Natural regeneration of woody and herbaceous species in ecological restoration areas in the Atlantic Forest

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ABSTRACT: Natural regeneration of forests is one of the most important tools for inferring about the behavior of forest restoration processes. In this context, the objective of this study was to evaluate the natural regeneration in an area of Dense Rainforest of the Lowlands after 8 years of implementation of the restoration project. The area consisted of six treatments (factorial 3 × 2), with three levels of species richness, two spacings and three repetitions, in randomized blocks. In each treatment and in the mature forest three plots of 5 × 10 m were demarcated, identifying all woody and herbaceous individuals. Floristic diversity (H') and equability (J') were calculated, in addition to the Distended Correspondence Analysis (DCA). The floristic diversity and equability were lower in areas undergoing restoration (H' = 1.82 nats indiv⁻¹ and J' = 0.51). The DCA resulted in the formation of distinct groups, which differ from the mature forest of the area under restoration. In all treatments, a large number of herbaceous individuals were registered (3,963), which may have negatively influenced the establishment of woody individuals (351). The statistics revealed that the shared treatments of many woody and herbaceous species, reinforcing that planting with greater richness of species is no guarantee of success in establishing natural regeneration with high diversity.

Key words: reference ecosystem; secondary succession; tabuleiro forest

Regeneração natural de espécies lenhosas e herbáceas em áreas de restauração ecológica na Floresta Atlântica

RESUMO: A regeneração natural das florestas é uma das mais importantes ferramentas para inferir sobre o comportamento dos processos de restauração florestal. Neste contexto, o objetivo deste estudo foi avaliar a regeneração natural em uma área de Floresta Ombrófila Densa das Terras Baixas após 8 anos da implantação do projeto de restauração. A área foi composta por seis tratamentos (factorial 3 × 2), sendo três níveis de riqueza de espécies e dois espaçamentos) e três repetições, em blocos casualizados. Em cada tratamento e na floresta madura foram demarcadas três parcelas de 5 × 10 m, identificando todos os indivíduos lenhosos e herbáceos. Foi calculada a diversidade florística (H') e a equabilidade (J'), além da Análise de Correspondência Distendida (DCA). A diversidade florística e equabilidade foram baixas nas áreas em processo de restauração (H' = 1,82 nats indiv⁻¹ e J' = 0,51). A DCA resultou na formação de grupos distintos, que diferem a floresta madura da área em processo de restauração. Em todos os tratamentos foi registrado grande número de indivíduos herbáceos (3,963), o que pode ter influenciado negativamente no estabelecimento dos indivíduos lenhosos (351). As análises revelaram que os tratamentos compartilham muitas espécies arbóreas e herbáceas, reforçando que o plantio com maior riqueza não é garantia de sucesso do estabelecimento da regeneração natural com alta diversidade.

Palavras-chave: ecossistema de referência; sucessão secundária; floresta de tabuleiro
Introduction

The Atlantic Forest is considered a hotspot for conservation priority, being one of the richest areas on the planet in biodiversity. However, this richness is threatened due to a long history of uncontrolled exploitation of natural resources, as a result of different types of land use (Joly, 2018). Thus, several restoration projects are implemented in order to recover the biodiversity of this biome (Brancalion et al., 2010).

The restoration of an ecosystem aims to reestablish ecological processes of biodiversity conservation and environmental services, as well as promoting succession as close to nature as possible (Reis et al., 2007; Brancalion et al., 2010). These artificial restoration processes are challenging, since nucleation techniques are developed at different successional rates (Reis et al., 2007).

Natural regeneration plays an important role in community development in forest restoration areas, thereby contributing to the floristic recomposition of the affected area (Chazdon & Guariguata, 2016). Promoting natural regeneration in restoration methodologies is an alternative to reforestation, since it is a low-cost procedure. In addition, the regeneration stratum contributes to maintaining already established forest environments, as with the canopy senescence there is a gradual replacement by individuals from this stratum (Brancalion et al., 2012).

Thus, it is important to consider the matrix in which the area under restoration is inserted (Martins et al., 2012), due to the possibility of the influence of nearby forest remnants on the increase of wealth and diversity (Chazdon et al., 2009). In addition, the majority of these are preserved forests or with minimal anthropic intervention (Numata et al., 2017).

Materials and Methods

Study area

The study was conducted in Reserva Natural Vale (RNV) (18° 08' 25'' S and 40° 04' 21'' W) located in the municipalities of Sooretama, Linhares and Jaguaré, in northern Espírito Santo State, Brazil (Figure 1). The study area is part of a forest

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**Figure 1.** Location of the study area and the Reserva Natural Vale in the state of Espírito Santo. T1: Treatment 1 (29 species; spacing of 2 × 2 m); T2: Treatment 2 (58 species; spacing of 2 × 2 m); T3: Treatment 3 (114 species; spacing of 2 × 2 m); T4: Treatment 4 (29 species; spacing of 3 × 3 m); T5: Treatment 5 (56 species; spacing of 3 × 3 m); T6: Treatment 6 (114 species; spacing of 3 × 3 m)
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The forest restoration project was installed in a 4.5 ha area of the Reserva Natural Vale. Prior to the installation of the project in this area, the land use was for planting *Eucalyptus* sp. The wood extraction left the area abandoned for approximately 25 years, being later occupied by *Urochloa* sp. During this period a process of natural succession was initiated with the emergence of some regenerating trees, which were maintained in the project. The seedlings were planted in January 2005.

**Data collection**

Experimental design was conducted in randomized blocks design, in a 3 × 2 factorial arrangement, three levels of species richness (29, 58 and 114) and two of spacing (2 m × 2 m and 3 m × 3 m), with three repetitions, totaling 18 plots with dimensions of 50 m × 50 m each (2,500 m²). Table 1 describes the different treatments used.

In order to assess the natural regeneration stratum in the different treatments, three 5 × 10 m (50 m²) subplots were installed in the centre of each plot. A mature forest located 200 m from the experimental site was considered as a reference ecosystem, where three subplots with the same dimensions were installed.

The height and diameter of all regenerating shrub-arboreal and woody lianas individuals greater than or equal to 30 cm up ground were measured, as well as the diameter at breast height less than 5 cm. The herbaceous individuals were only quantified and all botanical material from the regenerating individuals was collected.

**Table 1.** Description of the treatments in terms of richness and spacing used in the forest restoration project in Reserva Natural Vale, ES.

| Treatments | Species richness | Spacing   |
|------------|------------------|-----------|
| T1         | 29               | 2 × 2 m   |
| T2         | 58               | 2 × 2 m   |
| T3         | 114              | 2 × 2 m   |
| T4         | 29               | 3 × 3 m   |
| T5         | 58               | 3 × 3 m   |
| T6         | 114              | 3 × 3 m   |

**Data analysis**

The identification of the species was carried out using specialized bibliography, by comparison and, whenever necessary, with the aid of specialists. The Angiosperm Phylogeny Group - APG IV (APG IV, 2016) system was used for classifying the botanical families of the species, while the appropriate scientific nomenclature was verified by means of the list of Flora do Brasil 2020 (Flora do Brasil 2020 under construction, 2020). The species were classified according to their life habit as tree, shrub, herbaceous, liana (woody or herbaceous), grass and palm.

For herbaceous plants in which individuals could not be separated, the Braun-Blanquet (1932) scale of coverage and abundance was adopted in this study. The percentage of grass cover in the soil was estimated visually within the demarcated plots, and in the field record only the scale corresponding to the coverage of these individuals was noted.

The Shannon-Weaver diversity index ($H'$), the Pielou equation ($J'$) and the absolute density (adapted from Durigan’s proposal, 2003) have been estimated for the entire regenerating community and individually for woody and herbaceous species. All analyses were performed through the PAST 3.26 software (Hammer et al., 2001).

Floristic similarity relationships between the areas were investigated by means of a Distended Correspondence Analysis (DCA), building an abundance matrix of treatment species and mature forest, considering all the woody species that had occurred. A Cluster Analysis was performed employing the Mortisita-Horn index (Felfili et al., 2011). Subsequently, a Similarity Analysis permutation test (ANOSIM) was conducted using the Bray-Curtis dissimilarity matrix. The analyses were implemented in PAST software version 3.26 (Hammer et al., 2001).

Pearson correlation analysis was applied to each plot to assess the correlation between the presence of grasses and regenerating individuals, using the variables of grasses percentage and number of regenerants (trees, shrubs and woody vines). The correlation was calculated in electronic worksheets and tested by means of t-statistics at 5% significance level, using Microsoft Excel® 2013.

The species were classified according to the succession group (pioneer, early secondary and late secondary) and to the dispersion syndrome (zoochoric, anemochoric and autochoric).

**Results and Discussion**

In total, considering the area under restoration and the mature forest, 4,561 individuals belonging to 159 species and 52 families were sampled. Among these, 4,314 individuals from 89 species belong to the area in the process of restoration, while 247 individuals from 77 species were sampled in mature forest (Table 2).

Among the families with the highest values for species richness in the area under restoration were Fabaceae (33 spp.), Myrtaceae (20) and Asteraceae (7), of which species
Table 2. List with the most abundant species of natural regeneration sampled in the six treatments (T) and in the mature forest (MF), regarding life habit (LH), succession group (SG) and dispersion syndrome (DS), Reserva Natural Vale, ES.

| Family/Species                       | LH | SG  | DS | T1 | T2 | T3 | T4 | T5 | T6 | MF  |
|--------------------------------------|----|-----|----|----|----|----|----|----|----|-----|
| Acacia holosericea G.Don             | Tree | NC  | NC | 1  |
| Acacia auriculiformis Benth.         | Tree | PI  | Zoo | 6  | 2  | 3  | 1  |     |     | 1   |
| Acacia mangium Willd.                | Tree | PI  | Zoo | 3  | 11 | 1  | 6  | 2  |     |     |
| Acanthospermum australe (Loefl.) Kuntze | Herb. | PI  | NC | 1  | 13 | 10 | 6  |     |     | 2   |
| Actinostemon concolor (Spreng.) Müll.Arg. | Tree | LS  | Zoo |     |     |     |     |     |     |     |
| Aegiphila integrifolia (Jacq.) Moldenke | Tree | PI  | Zoo | 1  | 1  | 1  | 3  | 1  |     |     |
| Aeschynomene sp.                     | Herb. | PI  | NC | 5  |     |     |     |     |     |     |
| Allagoptera cauludescens (Mart.) Kuntze | Tree | NC  | NC | 2  |     |     |     |     |     |     |
| Andira anthelmia (Vell.) J.F.Macbr.* | Tree | ES  | Zoo | 1  |     |     |     |     |     | 1   |
| Andira fraxinifolia Benth.*          | Tree | ES  | Zoo | 1  |     |     |     |     |     |     |
| Annona tabulariae H. Rainer          | Shru. | LS  | Zoo | 2  |     |     |     |     |     |     |
| Asteraceae sp1                       | Herb. | NC  | NC | 1  | 47 | 8  | 79 |     |     |     |
| Asteraceae sp2                       | Herb. | NC  | NC | 2  |     |     |     |     |     |     |
| Asteraceae sp3                       | Herb. | NC  | NC | 10 |     |     |     |     |     |     |
| Astronium concinnum Schott*          | Tree | ES  | Ane | 1  |     |     |     |     |     |     |
| Borreria ocyphylora (Roem. & Schult.) Bacigalupo & E.L.Cabr. | Herb. | LS  | NC | 200 |     |     |     |     |     |     |
| Borreria verticillata (L.) G.Mey.    | Herb. | PI  | NC  | 360 | 121 | 221 | 150 | 205 | 613 |     |
| Bowdichia virgilioides Kunth*        | Tree | ES  | Ane | 1  |     |     |     |     |     |     |
| Byrsonima crassifolia (L.) Kunth.    | Tree | ES  | Zoo | 6  | 2  | 1  | 1  |     |     |     |
| Byrsonima sericea DC.*               | Tree | ES  | Zoo | 39 | 14 | 18 | 23 | 16 | 10  |     |
| Calathea linnaeana H. Kenn.          | Herb. | LS  | NC | 40 |     |     |     |     |     |     |
| Campomanesia esperatunisensis Landrum* | Tree | ES  | Zoo | 1  |     |     |     |     |     |     |
| Casearia aculeata Jacq.              | Tree | ES  | Zoo | 2  |     |     |     |     |     |     |
| Chamaecrista ensiformis (Vell.) H.S.Irwin & Barneby* | Tree | ES  | Aut. | 2  |     |     |     |     |     |     |
| Cordia hatschbachii J.S.Mill.        | Shru. | LS  | NC | 1  |     |     |     |     |     |     |
| Cordia tagueyenensis Vell.           | Shru. | LS  | Ane | 3  |     |     |     |     |     |     |
| Croton sp.                           | Herb. | PI  | NC  | 15 | 15 | 9  | 4  | 8  | 1   |     |
| Cryptanthus beuckeri E.Morren        | Herb. | LS  | NC | 2  |     |     |     |     |     |     |
| Cupania emarginata Cambess.*         | Tree | ES  | Zoo | 1  |     |     |     |     |     |     |
| Cyrtocymura scirpoides (Lam.) H.Rob. | Herb. | PI  | NC  | 11 | 15 | 13 | 4  |     |     |     |
| Desmodium axillare (Sw.) DC.         | Herb. | LS  | NC | 16 |     |     |     |     |     |     |
| Dictyoloma ventellanum A.Juss.       | Tree | PI  | Ane | 25 |     |     |     |     |     |     |
| Digiaria sp.                         | Gras. | PI  | NC  | X  | X  | X  | X  | X  | X   |     |
| Dorstenia milaneziana Carauta, C.Valente & Sucre | Herb. | LS  | NC | 10 |     |     |     |     |     |     |
| Elephantopus mollis Kunth            | Herb. | PI  | NC  | 1  | 2  | 106 | 12 |     |     |     |
| Eugenia bahiensis DC.                | Tree | LS  | Zoo | 4  |     |     |     |     |     |     |
| Eugenia brasiliensis Lam.*           | Tree | LS  | Zoo | 1  | 1  |     |     |     |     |     |
| Eugenia cf. pisiformis Cambess.      | Tree | LS  | Zoo | 12 |     |     |     |     |     |     |
| Eugenia excelsa O.Berg               | Tree | ES  | Zoo | 2  |     |     |     |     |     |     |
| Eugenia platyphylla O.Berg           | Tree | LS  | Zoo | 15 |     |     |     |     |     |     |
| Eugenia plicatocostata O.Berg        | Tree | LS  | Zoo | 1  |     |     |     |     |     |     |
| Eugenia prasina O.Berg               | Tree | LS  | Zoo | 8  |     |     |     |     |     |     |
| Eugenia sp.                          | Tree | LS  | Zoo | 2  | 1  |     |     |     |     |     |
| Eugenia suicata Spring ex Mart.*     | Tree | LS  | Zoo | 1  |     |     |     |     |     |     |
| Geissospermum laeve (Vell.) Miers *  | Tree | LS  | Zoo | 1  |     |     |     |     |     |     |
| Goepertia virginata (Petersen) Borchs. & S.Suárez | Herb. | NC  | NC | 3  |     |     |     |     |     |     |
| Goniothrichis marginata Taub.*       | Tree | LS  | Aut. | 1  |     |     |     |     |     |     |
| Guaiapi perambucens (Casar.) Lundl.* | Shru. | PI  | NC  | 1  |     |     |     |     |     |     |
| Guarea guaiana (L.) Sleumer*          | Tree | ES  | Zoo | 1  |     |     |     |     |     |     |
| Handroanthus aff. chrysotrichus (Mart. ex DC.) Mattos | Tree | ES  | Ane. | 3  |     |     |     |     |     |     |
| Handroanthus heptaphyllus (Vell.) Mattos* | Tree | ES  | Ane. | 1  |     |     |     |     |     |     |
| Hyptis brevipes Poit.                 | Herb. | PI  | NC  | 270 |     |     |     |     |     | 34  |
| Inga laurina (Sw.) Willd.*           | Tree | ES  | Zoo | 4  | 1  | 1  | 5  | 2  | 1   |     |
| Laguncularia verticillata (Spreng.) T.Koyama & Maguire | Gras. | PI  | NC  | X  | X  | X  | X  | X  | X   |     |
| Lasios ausgulata Hitchc. & Chase      | Gras. | LS  | NC  | X  |     |     |     |     |     | X   |
| Lecythid laceolata Poir.*             | Tree | ES  | Zoo | 1  |     |     |     |     |     |     |
| Lecythis lurida (Miers) S.A.Mori      | Tree | LS  | Zoo | 1  |     |     |     |     |     | 3   |
| Leucaena sp.                         | Tree | NC  | NC | 2  |     |     |     |     |     |     |

Continues on the next page.
Continuation of Table 2.

| Family/Species                  | LH | SG | DS | T1 | T2 | T3 | T4 | T5 | T6 | MF |
|---------------------------------|----|----|----|----|----|----|----|----|----|----|
| *Margaritaria nobilis* L. f.*   | Tree | PI | Zoo. |    |    |    |    |    |    | 1  |
| *Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs | Gras. | PI | NC | X | X | X |    |    |    |    |
| *Melicoccus spiritosantensis* Aecv.-Rodr.* | Tree | ES | Zoo. |    |    |    |    |    |    | 1  |
| *Melicoccus oliviformis* subsp. *intermedius* (Raddlk.) Aecv.-Rodr.* | Tree | ES | NC | 1 | 1 | 1 |    |    |    |    |
| *Mesophaerum suaveolens* (L.) Kuntze. | Herb. | PI | NC | 7 | 590 | 68 | 120 |    |    |    |
| *Micropholis gardneriana* (A.DC.) Pierre | Tree | LS | Zoo. |    |    |    |    |    |    | 2  |
| *Micropholis crassipedicellata* (Mart. & Eichler ex Miq.) Pierre | Tree | LS | Zoo. |    |    |    |    |    |    | 4  |
| *Myrica splendens* (Sw.) DC.* | Tree | LS | Zoo. |    |    |    |    |    |    | 2  |
| *Oecocedes maculata* (Lindl.) Lindl. | Herb. | LS | NC | 3 | 6 | 6 | 11 |    |    |    |
| *Oxypetalum banksii* Schult. subsp. *Banksii* | HL | ES | NC | 5 | 4 | 3 | 2 | 4 | 4 |    |
| *Paubrasilia echinata* (Lam.) Gagnon, H.C.Lima & G.P.Lewis* | Tree | ES | Aut. |    |    |    |    |    |    | 1  |
| *Phyllanthus niruri* L. | Herb. | PI | NC | 8 | 11 | 1 | 9 | 12 |    |    |
| *Pomfalia calceolaria* G.M.Barroso & Peixoto | Tree | LS | Zoo. |    |    |    |    |    |    | 3  |
| *Porophyllum ruderale* (Jacq.) Cass. | Herb. | PI | NC | 86 | 70 | 39 | 33 | 131 | 14 |    |
| *Pouteria coelomatica* Rizzini* | Tree | ES | Zoo. | 1 | 1 | 1 |    |    |    |    |
| *Protium heptaphyllum* (Aubl.) Marchand subsp. *heptaphyllum* | Tree | ES | Zoo. | 7 | 13 | 2 | 1 | 4 | 1 |    |
| *Pseudopiptadenia contorta* (DC.) G.P.Lewis & M.P.Lima | Tree | ES | Ano. |    |    |    |    |    |    | 4  |
| *Psidium guineense* Sw.* | Tree | ES | Zoo. | 2 | 2 | 1 |    |    |    |    |
| *Psidium longipetiolatum* D.Legrand* | Tree | LS | Zoo. |    |    |    |    |    |    | 1  |
| *Renvoizza trinii* (Kunth) Zuloaga & Morrone | Gras. | PI | NC | X | X |    |    |    |    |    |
| *Ricardia pulcherrima* Delpret* | Tree | ES | NC |    |    |    |    |    |    | 1  |
| *Schinus terebinthifolia* Raddi | Tree | ES | Zoo. | 2 | 1 |    |    |    |    |    |
| *Sebastiania brasiliensis* Spreng. | Tree | LS | Zoo. |    |    |    |    |    |    | 17 |
| *Senegalia langsdorffii* (Benth.) Seigler & Ebing | Shru. | NC | NC |    |    |    |    |    |    | 3  |
| *Senna multiflora* var. *verrucosa* (Vogel) H.S. Irwin & Barneby* | Tree | PI | Aut./Ane. | 1 | 1 | 1 |    |    |    |    |
| *Sida linfolia* Juss. ex Cav. | Herb. | PI | NC |    |    |    |    |    |    | 2  |
| *Solanoa sooretamum* Carvalho | Tree | ES | Zoo. | 1 | 2 |    |    |    |    |    |
| *Sorocea haliarii* Gaoudich. | Shru. | LS | Zoo. |    |    |    |    |    |    |    |
| *Stephanopodium* sp. | Tree | LS | Zoo. | 4 |    |    |    |    |    |    |
| *Strychnos cf. hirsuta* Spruce ex Benth. | Shru. | LS | NC |    |    |    |    |    |    | 2  |
| *Tabernaemontana salzmannii* A.DC. | Tree | LS | Zoo. | 2 |    |    |    |    |    |    |
| *Terminalia mameluco* Pickel* | Tree | ES | Ane. | 1 | 1 |    |    |    |    |    |
| *Tontelea* sp. | Tree | LS | NC |    |    |    |    |    |    | 4  |
| *Toulicia patentinveis* Raddlk.* | Tree | LS | Ane. |    |    |    |    |    |    | 1  |
| *Trichilia pseudostipulata* (A. Juss.) C. DC. | Tree | LS | Zoo. | 6 |    |    |    |    |    |    |
| *Trichilia pallens* C.DC. | Tree | LS | Zoo. | 3 |    |    |    |    |    |    |
| *Turnera ulmifolia* L. | Herb. | PI | NC | 1 | 11 | 3 | 7 |    |    |    |
| *Urochloa* sp. | Gras. | PI | NC | X | X | X | X | X |    |    |
| *Varronia polycephala* Lam. | Shru. | LS | Zoo. | 1 |    |    |    |    |    | 1  |
| *Vernonanthura polyanthes* (Sprengel) Vega & Dematteis | Tree | PI | Ane. | 1 | 1 | 1 | 1 |    |    |    |
| *Xylopia frutescens* Aubl. | Tree | ES | Zoo. | 1 | 1 | 1 |    |    |    |    |
| *Youngia japonica* (L.) DC. | Herb. | PI | NC | 2 | 18 | 18 | 38 |    |    |    |
| *Zeyheria tuberculosa* (Vell.) Bureu ex Verl.* | Tree | ES | Ane. | 1 | 2 | 11 | 3 |    |    |    |
| *Zornia latifolia* Sm. | Herb. | LS | NC | 2 | 1 |    |    |    |    |    |

*Species used for planting using regenerants in the area under forest restoration process.

belonging to the Asteraceae family are predominantly herbaceous. In other areas under restoration process, a high number of species and individuals from these families were also found (Trentin et al., 2018), thus corroborating our results. Some exotic species such as *Acacia auriculiformis* Benth. (26 individuals) and *Acacia mangium* Willd. (12), were found in all treatments. Exotic species may attribute risks to the successional development of the area, as most of the time they compete with native species (Souza et al., 2017).

The treatments for the woody community comprised 351 individuals and 68 species, while the mature forest included 190 individuals and 84 species. In the mature forest several species of woody lianas were found presenting a high number of species (15) and individuals (27), whereas in the area under restoration only 3 species and 7 individuals were accounted. Regarding the herbaceous community, 4,020 individuals were found distributed in 32 species. From these, the highest concentration occurred in the restoration area with 3,963 individuals (Table 3).
The high number of herbaceous individuals in the area under forest restoration process may be related to the ancient soil use in the region and the presence of discontinuous canopies (Franco et al., 2012), caused by mortality of the planting species, as well as the arrival of propagules from the seed rain from this group of species. The studied area is surrounded by pasture and other restoration projects, which include several herbaceous species which can be dispersed by natural agents. Other factors that contribute to the increase of herbaceous species in natural regeneration are the life cycle of these species, the high productivity and the facility of dispersing their seeds (Curtinhas et al., 2010).

Species such as *Borreria verticillata* (L.) G.Mey. was confirmed in all treatments, totaling 1,670 individuals. The high infestation was also found in fragments of Dense Ombrophylous Forest of the Lowlands by Soares Junior et al. (2008). This species can be indicated for recovery of degraded areas, mainly by its high adaptation in mining areas (Jesus et al., 2016). On the other hand, the high infestation of herbaceous species may negatively influence natural regeneration, leading to resistance in the succession process (Rodrigues et al., 2010; Silva et al., 2018).

Concerning the richness variable, a low average number of woody species was observed in the natural regeneration in all treatments of the area under forest restoration process (Table 3). The species richness in plant communities may be associated with forest age (Liebsch et al., 2007), as observed in studies by Aide et al. (2000), which noted a gradual increase of woody species richness along the successional process in areas with anthropic interference. Brancalion et al. (2010), reported that implementing less species richness and diversity in a restoration area may lead to unsuccessful outcomes, forming environments unable to maintain high biodiversity.

The diversity and equability indices were higher for the woody community when compared to those calculated for the general and herbaceous community (Table 3). These low values may be associated with the large number of herbaceous individuals in some species (Durigan, 2003), as observed e.g, in the species *Porophyllum ruderale* (Jacq.) Cass. (373 individuals), *Mesosphaerum suaveolens* (L.) Kuntze (785) and *Borreria verticillata* (L.) G.Mey.

Considering the reference ecosystem, the diversity found for the woody regenerating layer was 3.99 nats indiv⁻¹. Nevertheless, in the secondary forest fragment located in the Reserva Natural Vale the diversity values of natural regeneration were higher, increasing from 4.35 to 5.00 over a ten-year period (Souza et al., 2002). Diversity values of the woody community were low for all treatments, when compared to the reference ecosystem. During the natural succession process it is expected that floristic diversity values are higher in environments where there is a source of species propagation of advanced successional stage (Britez, 2007), however, this pattern was not observed.

Contrary to the observed in the area under restoration process, in the mature forest more species and woody individuals than herbaceous were sampled. Mature tropical forests form a continuous canopy, with scarce light reaching the soil (Guilherme, 2000), which inhibits the germination of a large number of herbaceous species. This increase in understorey shading may reduce the colonization of pioneer

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**Table 3. General parameters of natural regeneration in treatments (T) and in mature forest (MF), Reserva Natural Vale, ES.**

| General community | T1    | T2    | T3    | T4    | T5    | T6    | MF     |
|-------------------|-------|-------|-------|-------|-------|-------|--------|
| N. individuals*   | 582   | 315   | 1,317 | 675   | 519   | 906   | 247    |
| Density (ind ha⁻¹) | 38.800 | 21.000 | 87.800 | 45.000 | 34.600 | 60.400 | 13.200 |
| N. species        | 34    | 38    | 27    | 33    | 32    | 34    | 77     |
| N. families       | 27    | 24    | 19    | 22    | 19    | 17    | 32     |
| Diversity (H’)*   | 1.57  | 2.25  | 1.8   | 2.07  | 1.92  | 1.34  | 3.84   |
| Equability (J)*   | 0.43  | 0.61  | 0.54  | 0.58  | 0.54  | 0.38  | 0.85   |

| Woody community   |       |       |       |       |       |       |        |
| N. individuals     | 81    | 57    | 44    | 86    | 48    | 35    | 190    |
| Density (ind ha⁻¹) | 5.400 | 3.800 | 2.933 | 5.733 | 3.200 | 2.333 | 12.667 |
| N. species         | 20    | 25    | 14    | 18    | 19    | 22    | 71     |
| N. families        | 16    | 16    | 9     | 11    | 10    | 12    | 29     |
| Diversity (H’)*    | 2.07  | 2.62  | 1.91  | 2.15  | 2.48  | 2.72  | 3.99   |
| Equability (J)*    | 0.68  | 0.81  | 0.72  | 0.73  | 0.41  | 0.88  | 0.9    |

| Herbaceous community |       |       |       |       |       |       |        |
| N. individuals*      | 501   | 258   | 1,273 | 589   | 471   | 871   | 57     |
| Density (ind ha⁻¹)   | 33.400 | 17.200 | 84.867 | 39.267 | 31.400 | 58.067 | 533    |
| N. species           | 14    | 13    | 13    | 15    | 13    | 12    | 6      |
| N. families          | 11    | 11    | 10    | 13    | 11    | 10    | 5      |
| Diversity (H’)*      | 1.02  | 1.59  | 1.65  | 1.62  | 1.53  | 1.12  | 0.97   |
| Equability (J)*      | 0.36  | 0.6   | 0.62  | 0.57  | 0.58  | 0.45  | 0.54   |

* The number of grass individuals is not included.
species, and enhance the chance of establishing late secondary species (Oliveira et al., 2019).

Moreover, the natural tropical forests, such as those located in the north of Espírito Santo, are composed of a great richness and diversity of plant species (Paula & Soares, 2011). Therefore, Melo et al. (2006) and Brancalion et al. (2010), have reported that recruitment of species from different ecological groups by means of seed rain is related to the presence of a permanent and diversified canopy.

The high percentages of grasses are associated with the presence of high number of herbaceous plants. In the area under restoration, 55% of the sampled area had more than 15% coverage by grasses, and in some the percentage was approximately 90%, which may also have interfered in the germination of woody species. However, no significant correlation was found (r= -0.36 and p > 0.05), thus suggesting that there was no significant association between the percentage of grasses and the number of arboreal individuals in the sampling area (Figure 2).

A higher proportion of late secondary arboreal species was registered in the mature forest (63.23%), whereas in the area under restoration the initial secondary species were more numerous (41.93%) (Figure 3). Initial secondary species need intermediate light for their growth, therefore they preferentially occur in less shaded areas. The presence of the discontinuous canopy in the area under restoration process allows the entry of light, which may favor the establishment of species from this group.

Furthermore, a considerable number of shadow-tolerant species (37.09%) were observed in the area under restoration (Figure 3), suggesting that over time a breakthrough in the successional process occurs. Late secondary species are establishing themselves in the area due to favourable shading conditions created by light tolerant planting species, but which have not fully covered the area.

The analysis of DCA, using the abundance of woody species as a parameter, resulted in the formation of distinct groups, despite the proximity between the restoration project and the mature forest. The ordination generated distinct groups, showing the high floristic dissimilarity between the treatments and the mature forest (Figure 4).

Our results showed that even the treatments with the highest richness (T3 and T6) did not result in an increase in the number of individuals and diversity of areas under restoration, with the average number of species being 5.67 and 8, respectively. In contrast, Durigan et al. (2010), suggest that high diversity is not a guarantee of success in the restoration, since other factors such as filters or barriers can influence the stability of the restored ecosystem.

**Figure 2.** Diagram of dispersion between the number of woody individuals and the percentage of grasses, Reserva Natural Vale, ES.

**Figure 3.** Percentage of pioneer species (PI), early secondary (ES), late secondary (LS) and uncharacterized (NC) species in relation to the total number of shrub-arboreal species sampled in natural regeneration, in the area under restoration and in mature forest, Reserva Natural Vale, ES.

**Figure 4.** Ordination diagram of the species and plots of the woody community resulting from the Distended Correspondence Analysis (DCA), for different sample sites in the area under restoration and in mature forest, Reserva Natural Vale, ES.
Mature forest plots were grouped and another group was formed by treatments (Figure 4). It can be observed that the plots of treatment 4 are more distant, due mainly to the low sharing between species and the other plots, besides the abundance of individuals belonging to the species *Dictyoloma vandellianum* A.Juss., which obtained greater relevance and exclusivity in this treatment. It should be pointed out that the mentioned species was not used in the project planting.

Flora from the natural regeneration of the area under restoration process is composed of different species compared to mature forest, as confirmed by the One-Way ANOSIM test, which presented the values ($r = 0.323$ and $p = 0.001$). Even though there is no floricor similarity between the areas, mature forests are important sources of propagules for the natural regeneration (Britez, 2007; Peña-Domene et al., 2013).

Floristic dissimilarity was also observed by Melo & Durigan (2007), when assessing areas in the process of restoration with 7, 9 and 13 years and a mature forest. The authors reported that a long time is required to equalize the species composition of restored areas with natural forests.

Among the species used for planting, 34 were present in the stratum of natural regeneration of the area, however, several of these species were sampled in few treatments and in a small number of individuals. This finding was not in accordance with Daronco et al. (2013), whose results demonstrated that planted species have a minor influence on the floristic composition of the community under restoration.

When analyzing the dispersion syndrome of the regenerating species in both areas, an increased number of zoochoric species was registered (Figure 5).

The difference in dispersion strategies may vary according to the type of vegetation and its successional stage (Chazdon et al., 2007), however, this observed syndrome is a pattern in tropical forests (Venzke et al., 2014). Species of the restoration area are characteristics of areas undergoing an early to intermediate succession process, evidencing the successional stage, in which they were more representative in terms of abundance. On the other hand, late species were more abundant in mature forests.

**Conclusions**

During the evaluation of the natural regeneration after 8 years of project installation, it was possible to identify that the restored area presents difficulties to advance in the succession process. The composition of the natural regeneration of the entire area under restoration, regardless of the richness used for planting, has a high similarity, and with many woody species being shared among the treatments. Moreover, the area under restoration process shares few species with the mature forest, thereby making the dissimilar environments.

It was not possible to observe a correlation between the percentage of grasses and the number of arboreal individuals in the restored areas, suggesting that other processes have a negative influence on the regeneration of woody species in these environments. Thus, it is reinforced by the obtained information that even areas of planting with major species richness are not a guarantee of success in the establishment of natural regeneration with high diversity.

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**Literature Cited**

Aide, T. M.; Zimmerman, J. K.; Pascarella, J. B.; Rivera, L. Forest regeneration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. Restoration Ecology, v. 8, n. 4, p. 328-338, 2000. https://doi.org/10.1046/j.1526-100x.2000.80048.x.

Brancalion, P. H. S.; Rodrigues, R. R.; Gandolfi, S.; Kageyama, P. Y.; Nave, A. G.; Gandara, F. B.; Barbosa, L. M.; Tabarelli, M. Instrumentos legais podem contribuir para a restauração de florestas tropicais biodiversas. Revista Árvore, Viçosa, v. 34, n. 3, p. 455-470, 2010. https://doi.org/10.1590/S0100-67622010000300010.

Brancalion, P. H. S.; Viani, R. A. G.; Rodrigues, R. R.; Gandolfi, S. Avaliação e monitoramento de áreas em processo de restauração. In: Martins, S. V. (Ed.). Restauração ecológica de ecossistemas degradados. Viçosa: UFV, 2012. p. 262-293. http://www.esalqlastrop.com.br/img/aulas/Cumbuca%206(2).pdf. 15 Jan. 2020.
Natural regeneration of woody and herbaceous species in ecological restoration areas in the Atlantic Forest

Braun-Blanquet, J. Plant sociology. New York: McGraw-Hill, 1932. 439p.

Britez, R. M. Aspectos ambientais a serem considerados na restauração da floresta com araucária no estado do Paraná. Pesquisa Florestal Brasileira, n. 55, p. 37-43, 2007. https://pfb.cnpf.embrapa.br/pfb/index.php/pfb/article/view/115. 12. Jan. 2020.

Chazdon, R. L.; Guariguata, M. R. Natural regeneration as a tool for large scale forest restoration in the tropics: prospects and challenges. Biotropica, v. 48, n. 6, p. 716-730, 2016. https://doi.org/10.1111/btp.12381.

Chazdon, R. L.; Letcher, S. G.; Breugel, M. V.; Martínez-Ramos, M.; Borges, F.; Finegan, B. Rates of change in tree communities of secondary Neotropical forests following major disturbances. Philosophical Transactions of the Royal Society B, v. 362, n. 1478 p. 273-289, 2007. https://doi.org/10.1098/rstb.2006.1990.

Chazdon, R. L.; Peres, C. A.; Dent, D.; Shell, D.; Lugo, A. E. The potential for species conservation in Tropical Secondary Forests. Conservation Biology, v. 23, n. 6, p. 1406-1417, 2009. https://doi.org/10.1111/j.1523-1739.2009.01338.x.

Chiamolera, L. B.; Ângelo, A. C.; Boeger, M. R. Crescimento e sobrevivência de quatro espécies florestais nativas plantadas em áreas com diferentes estágios de sucessão no reservatório Iraí-PR. Floresta, v. 41, n. 4, p. 765-778, 2011. https://doi.org/10.5380/rf.v41i4.25341.

Curtinhas, J. N.; Santos, J. B.; Vicente, N. M. F.; Perez, A. L. Caracterização fitossociológica da vegetação herbácea de áreas alteradas pela atividade agropecuária na região do Médio Vale do Rio Doce, Minas Gerais. Revista Ceres, v. 57, n. 3, p. 321-329, 2010. https://doi.org/10.1590/S0034-737X2010000300006.

Daronco, C.; Melo, A. C. G.; Durigan, G. Ecossistema em restauração versus ecossistema de referência: estudo de caso da comunidade vegetal de mata ciliar em região de Cerrado, Assis, SP, Brasil. Hoehnea, v. 40, n. 3, p. 485-498, 2013. https://doi.org/10.1590/0100-67262013000300008.

Durigan, G. Métodos para análise de vegetação arbórea. In: Culler-Junior, L.; Rudran, R.; Pádua-Valadares, C. (Orgs.). Métodos de estudos em biologia da conservação e manejo da vida silvestre. Curitiba: Editora da UFPR, 2003. p. 455-479.Durigan, G.; Engel, V. L.; Torezan, J. M.; Melo, A. C. G.; Marques, M. C. M.; Martins, S. V.; Reis, A.; Scarano, F. R. Normas jurídicas para a restauração ecológica: uma barreira a mais a dificultar o êxito das iniciativas? Revista Árvore, v. 34, n. 3, p. 471-485, 2010. https://doi.org/10.1590/S0100-67262010000300011.

Felfili, J. M.; Eisenlohr, P. V.; Melo, M. M. R. F.; Andrade, L. A.; Meira-Franco, B. K. S.; Martins, S. V.; Miranda Neto, A.; Ribeiro, T. M. Uma abordagem sobre diversidade e técnicas de restauração ecológica. In: Martins, S. V. (Org.). Restauração ecológica de ecossistemas degradados. Viçosa: UFV, 2012. p. 17-40.

Guilherme, F. A. G. Efeitos da cobertura de dossel na densidade e estatura de gramíneas e da regeneração natural de plantas lenhosas em mata de galeria, Brasília-DF. Cerne, v. 6, n. 1, p. 60-67, 2000. http://www.cerne.ufla.br/site/index.php/CERNE/article/view/483/419. 15. Jan. 2020.

Hammer, Ø.; Harper D. A. T.; Ryan, P. D. PAST: Paleontological statistics software package for education and data analysis. Paleontology Electronic, v. 4, n. 1, article 4, 2001. https://palaeo-electronica.org/2001_1/past/past.pdf. 05 Nov. 2019.

Instituto Brasileiro de Geografia e Estatística - IBGE. Manual técnico da vegetação brasileira. 2.ed. Rio de Janeiro: IBGE, 2012. 251p. (IBGE. Manual Técnicos em Geociências, 1). https://servicodados.ibge.gov.br/visualizacao/livros/liv63011.pdf. 11 Nov. 2019.

Jesus, E. N. de.; Santos, T. S. dos.; Ribeiro, G. T.; Orge, M. D. R.; Amorim, V. O.; Batista, R. C. R. Regeneração Natural de Espécies Vegetais em Jazidas revegetadas. Floresta e Ambiente, v. 23, n. 2, p. 191-200, 2016. https://doi.org/10.1590/2179-8087.115914.

Joly, C. A. Biodiversity at risk in the Americas. Biota Neotropica, v. 18, n. 3, p. 1-2, 2018. https://doi.org/10.1590/1519-6766-0611-2018000300011.

Juvenhal, R. S. Localização da Reserva Natural Vale no estado do Espírito Santo. Jerônimo Monteiro: UFES, 2014. 20 Mar. 2014 (Trabalho técnico não publicado).

Liebsch, D.; Goldenberg, R.; Marques, M. C. M. Florística e estrutura de comunidades vegetais em uma cronosequência de Floresta Atlântica no Estado do Paraná, Brasil. Acta Botanica Brasilia, v. 21, n. 4, p. 983-992, 2007. https://doi.org/10.1590/S0102-33062007000400023.

Martins, S. V.; Kunz, S. H. Use of evaluation and monitoring indicators in a riparian forest restoration project in Viçosa, southeastern Brazil. In: Rodrigues, R. R.; Martins, S. V.; Gandolfi, S. (Eds.). High diversity forest restoration in degraded areas. New York: Nova Science Publishers, 2007. p. 261-273.

Martins, S. V.; Miranda Neto, A.; Ribeiro, T. M. Uma abordagem sobre diversidade e técnicas de restauração ecológica. In: Martins, S. V. (Org.). Restauração ecológica de ecossistemas degradados. Viçosa: UFV, 2012. p. 17-40.

Melo, A. C. G.; Durigan, D. Evolução estrutural de reflorestamentos de restauração de matas ciliares no Médio Vale do Paranapanema. Scientia Forestalis, n. 73, p. 101-111, 2007. http://www.lerf.esalq.usp.br/divulgacao/recomendados/artigos/durigan2007.pdf. 11. Jan. 2020.

Melo, F. P. L.; Dirzo, R.; Tabarelli, M. Biased seed rain in forest edges: Evidence from the Brazilian Atlantic Forest. Biological Conservation, v. 132, n. 1, p. 50-60, 2006. https://doi.org/10.1016/j.biocon.2006.03.015.

Miranda Neto, A.; Martins, S. V.; Silva, K. D. A.; Glieriani, J. M. Florística e estrutura do estrato arbustivo-arbóreo de uma floresta restaurada com 40 anos, Viçosa, MG. Revista Árvore, v. 36, n. 5, p. 869-878, 2012. https://doi.org/10.1590/S0100-67262012000500009.

Numata, I.; Silva, S. S.; Cochrane, M. A.; De Oliveira, M. V. N. Corrigendum to “Fire and edge effects in a fragmented tropical forest landscape in the southwestern Amazon”. Forest Ecology and Management, v. 427, n. 457, p. 135-146, 2017. https://doi.org/10.1016/j.foreco.2017.07.0100.
Natural regeneration of woody and herbaceous species in ecological restoration areas in the Atlantic Forest

Rev. Bras. Cienc. Agrar., Recife, v.15, n.4, e8160, 2020

Oliveira, P. A. N. Santos, J. M. F. F. dos.; Araújo, E. L.; Santos, D. M. dos.; Santos, A. M. M.; Silva, K. A. da. Natural regeneration of the vegetation of an abandoned agricultural field in a semi-arid region: a focus on seed bank and above-ground vegetation. Brazilian Journal of Botany. v. 42, p. 43-51, 2019. https://doi.org/10.1007/s40415-018-0510-8.

Paula, A.; Soares, J. J. Estrutura horizontal de um trecho de floresta Ombrófila Densa das Terras Baixas na Reserva Biológica de Sooretama, Linhares, ES. Floresta, v. 41, n. 2, p. 321-334, 2011. https://doi.org/10.5380/RF.V41N2A10.

Peña-Domene, M.; Martínez-Garza, C.; Howe, H. F. Early recruitment dynamics in tropical restoration. Ecological Applications, v. 23, n. 5, p. 1124-1134, 2013. https://doi.org/10.1002/1052-3380.C00027.

Reis, A.; Tres, D. R.; Scarlott, E. C. Restauração na Floresta Ombrófila Mista através da sucessão natural. Pesquisa Florestal Brasileira., n. 55, p. 67-73, 2007. https://pfb.cnptia.embrapa.br/pfb/index.php/pfb/article/view/120. 20 Nov. 2019.

Rodrigues, B. D.; Martins, S. V.; Leite, H. G. Avaliação do potencial da transposição da serapilheira e do banco de sementes do solo para restauração florestal em áreas degradadas. Revista Árvore, v. 34, n. 1, p. 65-73, 2010. https://doi.org/10.1590/S0100-67622010000100008.

Schorn, L. A.; Galvão, F. Dinâmica da regeneração natural em três estágios sucessionais de uma Floresta Ombrófila Densa em Blumenau, SC. Floresta, v. 36, n. 1, p. 59-74, 2006. https://doi.org/10.5380/RF.V36N1A5.

Silva, A. P.; Resende, A. S. de.; Chaer, G. M.; Gonçalves, F. L. A.; Campello, E. F. C. Influência da forma e posição da encosta nas características do solo e na regeneração natural em áreas de pastagem abandonadas. Ciência Florestal, v. 28, n. 3, p. 1239-1252, 2018. https://doi.org/10.5902/1980509833666.

Soares Junior, R. C.; Almeida Junior, E. B. de.; Pessoa, L. M.; Pimentel, R. M. M.; Zickel, C. S. Flora do estrato herbáceo em um fragmento urbano de floresta atlântica – PE. Revista de Geografia. v. 25, n. 1, p. 35-49, 2008. https://periodicos.ufpe.br/revistas/revistageografia/article/view/228749/23162. 22 Mar. 2020.

Souza, A. L.; Schettino, S.; Jesus, R. M.; Vale, A. B. Dinâmica da regeneração natural em uma Floresta Ombrófila Densa secundária, após corte de cipós, Reserva Natural da Companhia Vale do Rio Doce S.A., estado do Espírito Santo, Brasil. Revista Árvore, v. 26, n. 4, p. 411-419, 2002. https://doi.org/10.1590/S0100-67622002000400003.

Souza, T. R.; Costa, F. R. C.; Bentos, T. V.; Leal Filho, N.; Mesquita, R. C. G.; Ribeiro, I. O. The Effect of forest fragmentation on the soil seed bank of central Amazonia. Forest Ecology and Management, v. 393, p. 105-112, 2017. https://doi.org/10.1016/j.foreco.2017.03.020.

The Angiosperm Phylogeny Group - APG IV. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society, v. 181, n.1, p. 1-20, 2016. https://doi.org/10.1111/bot.12385.

Trentin, B. E.; Estevan, D. A.; Rossetto, E. F. S.; Gorenstein, M. R.; Brizola, G. P.; Bechara, F. C. Restauração Florestal na Mata Atlântica: Passiva, Nucleação e Plantação de Alta Diversidade. Ciência Florestal, v. 28, n. 1, p. 160-174, 2018. https://doi.org/10.5902/1980509831647.

Venzke, T. S., Martins, S. V., Neri, A. V., Kunz, S. H. Síndromes de dispersão de sementes em estágios sucessionais de mata ciliar, no extremo sul da Mata Atlântica, Arroio do Padre, RS, Brasil, Revista Árvore, v. 38, n. 3, p. 403-413, 2014. https://doi.org/10.1590/S0100-67622014000300002.

Viana, E. G.; Bazoni, A. M. B.; Tetnzer, A.; Capucho, M. A.; Celestrini, N. M.; Duarte, D. N.; Lourenço, R. S.; Pulchsen, E. T.; Silva, A. M.; Souza, G. A. P.; Carvalhais Júnior, D.; Barbosa, D. F. Programa de assistência técnica e extensão rural proater 2011 – 2013. Linhares. Planejamento e programação de ações - (2011). Vitória: Governo do estado do Espírito Santo; Secretaria da Agricultura, Abastecimento, Aquicultura e Pesca; Incaper. 2011. 23p. https://incaper.es.gov.br/media/incaper/proater/municipios/Nordeste/Linhares.pdf. 05 Nov. 2019.