = Secundárias Iniciais; ST= Secundárias Tardias; CL= Clímax.

A survey of the species present in the area was carried out 16 years after the experiment implementation, which included all individuals with Diameter at Breast Height (DBP≥ 15 cm). All individuals were classified into families and scientific nomenclature according to the Angiosperm Phylogeny Group (APG IV, 2016), with information obtained through consultations in the Reflora Virtual Herbarium. Phytosociological parameters of relative density and dominance were calculated, as well as cover value and community diversity indices through processing in the Fitopac 2.1 software program (SHEPHERD, 2012).

Next, an analysis of variance was performed to compare the number of individuals in each treatment and block (P-value ≥ 0.05). Furthermore, the species found in the current survey were classified according to their respective successional categories, as adapted by Gandolfi et al. (1995) for Brazilian secondary forests: PI = Pioneers; IS = Initial Secondary; LS = Late Secondary; CL = Climax, and for the dispersion syndrome in: ANE = Anemochoric; ZOO = Zoochoric; AUTO = Autochoric; and NC = Not classified, according to Pijl (1982).

RESULTS

A total of 106 individuals, 5 distinct botanical families and 16 species were found (Table 2). It is worth noting that this list includes the regenerating individuals that entered the area over the years (individuals that were not sown).

Table 2. Species and total number of individuals found in each treatment 16 years after the experiment implementation.

Tabela 2. Espécies e número total de indivíduos encontrados em cada tratamento 16 anos após a implantação do experimento.

Species	**T1**	**T2**	**T3**	**Total**	**EG**	**DS**
Abarema cochliacarpos (Gomes) Barneby & J.W.Grimes	1	0	1	2	IS	NC
Acacia mangium	0	0	1	1	PI	Zoo
Albizia polycephala (Benth.) Killip ex Record	1	0	0	1	PI	Auto
Andira fraxinifolia Benth.	0	0	2	2	IS	Zoo
Apuleia leiocarpa (Vogel) J.F. Macbr.	3	0	1	4	LS	Auto
Bauhinia forficata Link subsp. Forficata	1	0	0	1	IS	Auto
Bowdichia virgilioides Kunth	2	0	2	4	IS	Ane
Joannesia princeps Vell.	23	8	11	42	PI	Zoo
Leucaena leucocephala (Lam.) de Wit.	0	1	1	2	PI	Auto/Zoo
Mimosa bimucronata (DC.) O. Kuntze var. bimuctronata	1	0	0	1	PI	Auto
Mimosa schomburgkii Benth.	0	0	1	1	PI	Auto
Peltophorum dubium (Spreng.) Taub.	2	3	1	6	IS	Auto
Pterogyne nitens Tul.	6	0	1	7	IS	Ane
Senna multijuga (Rich.) H.S.Irwin & Barneby	0	0	1	1	IS	Zoo
Spondias macrocarpa Engl.	4	0	0	4	IS	Zoo
Spondias venulosa (Engl.) Engl	13	6	8	27	IS	Zoo
Total	**57**	**18**	**31**	**106**		
Standard deviation	6,15	2,44	3,06			

Where: EG = Ecological group; DS = Dispersion syndrome.
Onde: GE = Grupo Ecológico; SD = Síndrome de Dispersão.

There was a greater number of species and individuals in treatments T1 and T3, and T1 had a total of 57 individuals (53.8%), including 11 different species. A total of 31 individuals (29.2%) were found for the T3 treatment, covering 12 different species (Figure 2). However, when evaluating the number of individuals in each treatment through analysis of variance, there was no significant difference (P-value ≥ 0.05) between blocks or treatments.

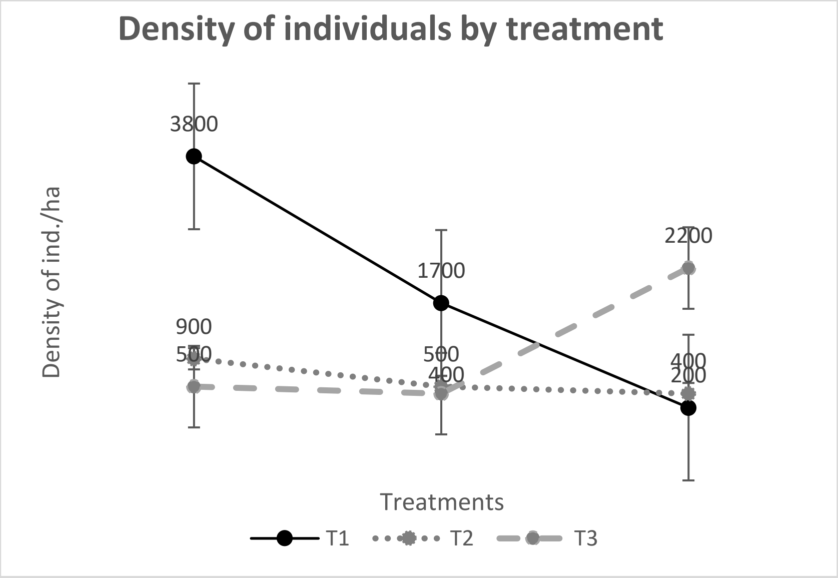

Figure 2. Individual density per hectare on each treatment.
Figura 2. Densidade de indivíduos por hectare em cada tratamento.

A Shannon-Wiener index (H') = 1.917 was found regarding the total diversity indices of the stand, which can be considered low, as well as Pielou's evenness index (P) = 0.691, demonstrating a low floristic diversity in the area and occurrence of ecological dominance. The highest values regarding the importance value (IV) and coverage value (CV) were found for the following species: *Joannesia princeps* (42.4% and 53.1%), *Spondias venulosa* (22.3% and 24.2%) and *Peltophorum dubium* (5.6% and 3.7%), which consequently presented higher relative frequencies (RF%), representing 20.9%; 18.6% and 9.3%, as well as higher relative dominance (RD%), with values of 66.7%; 23% and 1.8%, respectively.

It was generally observed that of the 29 species used in direct seeding, 11 species (37.9%) remained in the system after 16 years, being: *Joannesia princeps*; *Spondias venulosa*; *Peltophorum dubium*; *Pterogyne nitens*; *Bowdichia virgilioides*; *Apuleia leiocarpa*; *Spondias macrocarpa*; *Abarema cochliacarpos*; *Andira fraxinifolia*; *Senna multijuga* and *Bauhinia forficata.* Of these species that remained in the system, 72.7% belong to the group of initial secondary species; 18.1% of the pioneers; and 9.1% of the late secondary species, thus showing an establishment pattern depending on the ecological and successional characteristics of the species, which can be considered of high potential for implementing Recovery of Degraded Area (RDA) projects using the direct seeding technique.

In addition to these species, the entry of 5 new species into the area through natural regeneration (influence of propagules from the surrounding forest area) was verified, with the presence of native species being found (*Albizia polycephala; Mimosa bimucronata* and *Mimosa schomburgkii*), represented by 1 individual (6.2%) for each species, in addition to 2 exotic species with high potential for dispersion and invasion: *Acacia mangium* and *Leucaena leucocephala*, which respectively represented 12.5% and 6.2% of the total individuals found in the area after 16 years of the experiment implementation.

Regarding the dispersion syndrome of the species identified in the current survey, it was observed that 43.7% were zoochoric, 37.5% autochoric and 12.5% anemochoric, making it possible to infer that the area has good potential for attracting the surrounding fauna and increasing species diversity through seed dispersal.

Figure 3 below shows the existing variations for the mean DBH and diameter classes of the individuals found in the area:

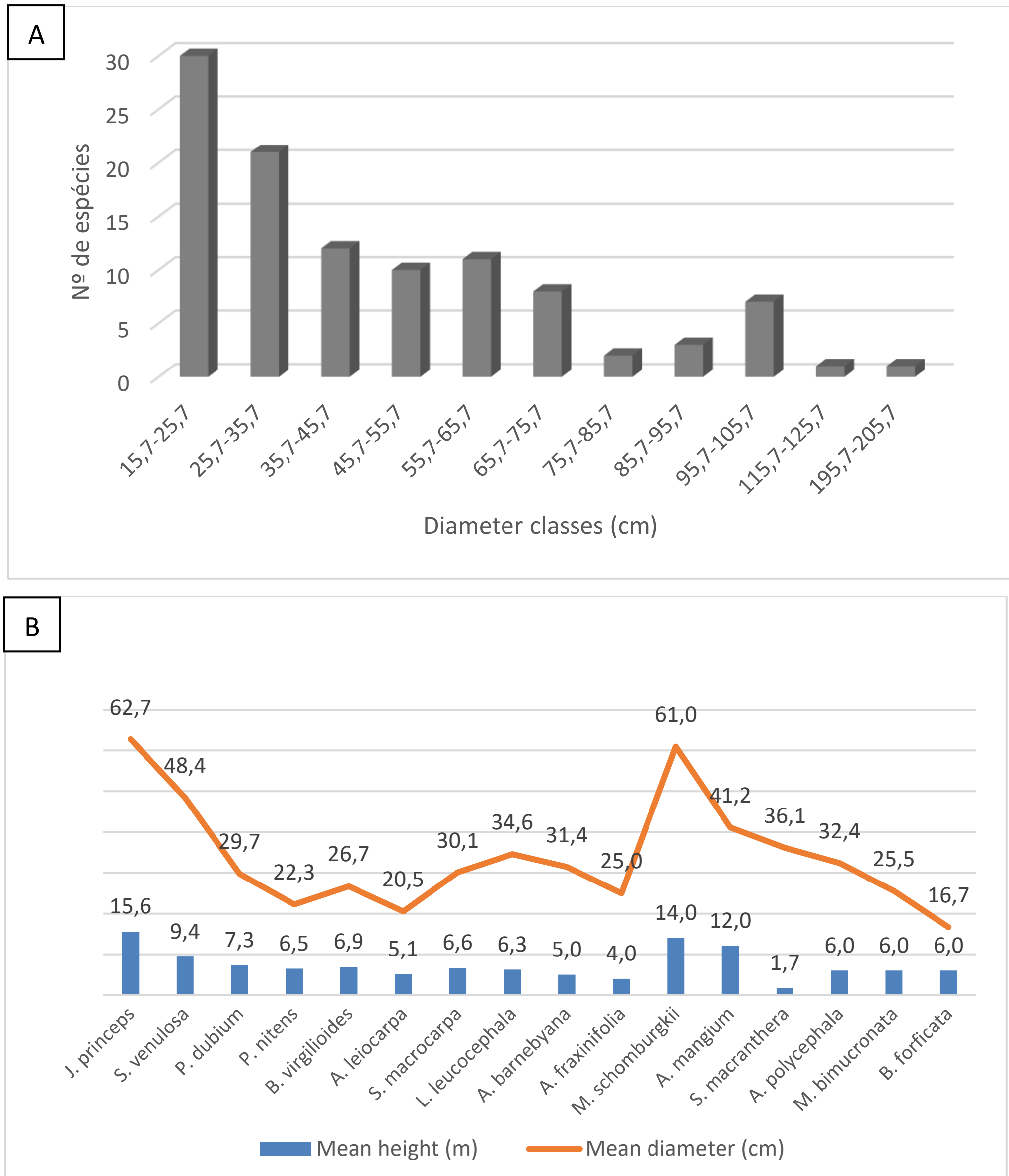

Figure 3. Individual diameter classes (A) and mean height and DBH (B) for the species found in the area.
Figura 3. Classes de diâmetro dos indivíduos (A) e média da altura e DAP (B) para as espécies encontradas na área.

The largest diameters and heights of the species found in the area (Figure 3b) were found for: *Joannesia princeps*; *Mimosa schomburgkii*; *Spondias venulosa*; and *Acacia mangium*, forming a forest structure characterized by a few species dominating the upper canopy and the vast majority of species forming part of the sub-canopy.

DISCUSSION

It was possible to observe the low floristic diversity in the remaining population 16 years after implementing the experiment with no-tillage (direct seeding). In this sense, due to the fact that this population presents dominance of species from initial ecological groups and the tendency to form an "inverted j" in the division between diametric classes (Figure 2a), it can be said that the current population is in development/ training, being considered young.

The statistics did not indicate a significant difference between the management types in terms of plant establishment in the evaluated area, following the same result of the evaluations carried out 11 months after implementing the experiment (ROLIM *et al*., 2007). However, 2 years after seeding, there was a significant difference in the management of seedling density, as also observed by the authors. Treatment 1, in which chemical control of grasses was performed, showed a greater number of forest individuals established in the area compared to the other treatments, which may be related to an advantage in terms of time spent in the clean area and consequently no weed competition with the seedlings.

It should be noted here that such results may have been influenced over time, since the area was abandoned, and no further intervention was carried out in the treatments. However, even so, the results prove the importance of monitoring areas undergoing restoration process, in addition to the possible need for interventions in order to help the ecological evolution process, which can be carried out through use in conjunction with other restoration techniques (ex.: enrichment planting, control of exotic species, diversity centers, etc.).

The greater ecological dominance of *Joannesia princeps* and *Spondias venulosa* (which showed large size and higher density of individuals in most treatments), is in line with the results observed by França and Stehmann (2013), who also highlight *Joannesia princeps* in primary and secondary forests of the Atlantic Forest. In this sense, as presented by Doust *et al*. (2006) and Tunjai and Elliott (2012), characteristics such as seed size can influence the germination process and establishment of plant species used (larger seeds generally have greater germination potential). This confirmation could also be verified in this study, in which it was observed that the two species with the greatest presence of individuals and ecological dominance in the treatments (*Joannesia princeps* and *Spondias venulosa*) had large seeds and fast growth (in this case also including *Peltophorum dubium*), which may have contributed to the emergence, establishment and permanence of these species in the area.

Low plant establishment was observed over the years for the permanence of the sown species 16 years after planting the area (37.9%). Studies which also show this tendency (low germination rate, establishment and permanence of the implanted species) include those by Ceccon *et al*. (2015); Grossnickle and Ivetic (2017). Furthermore, in studies developed over 10 years in tropical forests in Mato Grosso, Freitas *et al*. (2019) reported that restoration through direct seeding presented variable results depending on the implanted environment.

This variation may be related to microclimatic (MALAVASI *et al*. 2010) and edaphic (MELI *et al*. 2018) conditions and issues related to seeds (storage, germination rate/viability, need to break dormancy, use of physical protector, etc.), as presented by Ferreira *et al*. (2015). In view of this, it is worth considering that the state of Espírito Santo went through a historic drought in 2015, which may have negatively influenced the restoration process of the area. Another interesting point was the low number of regenerating species in the area over the 16 years (5 species), in addition to the presence of exotic species, which represented 50% of regenerating individuals. This information makes it possible to draw attention to the invasion and dissemination problem of *Acacia mangium* and *Leucaena leucocephala* (Lam.) de Wit in surrounding areas, since they have the ability to form a high seed bank in the soil and be dispersed over long distances.

Therefore, with this study we can verify that monitoring areas undergoing restoration process, as well as the correct choice of species according to their growth characteristics, ecological group, and seed characteristics are fundamental for the success of the direct seeding technique. In turn, with the observed results, it is suggested to enrich the area with diverse species and eliminate exotic species with invasive potential, thus enhancing the ecological succession and restoration of the area.

CONCLUSIONS

- Direct seeding showed satisfactory results 16 years after implementing the experiment;
- Monitoring the direct seeding technique, as well as the choice of species (prioritization of species from the initial ecological groups), is crucial for the establishment and permanence of species in the system in the medium term;
- The direct seeding technique should be complementary to other techniques when necessary, and can be reconciled with enrichment/diversity plantings to enhance the successional advancement process of the restoration.
- It is recommended to carry out new long-term studies with direct seeding experiments in the Atlantic Forest to compare information and better understand the processes.

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