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# Different Species Proportions Influence Silvicultural Heterogeneity of Trees in a Restoration of a Ombrophilous Dense Forest in Lowlands

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**Abstract:** In order to generate strategies for the use of native species for ecological restoration, this paper presents the effects resulting from planting with facilitating tree species, in different proportions, after 13 years of forest restoration, in an area previously used for cattle buffaloes. The implantation was carried out in the Ombrophilous Dense Forest in the Lowlands, in the Atlantic Rainforest biome of the coastal plain of the state of Paraná and consisted of the plantation of 10 native species, distributed in two treatments: equal (A) and unequal (B) proportions of trees per species. After conducting a forest census, it was identified that the silvicultural expression of the facilitating tree species in the treatments differed significantly, and proportion A contributed to a scenario with greater silvicultural heterogeneity in the areas, which may be beneficial to the evolution of the ecological dynamics of the forest restoration process. In addition, the monitoring of *Alchornea glandulosa*, *Inga edulis*, and *Myrsine coriacea* expressed better development in the area and high resilience to the environmental adversities arising from the cattle ranching activity previously carried out, especially in relation to invasive grasses; therefore, they are recommended for use in the forest restoration of associated ecosystems.

**Keywords:** facilitating tree species; Atlantic rainforest; environmental adversities

## 1. Introduction

The forest restoration approach consists of an integrated system of many ecological, economic, and social factors, and the self-perpetuation of its ecosystems cannot always be guaranteed without the interrelationships [1] of different biotic and abiotic components on a local and regional scale. Every forest restoration project should be guided by the concept and process of succession and seek the best results in view of compensating for past damage and progressively increasing the extent and functioning of ecosystems [2]. In this way, the dynamic processes that generate interrelationships are sufficient to continue their development in the absence of anthropogenic assistance [3].

In recent decades, restoration has assumed an ascending role associated with sustainable development and the ecology of restoration in which it is critical to prepare for the uncertain effects of climatic change on ecosystem functioning and socially relevant services [4,5]. The world is committed to restoring millions of hectares of forest as a strategy to mitigate climate change with many other co-benefits, although the suitability of climatic conditions for the trees being planted at the restoration sites is changing, which may reduce the long-term viability of these projects [6,7].

Even so, the intensity of the degradations is increasing and is associated with the social impoverishment of the region [8,9], the deforestation has resulted in the fragmentation of the ecosystem with the aim of transforming forests into land for agriculture and cattle ranching [10]. Concomitantly, to supply the implanted production system, the area has been biologically contaminated with exotic grasses of the genus *Urochloa* spp. inserted for pasture formation, observed mainly by the presence of *Urochloa decumbens* (Stapf) R.D. Webster (Brachiaria) [11].

In other more serious situations, such as this study, another disturbance reported is the detour of the Capivari River, located on the First Plateau of Paraná, which resulted in additional water flow to the Cachoeira River on the coastal plain, significantly increasing its flow [12] and causing flooding in the region. The historical process was marked by intense transformations in the landscape through tax policy incentives that were contrary to regional development, stimulating the deforestation of vast areas and the expropriation of a large number of local farmers' lands [8].

Over time, the intensity of the degradation generated has expressively affected its resilience [11] and made, in many cases, the ecological restoration by means of conducting natural regeneration unfeasible. In this sense, the complex interactions among endangered ecosystems, landowners' interests, and different models of land tenure and use constitute an important series of challenges for those seeking to maintain and restore biodiversity and augment the flow of ecosystem services [13].

The species that establish themselves in the face of various factors of environmental heterogeneity—topography, pedology, faunal interactions, climate, among others—confer characteristics specific to the places, making it possible to observe trends in their ecological composition [14,15]. Additionally, understanding the dynamics of native forest loss and gain is critical for biodiversity conservation and ecosystem services, especially in regions experiencing intense forest transformations [16].

So, is planting with a low diversity of tree species, such as pioneer and early secondary species, an interesting strategy for ecological restoration? What proportion of trees per species would result in better environmental conditions for restoration? What is the silvicultural response of species planted for low diversity forest restorations?

Given the importance of the expected effects of restoration, this work aimed to evaluate the silvicultural structure resulting from the use of ten facilitator tree species inserted under different planting ratios in the restoration of the Ombrophilous Dense Forest in the Lowlands of the Coastal Plain of Paraná, Southern Brazil.

## 2. Materials and Methods

### 2.1. Characterization of the Study Area

The study area is located in Antonina, State of Paraná, Southern Brazil, at the following geographic coordinates: latitude 25°31′32″ S, longitude 48°70′15″ W; and latitude 25°30′72″ S, longitude 48°70′11″ W. It is located in the SPVS Guaricica Natural Reserve, bordering the Cachoeira River, on the PR-405 highway and the Bom Jesus Biological Reserve, inserted in a hydrographic relief unit of the Paraná Coastal Plain (Figure 1). The geological formation is considered to be Quaternário Fluviomarino and the soil is classified as Plintossolo Háplico Distrófico Típico [17].

The region has an elevation of less than 100 m, with a climate classified by Köppen as Cfa, humid subtropical with hot summers. The average annual temperature of the study area is 21 °C, and rainfall rate ranges between 2200 and 2600 mm, with December to March being the months with the highest precipitation [18].

Prior to the implementation of the restoration project, the existing vegetation cover was composed of abandoned pastures of exotic grasses of the genus *Urochloa* spp. Originally, the phytogeography of the area was composed of Ombrophilous Dense Forest in Lowlands typology of the Atlantic Forest biome [19].

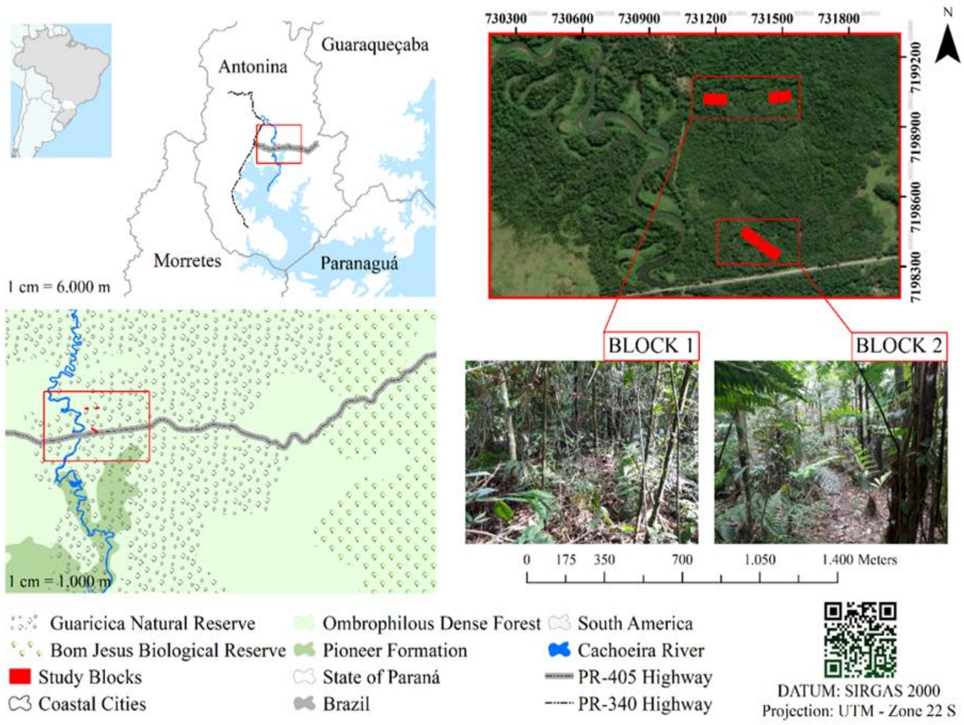


**Figure 1.** Location and environmental information of the study area in the Guaricica Natural Reserve in Ombrophilous Dense Forest in the coastal plain of Paraná, Brazil.

*2.2. Implementation of the Restoration Area*

The experiment was implemented from June to September 2006 and consisted of the plantation of 10 mixed native species. Due to the homogeneous local conditions, a randomized block design (RBD) was applied, with 50 × 100 m plots, or 5000 $m^2$ (0.5 ha) in two repetitions, resulting in a total experimental area of 2.0 ha (Figure 1).

The species were planted, providing 4 $m^2$ per plant, for a total of 5000 seedlings in 4 blocks. In each block, characterized by environmental conditions and not by trials, the treatments consisted of two types of facilitating plots (PF): A equal and B different proportions of seedlings per species. The species were numbered from 1 to 10 and show characteristics of ecological succession from pioneer to early secondary [20], with rapid growth (Table 1).

**Table 1.** Identification (NI) of species planted under the different proportions (A equal and B unequal trees per species) in facilitator stands (FS) and their successional stage (SS) classification: pioneer (Pi), early secondary (Es).

| Identification and Taxonomy | | | FS% | | SS |
|---|---|---|---|---|---|
| **NI** | **Scientific Name** | **Family** | **A** | **B** | |
| 1 | *Alchornea glandulosa* Poepp. & Endl. | Euphorbiaceae | 10 | 7 | Pi, Es |
| 2 | *Citharexylum myrianthum* Cham. | Verbenaceae | 10 | 10 | Pi, Es |
| 3 | *Hieronyma alchorneoides* Allemão | Phyllanthaceae | 10 | 7 | Es |
| 4 | *Inga edulis* Mart. | Fabaceae | 10 | 17 | Pi, Es |
| 5 | *Inga laurina* (Sw.) Willd. | Fabaceae | 10 | 7 | Es |
| 6 | *Inga marginata* Willd. | Fabaceae | 10 | 10 | Pi, Es |
| 7 | *Mimosa bimucronata* (DC.) Kuntze | Mimosaceae | 10 | 12 | Pi |
| 8 | *Myrsine coriacea* (Sw.) R. Br. Ex Roem. & Schult. | Primulaceae | 10 | 7 | Pi |
| 9 | *Schizolobium parahyba* (Vell.) Blake | Fabaceae | 10 | 7 | Pi, Es |
| 10 | *Senna multijuga* (Rich.) H. S. Irwin & Barneby | Fabaceae | 10 | 17 | Pi |

The seedlings from the Guaricica Nature Reserve nursery were 10 to 30 cm tall. The soil was prepared mechanically with the use of a tractor with a subsoiler and a rotary hoe, and the digging of the pits was conducted manually. In post-planting maintenance, manual crowning was conducted with a sickle, leaving the residues around the seedling as mulch. Between the planting rows, maintenance was semi-mechanized using a mechanical brush cutter.

### *2.3. Data Collection and Analysis after 13 Years*

We opted for a census forest inventory consisting of four 50 × 100 m plots divided into 5 × 100 m subplots, containing two or three rows of trees according to the planting spacings in each block. The action was guided by SPVS rangers who planted the seedlings in 2006.

In measuring each surviving tree, quantitative and semi-quantitative data were collected and subsequently grouped into a variables combination (VC), determined according to the characteristics of interest to the researchers' experiment, to perform the statistical analysis (Table 2).

**Table 2.** Description of the database collected and grouped into each variable combination (VC) for statistical analysis.

| VC | | Variables | Database Collection | |
|---|---|---|---|---|
| | | | | Quantitative data |
| VC1 | Dimensions | Mean diameter (MD)<br>Commercial height (CH)<br>Total height (TH) | Diameter at breast-height (DBH 1.30 cm)<br>Of possible use (m)<br>From the base to the end of the crown (m) | |
| | | | | Semi-quantitative data |
| VC2 | Stratification | Sociological position (SP) | 1: canopy<br>2: intermediate | 3: understory |
| | | Canopy luminosity (CL) | 1: illuminated<br>2: 25% shaded<br>3: 50% shaded | 4: 75% shaded<br>5: 100% shaded |
| VC3 | Qualities | Stem quality (SQ) | 1: straight stem-tree<br>2: 50% tortuous stem-tree<br>3: >50% tortuous stem-tree | 4: forked stem-tree > DAP<br>5: forked stem-tree < DAP<br>6: prop root |
| | | Stem health (SH) | 1: sane<br>2: deteriorated<br>3: hollow tree | 4: dead<br>5: stump sprout |
| | | Crown quality (CQ) | 1: 100% existent<br>2: species deciduous<br>3: 25% lifeless crown | 4: 25%–50% lifeless crown<br>5: >50% lifeless crown<br>6: 100% nonexistent |

The combination of variables for the dimensions (VC1) is composed of quantitative data obtained by using a tape measure to take the diameter at 1.3 m from the ground (d1.3) and the "Haglof" Clinometer for the height. The other groupings comprise semi-quantitative data, obtained from visual estimation, with daily beaconing by the collection team consisting of 3 to 5 people.

For each VC, a multivariate analysis of variance (MANOVA) was applied. When differences were identified between the group means, for each VC and proportions, discriminant analysis was conducted. The analyses were performed in the IBM SPSS Statistics 28.0 software [21]. The data were standardized to eliminate the effect of the unit of measure.

## 3. Results

### *3.1. Multivariate Analysis of Variance (MANOVA)*

The results of the multivariate analysis of variance (MANOVA) for each combined group indicate that, for all tests applied in MANOVA, there were significant differences between the group means for each VC analyzed (Table A1).

### *3.2. VC1*

For species sizes (VC1), three discriminant functions were determined, and only two functions explain more than 90% of the total variability in the data. Additionally, in view of the resulting values for structure matrix, a high canonical correlation is observed for the total height (0.890 and 0.854) and mean diameter (0.842 and 0.869) with function 1, and for commercial height (0.804 and 0.806) with function 2, for both proportions (Table A2).

The values of the group centroids for the discriminant functions correlated with the variables for each species' express differences for each treatment, from −1.351 to 1.132 in A, and −1.404 to 0.934 in B (Table A3).

According to the discriminant analysis, comparatively, proportion A shows that the centroids of each species are more distant from each other than proportion B. Thus, in relation to the variables of mean diameter, commercial height, and total height, proportion A resulted in greater silvicultural heterogeneity among the species, and proportion B greater homogeneity (Figure 2).

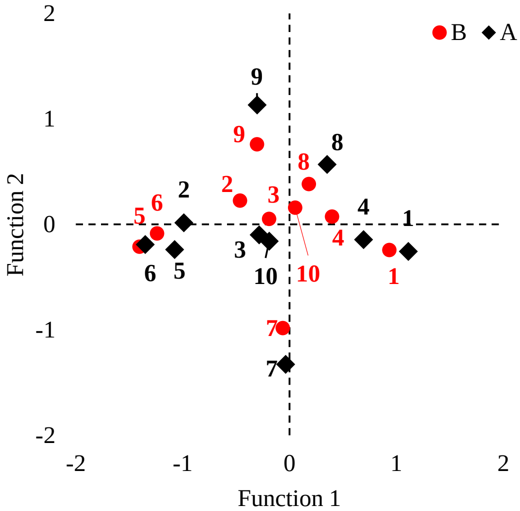


**Figure 2.** Discriminant analysis of the combination of dimensions variables (VC1) (mean diameter—MD, commercial height—CH, and total height—TH), for the 10 species (1 *A. glandulosa*; 2 *C. myrianthum*; 3 *H. alchorneoides*; 4 *I. edulis*; 5 *I. laurina*; 6 *I. marginata*; 7 *M. bimucronata*; 8 *M. coriacea*; 9 *S. parahyba*; 10 *S. multijuga*), in the proportions A (equal amount of trees per species) and B (unequal amount of trees per species).

When considering function 1 (MD and TH) among the species with the best results, *Alchornea glandulosa* (1), *Inga edulis* (4), and *Myrsine coriacea* (8) express themselves closer to each other in both proportions, evidence of their greater suitability for the study region and that the proportion of planting is irrelevant to their development (Figure 2).

In contrast, species 2, 5, and 6, corresponding to *Citharexylum myrianthum* Cham., *Inga laurina* (Sw.) Willd., and *Inga marginata* Willd., respectively, showed the lowest values among the planted species, in both proportions, although a subtly higher result could be observed for *C. myrianthum*, in proportion B (Figure 2).

In the analysis of function 2, correlated to commercial height (CH), in the proportions A and B, species 10 (*Senna multijuga* (Rich.) H. S. Irwin & Barneby) and 8 (*M. coriacea*) express the best results. The result of species 7, *Mimosa bimucronata* (DC.) Kuntze, on the other hand, differs widely, having less commercial measurements of the variable.

### 3.3. VC2

The combination of stratification variables (VC2) of the species, in both proportions, observed that function 1 expressed more than 97% of the total variability, a high canonical correlation of the variables with the same function, where the sociological position (SP) held values of 0.939 in proportion A and 0.948 in proportion B, and canopy luminosity (CL) held values of 0.707 in proportion A and 0.807 in proportion B (Table A2).

The group centroids for the discriminant functions correlated with VC2 expressed the differences for the species with values from −0.944 to 1.490 for proportion A and values from −0.724 to 1.555 for proportion B (Table A3).

In the discriminant analysis of VC2, as occurred for VC1, proportion A generated a greater heterogeneity than proportion B (Figure 3). This means that in proportion B, the sociological position and canopy luminosity are similar for the species and contribute to a more homogeneous environment with respect to the strata and species shading. It is noteworthy that the correlation of the canopy luminosity variable with function 2 (Table A2) determined the distinction of the species necessary in proportion A.

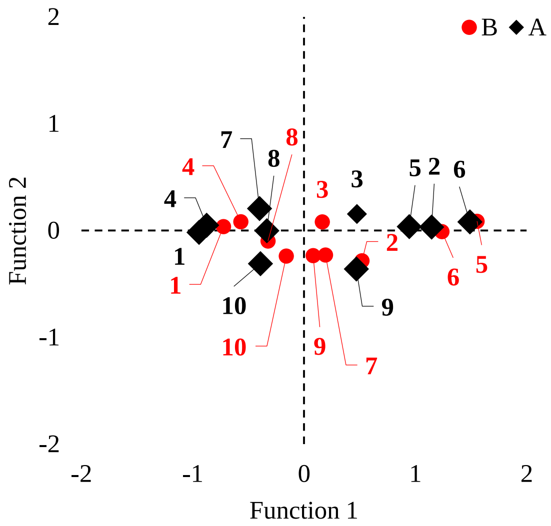


**Figure 3.** Discriminant analysis of the combination of stratification variables (VC2) (sociological position—SP, and canopy luminosity—CL), for the 10 species (1 *A. glandulosa*; 2 *C. myrianthum*; 3 *H. alchorneoides*; 4 *I. edulis*; 5 *I. laurina*; 6 *I. marginata*; 7 *M. bimucronata*; 8 *M. coriacea*; 9 *S. parahyba*; 10 *S. multijuga*), in the proportions A (equal trees per species) and B (unequal trees per species).

In this sense, when analyzing function 1, species 1, 4, and 8, in both proportions, contributed to the formation of the forest canopy simultaneously with the highest percentage of luminosity in the canopy (Figure 3).

Contrarily, species 2, 5, and 6 form the forest understory with lower light incidence in their canopies. Species 3 (*Hieronyma alchorneoides* Allemão), 7, 9 (*Schizolobium parahyba* (Vell.) Blake), and 10, statistically do not represent a specific stratum or luminosity of the forest, because they show more variability among themselves and are closer according to the number of individuals within the variables evaluated (Figure 3).

### 3.4. VC3

Functions 1 and 2 account for over 87% of the total variability, and the variables most correlated with these functions, by the structure matrix, were stem health (SH) for function 1 (0.843 and 0.913) and stem quality (SQ) for function 2 (0.792 and 0.843). For canopy quality (CQ), higher correlation is observed with function 1 (0.467 and 0.514) (Table A2).

The centroids of the groups for the functions correlated with VC3 expressed values between −1.002 and 1.920 for proportion A and −0.675 and 2.128 for proportion B (Table A3).

In the discriminant analysis (VC3), once again proportion A contributes to more heterogeneous characteristics, mainly determined by stem health (function 1). In proportion B, the species form small groups influenced by the quality of the stem (Figure 4).

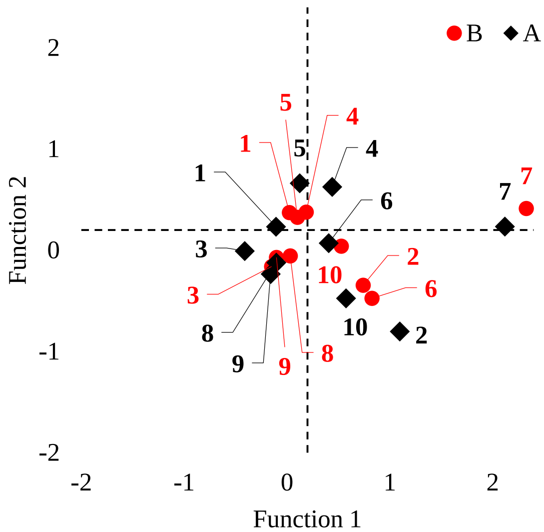


**Figure 4.** Discriminant analysis of the combination of qualities variables (VC3) (stem quality—SQ, stem health—SH, and crown quality—CQ), for the 10 species (1 *A. glandulosa*; 2 *C. myrianthum*; 3 *H. alchorneoides*; 4 *I. edulis*; 5 *I. laurina*; 6 *I. marginata*; 7 *M. bimucronata*; 8 *M. coriacea*; 9 *S. parahyba*; 10 *S. multijuga*), in the proportions A (equal trees per species) and B (unequal trees per species).

In both proportions, species 7 is, according to function 1, the most dissimilar, with the most impaired stem health, caused mainly by a greater number of trees containing rot and/or termites. Additionally, other species 6, 2, and 10, were also influenced by this variable, however, with a much lower number of trees than 7 (*M. bimucronata*) (Figure 4).

Crown quality (CQ) is mostly associated with function 1, and it is emphasized that the species with the lowest stem health are the same as those with low canopy dense estimates for this variable. Among the others, 1, 4, and 5 stood out with good stem health and canopy quality (Figure 4).

In function 2, correlated to the stem quality (SQ), species 2, 3, 6, 8, 9, and 10 are similar to each other more precisely because of the presence of crookedness. The same occurs for species 1, 4, 5, and 7 due to the similar amount of bifurcations, except when looking at the number of trees sampled per species. In this sense, the species that presented the most bifurcations below 1.30 m (DBH) was number 7 (*M. bimucronata*) (Figure 4).

## 4. Discussion

From an ecological restoration standpoint, greater silvicultural heterogeneity shows a more desirable structure for species diversification and is expressed as one of the main factors contributing to the better floristic-structural composition of a forest [22,23], because the diversity of factors interacting in the community contributes to an interesting successional scenario.

Thus, the greater heterogeneity provides the formation of a wider range of ecological niches, intensified by the abundance of propagules from the study region. On the other hand, the presence of *Urochloa* spp. is an important obstacle to natural regeneration, and restoration plantings that result in more homogeneous structures tend to generate a faster and more effective overlay in controlling the grasses. Therefore, both ratios evaluated meet the restoration goals and promote heterogeneity in a broader sense.

Firstly, it makes the practice of ecological restoration with the planting of seedlings more attractive to the detriment of natural regeneration, especially among the majority of rural workers, who represent greater connectivity between different environments and stop planting due to the high costs of obtaining native seedlings in high diversity.

Secondly, there is a great shortage of forest nurseries that produce native seedlings for use in ecological/forest restoration. The application of ecological restoration projects with low diversity, in addition to standardizing field maintenance activities, makes their effectiveness more accessible to restorers less assisted by government institutions.

Last but not least are the environmental benefits. The recurrence of greater heterogeneity with the planting of equal proportions of trees per species across all combinations of variables (VC) demonstrates conditions of greater ecological dynamics.

Among the benefits, the variation of radiation and temperature in the stratification levels extend to the variables of canopy quality that provide perches for wildlife and the quality and health of the stem, where decomposition, tortuosity, and bifurcations generate conditions for nest formation and consolidate the food chain for many animals, and contribute to the occurrence of nutrient cycling in the forest. All this ensures the ability of the forest, which is in the process of restoration, to renew itself and perpetuate its ecological functions necessary for the continuity of nature's goods and services for today's society, especially in minimizing the impacts of global warming.

At the local level, it can be said that there is a high impact of micro-site variations in the coastal plain, related to soil drainage capacity, so that studies in the surrounding area show different dominant species, either in natural regeneration or in restoration plantations.

Of course, the arrangement of species chosen for use in the restoration and their behavior in the area are crucial to obtaining such environmental characteristics. From this perspective, the species in this study that showed greater local suitability, such as *A. glandulosa*, *I. edulis* and *M. coriaceae* (1, 4, 8) are suitable for strategic use in the restoration of areas dominated by invasive exotic grasses (*Urochloa* sp.), given their potential to contribute to the vertical and horizontal structure of the forest.

The vigorous development of plantations with *I. edulis* and *M. coriacea* (4 and 8), with high expressiveness of the latter, along with *A. glandulosa* (1), also in natural regeneration, are constantly reported for the region [11,24], and reaffirm their contribution to forest canopy formation and their suitability for territorial occupation of both proportions in this study [25], undoubtedly an essential feature of forest restoration.

Similar results are observed with *I. edulis* and *C. myrianthum* (4 and 2) standing out at the expense of I. marginata. In fact, there is an important contrast with the study area in which *C. myrianthum* was not among the species that showed the best development [24]. On the other hand, *C. myrianthum*, *S. parahyba*, *M. bimucronata*, and *S. multijuga* (2, 9, 7, and 10), show a higher development than that observed in the study area, when in locations more suitable to their self-ecological demands [20]. At the same time, among the most abundant species in the regeneration of abandoned pastures near the study area are *S. multijuga* (10) and *H. alchorneoides* (3) [11].

*I. laurina* and *I. marginata* (5 and 6), even with characteristics of rapid initial growth and longevity greater than the pioneers (25 to 60 years) [20], could not fully manifest their physiological activities, so that after 13 years, they seem to wait for favorable conditions to develop and are less competitive in relation to the other species studied. Oppositely to what was expected, *S. multijuga* (10), which commonly exposes strong lateral branches, forks, and shoots from the base, stood out in the variable commercial height, probably explained by the competition arising from the planting alignment.

However, one should also consider that the number of trees sampled from this species, along with *M. bimucronata* (7), is smaller than the others; moreover, the phytosanitary conditions of the stem indicate that both are leaving the system to favor others, advancing in the restoration process. This is confirmed by the presence of standing and fallen logs and the absence of living trees for the species [24]. Therefore, further monitoring of the areas is necessary to ensure that the abrupt exit of these species from the system does not interrupt the progress of successional stages, if natural regeneration is still unable to occupy the spaces opened by mortality [20].

In particular, fragmented landscapes or landscapes with an incidence of invasive exotic species, poorly diverse restoration plantings, where the selected species occupy large proportions of area, can lead to difficulty in stabilizing the ecosystem being restored. However, it is possible to read the behavior of certain species. The pioneer characteristic and low arboreal life form of *M. bimucronata* (7) results in higher percentages of canopy importance and occupancy between 3 and 8 years of age [26,27], and decreases over time simultaneously with the vigorous characteristics of the other species that stood out in this study. The inverse highlight for *M. bimucronata* is explained by the species inherent characteristic of tortuous stem arrangement with a large number of bifurcations, which resulted in lower commercial heights even with the planting alignment.

Besides being a species that indicates advances in the forest restoration process when suppressed by other species, it also expresses interesting ecological contributions to restoration. Characteristics such as nitrogen fixation [28] and nucleator character are cited, as it shelters fauna and has the function of perching for avifauna, besides protecting the seedlings of several species, among them *M. coriacea* (8) [29], which represents one of the species highlighted in this study and may have benefited, given its low mortality [24] and continuous dispersal of its seeds.

In the absence of these risk factors to the progression of successional stages, the inclusion of short-cycle species in restoration projects in well-preserved landscapes, especially when in moderate proportions, can favor the development of early and late secondary species of natural regeneration and is therefore beneficial to the successional process, besides enabling greater environmental heterogeneity.

## 5. Conclusions

In general, planting an equal number of trees of each species resulted in greater environmental heterogeneity, which may make the results obtained for proportion A more interesting for forest restoration. However, given the degradation history prior to restoration and the presence of *Urochloa* spp., proportion B is an interesting alternative, given the need to combat invasive exotic species present on the soil surface, which tends to reduce restoration costs; and the unavailability of seedlings of other species at the time of planting.

Certainly, the results highlight the need to observe the objective of each project, as well as the barriers related to each situation, when defining the restoration methodology to be applied. In this case, we started with the premise of combining different qualities of native species in a plantation, enabling the formation of an attractive environment for native propagules and dispersing agents.

For forest restoration in regions with similar phytogeographic characteristics and degradation factors, it can be assumed:

- Species 1, 4, and 8 are highly competitive to the presence of exotic grasses and are resilient to the transitional circumstances of the restoration process. In addition, they contributed to canopy formation and forest health associated with lower maintenance costs.
- Species 2, 3, 5, 6, and 9 are suitable for use in ecological restoration and contribute to different lower forest strata.
- Species 7 and 10 played an important role in the initial overlay, and their senescence indicates the evolution of the restoration process.

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**Conflicts of Interest:** Author Antonio Aparecido Carpanezzi and Edinelson Jose Maciel Neves were employed by the company Brazilian Agricultural Research Corporation. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Appendix A

**Table A1.** Significance results ($\alpha$) of the multivariate analysis of variance for the variables combination of dimensions (VC1), stratification (VC2), and qualities (VC3), by Wilks Lamba ($\lambda_{Wilks}$) and Roy largest Root ($\lambda_{Roy}$) tests.

| Factor | Test | VC1 | | VC2 | | VC3 | |
|---|---|---|---|---|---|---|---|
| | | Value | $\alpha$ | Value | $\alpha$ | Value | $\alpha$ |
| Proportions | $\lambda_{Wilks}$ | 0.992 | 0.003 | 0.995 | 0.009 | 0.993 | 0.005 |
| | $\lambda_{Roy}$ | 0.008 | 0.003 | 0.005 | 0.009 | 0.007 | 0.005 |
| Species | $\lambda_{Wilks}$ | 0.492 | <0.001 | 0.596 | <0.001 | 0.732 | <0.001 |
| | $\lambda_{Roy}$ | 0.657 | <0.001 | 0.658 | <0.001 | 0.223 | <0.001 |
| Interaction | $\lambda_{Wilks}$ | 0.975 | 0.008 | 0.967 | <0.001 | 0.957 | <0.001 |
| | $\lambda_{Roy}$ | 0.014 | 0.002 | 0.030 | <0.001 | 0.022 | <0.001 |

**Table A2.** Description of the discriminant functions (F) of eigenvalues (AU), coefficient of variation (CV%), canonical correlation (CC); and structure matrix (SEM) obtained by correlation, in proportions (P) A (equal trees per species) and B (unequal trees per species), from the combination of the variables of dimensions (VC1)—mean diameter (MD), commercial height (CH), and total height (TH), stratification (VC2)—sociological position (SP) and canopy luminosity (CL), and qualities (VC3)—stem quality (SQ), stem health (SH), and crown quality (CQ).

| VC | P | F | | | | SEM | | |
|---|---|---|---|---|---|---|---|---|
| | | F | 1 | 2 | 3 | F | 1 | 2 |
| VC 1 | A | AU | 0.755 | 0.263 | 0.069 | TH | 0.890 * | −0.061 |
| | | CV% | 69.50 | 93.70 | 100 | MD | 0.842 * | −0.254 |
| | | CC | 0.656 | 0.456 | 0.253 | CH | 0.589 | 0.804 * |
| | B | AU | 0.634 | 0.115 | 0.040 | MD | 0.869 * | −0.313 |
| | | CV% | 80.30 | 95.00 | 100 | TH | 0.854 * | 0.086 |
| | | CC | 0.623 | 0.322 | 0.196 | CH | 0.579 | 0.806 * |
| VC 2 | A | AU | 0.762 | 0.016 | | SP | 0.939 * | −0.343 |
| | | CV% | 97.90 | 100 | | CL | 0.770 * | 0.638 |
| | | CC | 0.658 | 0.126 | | | | |
| | B | AU | 0.682 | 0.014 | | SP | 0.948 * | −0.319 |
| | | CV% | 97.90 | 100 | | CL | 0.807 * | 0.591 |
| | | CC | 0.637 | 0.119 | | | | |
| VC 3 | A | AU | 0.258 | 0.156 | 0.062 | SH | 0.843 * | −0.379 |
| | | CV% | 54.20 | 87.00 | 100 | SQ | 0.585 | 0.792 * |
| | | CC | 0.453 | 0.368 | 0.241 | CQ | 0.467 | −0.460 |
| | B | AU | 0.213 | 0.066 | 0.028 | SH | 0.913 * | −0.164 |
| | | CV% | 69.50 | 90.90 | 100 | SQ | 0.486 | 0.843 * |
| | | CC | 0.419 | 0.248 | 0.164 | CQ | 0.514 | −0.405 |

* Variables with the highest correlation with the discriminant function.

**Table A3.** Group centroids for each function (F) and species, in proportions (P) A (equal trees per species) and B (unequal trees per species), from the combination of variables from dimensions (VC1), stratification (VC2) and qualities (VC3).

| VC | P | F | Species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| VC1 | A | 1 | 1.111 | −0.989 | −0.285 | 0.693 | −1.076 | −1.351 | −0.037 | 0.352 | −0.303 | −0.190 |
| | | 2 | −0.257 | 0.015 | −0.101 | −0.146 | −0.240 | −0.192 | −1.328 | 0.568 | 1.132 | −0.160 |
| | B | 1 | 0.934 | −0.464 | −0.191 | 0.398 | −1.404 | −1.240 | −0.063 | 0.181 | −0.305 | 0.052 |
| | | 2 | −0.243 | 0.224 | 0.052 | 0.074 | −0.213 | −0.086 | −0.985 | 0.382 | 0.758 | 0.158 |
| VC2 | A | 1 | −0.944 | 1.146 | 0.476 | −0.875 | 0.945 | 1.490 | −0.400 | −0.335 | 0.470 | −0.392 |
| | | 2 | −0.017 | 0.032 | 0.154 | 0.050 | 0.037 | 0.080 | 0.206 | −0.002 | −0.360 | −0.311 |
| | B | 1 | −0.724 | 0.521 | 0.164 | −0.568 | 1.555 | 1.239 | 0.193 | −0.324 | 0.082 | −0.159 |
| | | 2 | 0.037 | −0.284 | 0.080 | 0.082 | 0.087 | −0.011 | −0.229 | −0.099 | −0.235 | −0.240 |
| VC3 | A | 1 | −0.307 | 0.897 | −0.611 | 0.240 | −0.076 | 0.206 | 1.920 | −0.304 | −0.359 | 0.375 |
| | | 2 | 0.033 | −1.002 | −0.207 | 0.426 | 0.463 | −0.129 | 0.034 | −0.321 | −0.434 | −0.675 |
| | B | 1 | −0.176 | 0.541 | −0.350 | −0.013 | −0.099 | 0.627 | 2.128 | −0.168 | −0.302 | 0.328 |
| | | 2 | 0.173 | −0.546 | −0.361 | 0.177 | 0.126 | −0.675 | 0.213 | −0.255 | −0.271 | −0.160 |

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