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Band planting: a new restoration technique under the multi-criteria analysis of ecological functionality

Plantio em faixas: uma nova técnica sob a análise multicriterial da funcionalidade ecológica

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ABSTRACT

We evaluated band planting (BP) to assess its efficiency in the early restoring of ecological processes using a multi-criteria protocol known as Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators (MESMIS) to obtain the ecological functionality consolidation index (EFCI). We sampled a 4.3 ha^{-1} plantation, aged 3 years, with BP, 1.5-m space between bands, 2-m space between seedlings, and a 3.5-m band of natural regeneration, ten areas with conventional planting (CP), aged 5 years, in the coverage and diversity models, and ten areas restored by natural regeneration (NR), aged 4 years. Sampling was carried out in 36 10 m x 10 m blocks, totaling 144 plots, 15 blocks for BP, 11 blocks for CP, and 10 blocks for NR. Species richness was similar between the areas; however, there was a significant difference between BP and the other areas (CP and NR) by the Dunn's test ($p < 0.05$). The NR area had the highest diversity (H' = 3.03; J' = 0.76), followed by BP (H' = 2.56; J' = 0.62), and CP (H' = 2.0; J' = 0.48), whereas the BP area (4.348 ind.ha^{-1}) had the highest density. The BP had the highest EFCI for diversity (0.100), control, and management (0.067) compared to NR, for diversity (0.022), and similar to CP in soil protection and nutrient cycling (0.047). BP was efficient in recovering early ecological processes under conditions similar to fragments in the initial stage of succession.

Keywords: ecological restoration; functional attributes; indicators; ecological functions.

RESUMO

Avaliamos o plantio em faixas (PF) em relação a sua eficiência na restauração precoce de processos ecológicos utilizando o protocolo multicriterial, para obter o índice de consolidação da funcionalidade ecológica (ICFE). Amostramos um plantio de 4,3 ha^{-1}, com três anos de idade, no modelo de PF com 1,5 m de espaçamento entre faixas, 2 m entre mudas e uma faixa de 3,5 m de condução de regeneração natural, dez áreas com plantio convencional (PC), com cinco anos de idade, no modelo de preenchimento e diversidade e dez áreas restauradas por regeneração natural (RN), com três anos de idade. A amostragem foi realizada em 36 blocos com dimensões de 10 m x 10 m, totalizando 144 parcelas, sendo 15 blocos para PF, 11 blocos para PC e 10 blocos para RN. A riqueza de espécies foi semelhante entre as áreas, mas houve diferença significativa entre o PF e as demais áreas (PC e RN) pelo teste de Dunn ($p < 0,05$). A diversidade foi maior na área RN (H' = 3,03; J' = 0,76), seguida por PF (H' = 2,56; J' = 0,62 e PC (H' = 2,0; J' = 0,48), mas a maior densidade foi registrada para PF (4.348 ind.ha^{-1}). PF apresentou o maior ICFE para diversidade (0,100), controle e manejo (0,067) em comparação com RN (0,022) e semelhante ao PC na proteção do solo e ciclagem de nutrientes (0,047). O PF foi eficiente na recuperação de processos ecológicos precoces em condições semelhantes a fragmentos em estágio inicial de sucessão.

Palavras-chave: restauração ecológica; atributos funcionais; indicadores; funções ecológicas.

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Introduction

Several global commitments have guided the ecological restoration of degraded areas as a way to address environmental issues (Antoniazzi et al., 2016), especially climate change, identified as the key alternative for the necessary carbon sequestration from the atmosphere (Benini and Adeodato, 2017). Recently, Brazil made international commitments involving the restoration of 12.5 million hectares by 2030 (Calmon, 2021). Thus, to achieve ambitious goals such as restoring 350 million hectares by 2030 (Dave et al., 2019), it is necessary to develop more efficient ecological restoration techniques and means to monitor the success of restorations through the return of ecological processes (Hobbs et al., 2011).

In Brazil, several restoration models have been produced to recover degraded ecosystems, such as the Miyawaki method (1999) and the dense-diverse-functional model, which focus on rapid soil covering, favoring succession and nutrient cycling processes, with a high density of individuals, high levels of species richness, and high diversity of ecological functions in their implantation (Piña-Rodrigues et al., 1997; Schirone et al., 2011; Galetti et al., 2018).

Although restoration by planting seedlings is one of the most used techniques (Schorn et al., 2010), other alternatives can also be used, either combined or isolated, which require less investment of resources, such as conducting regeneration, especially in areas of difficult access (Leal-Filho et al., 2013), nucleation based on the formation of biodiversity nuclei that favor the process of ecological succession (Reis et al., 2003), the use of functional groups as proposed by Gandolfi et al. (2009) with the so-called “covering species”, which grow quickly covering the soil, and “species of diversity”, which are generally slower in growth and take longer to cover the soil but increase species richness. Combinations between agroecological and agroforestry techniques as a transitional phase at the beginning of forest restoration were also proposed to reconcile ecological restoration with sustainable development. (Vieira et al., 2009).

Despite the various restoration models, it is necessary to assess their efficiency in restoring ecological processes. The restoration of ecological functionality is associated with factors that affect biotic communities expressed in their indicators of community diversity, structure, and similarity (Gatica-Saavedra et al., 2017), and in the presence of biotic interactions interfering with ecosystem functioning and provision of environmental services (Hopper et al., 2004). Thus, the successful restoration of ecological functions is associated with measurement based on indicators that provide information about the ecosystem that is being formed (Ramos Filho et al., 2007).

The method known as MESMIS (Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators) has wide applicability in different activities around the world (Loureiro et al., 2020) and is classified as flexible and adaptable as it reflects the specificities of the contexts being assessed (Cândido et al., 2015). Despite being widely used in agroecology due to its versatility, it can also be used to assess the recovery of ecological functions in different restoration models (Galetti et al., 2018). The method is based on stability indicators, which would be the system’s ability to maintain a stable balance, or resilience, which is the ability to return to equilibrium or maintain its productive potential after disturbances, and system reliability, defined as the ability to maintain productivity at levels close to its equilibrium over time (López-Ridaura et al., 2002; Theodoro et al., 2011; Pinã-Rodrigues et al., 2015; Galetti et al., 2018).

In this context, given the demands for restoration methods that efficiently recover the ecological functions of an ecosystem, since the use of pre-established restoration models based on adjustments to each condition has been identified as one of the causes of failure in restoration plantations (Durigan et al., 2010), we evaluated a new ecological restoration technique called band planting through its ecological functionality proposed by Piña-Rodrigues et al. (2015). Considering the above, this work intends to answer the following questions:

- Is the band planting restoration technique efficient in restoring stability and resilience, reliability, and ecological processes compared to conventional planting of seedlings and natural regeneration?
- What conditions or processes have affected the establishment of ecological functionality in the restoration models assessed?

Material and Methods

Study areas

The survey was conducted in 21 areas, totaling 31.7 hectares, located in the municipalities of Borborema, between 384-387 m altitude, and Itapira, at 954 m altitude, both in the state of São Paulo, Brazil (Figure 1). The areas before expropriation had been used as cattle pasture with grass (*Paspalum notatum* Flüggé).

The regions are characterized with a predominance of Seasonal Semideciduous Forest, with a tropical climate and little rain in the winter, classified by Köeppen as Aw (Alvares et al., 2014). The average temperature is 22.2°C and the average annual rainfall is 1.231 mm. August is the driest month, with 19 mm. The highest precipitation occurs in January, with an average of 234 mm. January is the warmest month of the year, with an average temperature of 24.8°C. The average temperature in June is 18.5°C (Climate-Data.org, 2019).

In the surroundings of the study areas, we observed fragments of seasonal semideciduous forest, with secondary vegetation, with herbaceous, shrub, and tree strata. The canopy is approximately 12 meters high, with emerging species. The canopy is occasionally discontinued, with exotic shrub and grass species in the openings.

The first treatment was performed by BP, aged three years, where 8,600 seedlings of 97 shrub and tree species were distributed in an area of 4.3 hectares. The second one comprised ten areas with CP, aged five

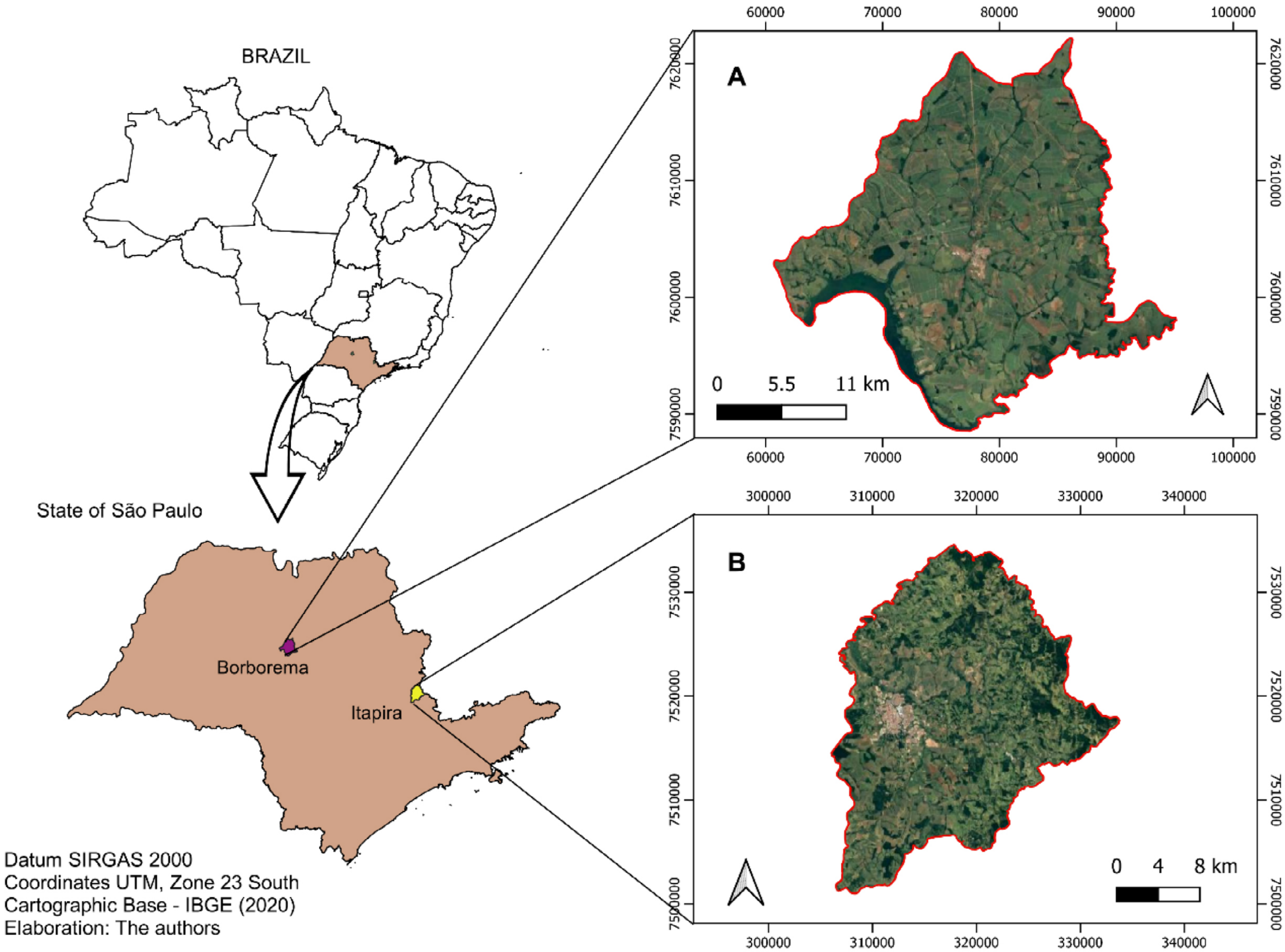

Figure 1 – Location of the study areas. (A) municipality of Borborema and (B) municipality of Itapira.

years, where 22,455 seedlings of 97 shrub and tree species were planted on 13.47 hectares. The third treatment consisted of ten areas with the conduction of natural regeneration (NR), aged 4 years, totaling about 14 hectares (Figure 2).

The collections were carried out between June and July 2020, in 36 blocks totaling 144 plots, 15 blocks for the band planting method, 11 blocks for conventional planting, and 10 blocks for the natural regeneration conduction method. For the diversity descriptors and functional parameters of the community, all arboreal individuals were identified, and their total height (cm) and circumference at breast height (CBH) were measured.

Each species was classified by successional group (pioneer and non-pioneer), using the same criteria as in SMA Resolution No. 08 (São Paulo, 2008) and Barbosa et al. (2015). The observed tree specimens were evaluated regarding the presence of vines and vascular epiphytes. In the control and management descriptor, soil cover per canopy was estimated, calculated according to the indications of SMA Resolution No. 32/2014 (São Paulo, 2014).

Canopy cover (%), cover with exotic grasses (%), and impacts caused by human presence, both positive (management, weeding, and absence of fires) and negative (trails, paths, and fires), were assessed through visual inspection of the 100 m² blocks. Regarding soil protection and litter input, the following descriptors were estimated: soil cover with herbaceous plants (%), soil cover with regenerating individuals (%), mulch (%), and litter height (cm).

The indicators of soil cover with litter, mulch, soil cover with herbaceous plants, cover with regenerating individuals, and cover with exotic grasses were obtained using a 0.50 x 0.50-m table, subdivided into 4 squares of 0.25 x 0.25 meters, launched in 3 points of each plot. Each grid filled in more than half of its area, representing 25% cover. Subsequently, the average percentage of the cover was calculated for each indicator.

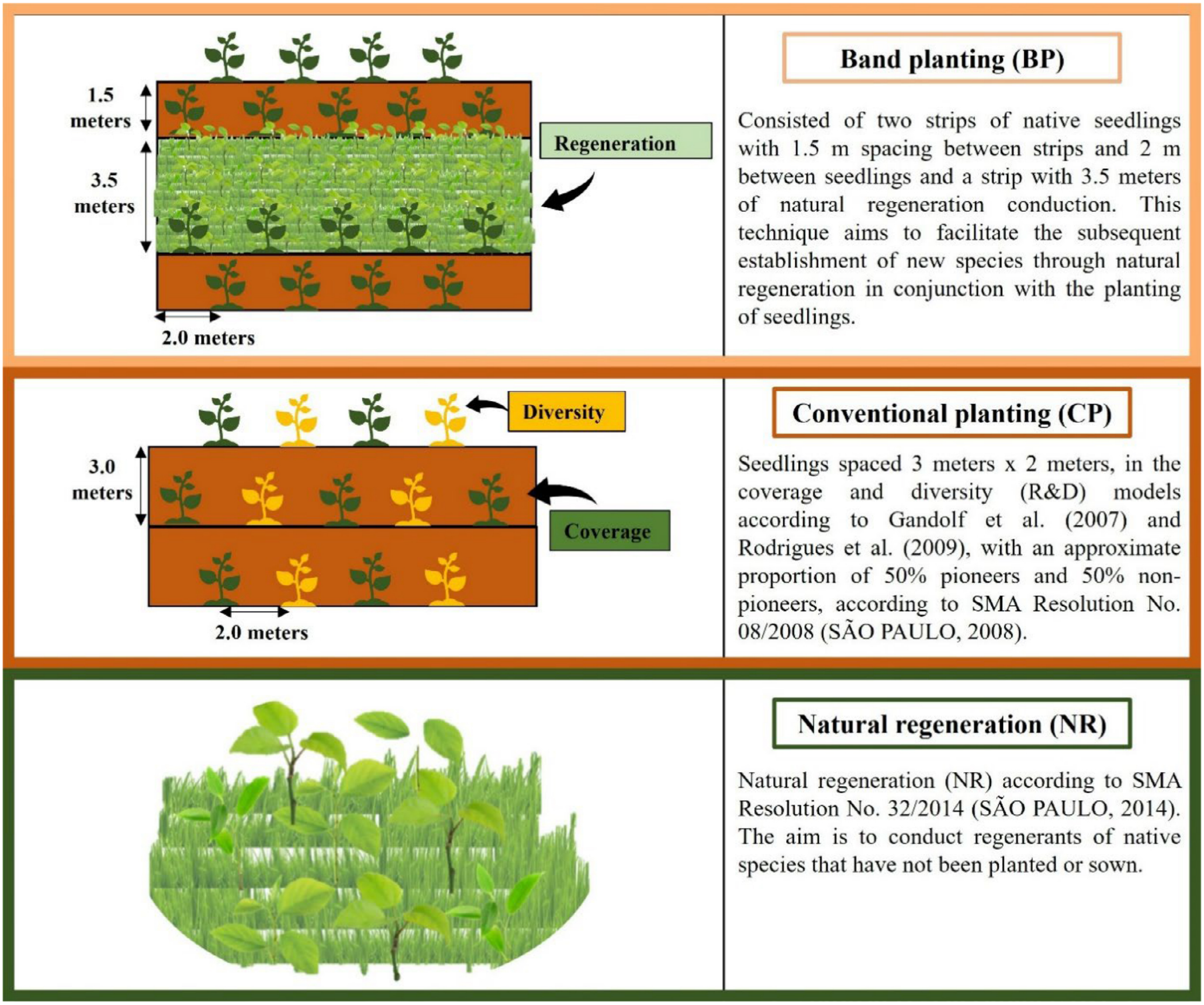

Figure 2 – Description of the treatments (restoration models) studied.

Analysis of ecological functionality

Since interactions in restored systems or the restoration process follow trajectories at different levels, the multicriterial selection of indicators using the MESMIS provides for protocols for the selection and application of indicators, making it possible to combine temporal and spatial variations to assess ecological processes (Masera et al., 1999; Priego-Castillo et al., 2009; Cândido et al., 2015). Thus, the MESMIS protocol (Masera et al., 1999), adapted by Piña-Rodrigues et al. (2015), was used to evaluate the different restoration methods, for which the attributes of stability, resilience and reliability, descriptors, and referential scenarios were defined and evaluated through indicators and their parameters (Galetti et al., 2018). For each indicator, positive and negative scenarios and references were proposed, based on a bibliographic review (Table 1).

Following the method by Galetti et al. (2018), scores ranging from 0-3 were assigned as follow: 0-1 = critical: bad, nonexistent, or distinct from the positive scenario; 2 = acceptable degree; and 3 = desired degree of sustainability, similar to the positive scenario. From this analysis, radar charts were elaborated, contemplating the indicators of stability and resilience, and reliability. In the graph, each radius represents one of the indicators, the length of which is proportional to the score of the indicator (0-3).

Data analysis

To calculate diversity, the Shannon-Weaver Index (H’) and Pielou’s Evenness Index (J’) were used according to Martins and Santos (1999). Density, species richness, and abundance of successional groups were calculated according to Barbosa et al. (2015).

Table 1 – Protocol for assessing the ecological functionality of restoration areas based on the MESMIS system.

Attribute	Keywords	Indicators	Scenarios and References	Parameters
Stability and Resilience	**Community diversity**	Diversity of tree species (H')	Shannon-Weaver index close to expected for Seasonal Forest fragments according to Galleti *et al.*, 2018	H' > 3.0 = 3 1.0 < H' < 2.9 = 2 H' < 0.9 = 1
		Richness of native species (S)	Undesirable: lower than expected according to SMA Resolution No. 08/08. Regular: low diversity impairs the establishment of a future community. Desirable: according to SMA Resolution No. 08/08.	Number of species > 30 = 3 10 > Number of species < 30 = 2 Number of species < 10 = 1
		Density of arboreal individuals (Number of ha^{-1}) (d)	Undesirable: high mortality, considering the density of plants recommended by SMA Resolution No. 08/08. Regular: average density values based on SMA Resolution No. 08/08. Desirable: values close to those recommended by SMA Resolution No. 08/08.	> 1.200 = 3 > 800 and < 1.200 = 2 > 400 and < 800 = 1 < 400 = 0
		Evenness (J')	Pielou's index (J') close to that expected for fragments of seasonal forest according to Galleti *et al.*, 2018	J' ≥ 1 – high = 3 0.5 < J' < 0.9 – average = 2 J' < 0.5 – low = 1
		Number of successional individuals/group (IND/Ge)	Undesirable: does not meet SMA Resolution No. 08/08. Desirable: meets SMA Resolution No. 08/08.	> 40% and < 60% of species/group = 3 IND < 40% and IND > 60% of species/group = 1
Stability and Resilience	**Functional Diversity**	Number of species per group of successional tree species D(GE)	Higher number of non-pioneer species present in the system.	P < NP= 3 P ± NP = 2 P > NP = 1
		Average basal area – AB (m^2)	Close to the expected for Seasonal Forest fragments according to Galleti *et al.*, 2018	AB > AR = 3 AB ≈ AR = 2 AB < AR = 1
		Diversity of ecological functions – F (eco)	The main functions of the forest were considered: (a) presence of manure or fertilizer species (with interaction with microorganisms for nitrogen fixation); (b) contribution of biomass (deciduous species); (c) attraction of fauna (zoochoric species); (d) ground cover (wide and dense crowns).	F (eco) > 4 = 3 1 > F (eco) < 4 = 2 1 F (eco) = 1 No role = 0
		Vascular epiphytes (EPI)	Undesirable: absent. Desirable: present, predominance of position in the upper (TS) and middle (TM) thirds of tree individuals. Reference: Resolution No. 04/1994 (BRASIL, 1994).	Abundant = 3 Regular/present = 2 Few = 1 Absent = 0
		Creepers (CIP)	Undesirable: dominating the canopy of trees, especially the upper and middle thirds.	Absent =3 Few = 2 Regular, present = 1 Abundant = 0
		Canopy cover – CC (m) (%)	3 years > 15%. 5 years > 30%. Reference: SMA Resolution No. 32/14 (São Paulo, 2014).	CC > 80 = 3 30% < CC < 80 = 2 15% < CC < 30 = 1 CC < 15% = 0
Reliability	**Control and management**	Canopy closure – L (%)	Undesirable: open areas, without canopy cover, with brightness greater than 50%. Desirable: closed areas with less light (< 50%).	0 < L < 25% = 3 25% < L < 50% = 2 50% < L < 75% = 1 75% < L < 100% = 0
		Ground cover with exotic grasses - GRAM (%)	Undesirable: SMA Resolution No. 08/08 provides for initial control of competitors. Desirable: low invasive density is favorable to the development of native species.	Absent to 10% = 3 > 10 to 25% = 2 25 to 50% = 1 > 50% of coverage = 0

Continue...

Table 1 – Continuation.

Attribute	Keywords	Indicators	Scenarios and References	Parameters
Reliability	**Control and management**	Human presence positive - Phum (+) (positive impacts)	Periodic visits and management of the area.	Recent management = 3 Old management = 2 Unmanaged = 1
		Human presence negative - Phum (-) (negative impacts)	Presence of traces of fires in the area, trails, paths and trash.	Not visited = 3 Little visited = 2 Very visited = 1
		Ground cover with regenerating species (herbaceous) – %herb	Undesirable: absence of regenerating species. Regular: presence of some regenerating species in the area. Desirable: presence of regenerating species.	75 to 100% = 3 50 to 75% = 2 25 to 50% = 1 1 to 25% = 0
	Soil protection and Litter input	% of regenerating cover - %reg	% litter close to that found in the reference area (75 to 100%).	75% to 100% = 3 50% to 75% = 2 25% to 50% = 1 1% to 25% = 0
		% of dead matter cover in the soil - %mmo	% litter close to that found in the reference area (75 to 100%).	75% to 100% = 3 50% to 75% = 2 25% to 50% = 1 1% to 25% = 0
		% Litter covering the soil -% s.e.r.	% litter close to that found in the reference area (75 to 100%).	75 to 100% = 3 50 to 75% = 2 25 to 50% = 1 1 to 25% = 0
		Litter height (cm) – H-Ser	Litter covering the soil with values close to that expected for fragments of Seasonal Forest according to Galleti et al., 2018	Bigger than AR = 3 Similar to AR = 2 Smaller than AR = 1

Source: MESMIS (Masera et al., 1999); descriptors, indicators, scenarios and references and parameters adapted by Piña-Rodrigues et al. (2015).

Data concerning the height of tree individuals, species richness, density of individuals, litter height, and basal area of individuals in each of the restoration techniques were assessed for normality, using the Shapiro-Wilk test, and homoscedasticity through the Levene's and Kruskal-Wallis tests. Based on the results, the restoration models were compared by Dunn's post-test ($p < 0.05$). All analyses were performed using the R program (R Core Team, 2020).

For the set of indicators of community and functional diversity, control and management, soil protection, and litter input, the EFCI was calculated, using the Equation 1:

$$EFCI \; \frac{\sum scores\ of\ the\ indicators - number\ of\ indicators}{(number\ of\ indicators) \times (\sum No.of\ parameters\ per\ indicator)} \quad (1)$$

Results and Discussion

we found that the species richness among the restoration techniques was close, ranging from 47 to 55 species sampled. However, the Kruskal-Wallis analysis evidenced that there was a difference in richness among the techniques ($p < 0.01$), and Dunn's post-test showed that the BP restoration technique differed ($p < 0.05$) from CP (Figure 3). We observed that there was a loss in the richness of 42 species both for CP and BP since 97 species were planted at the beginning of the restoration.

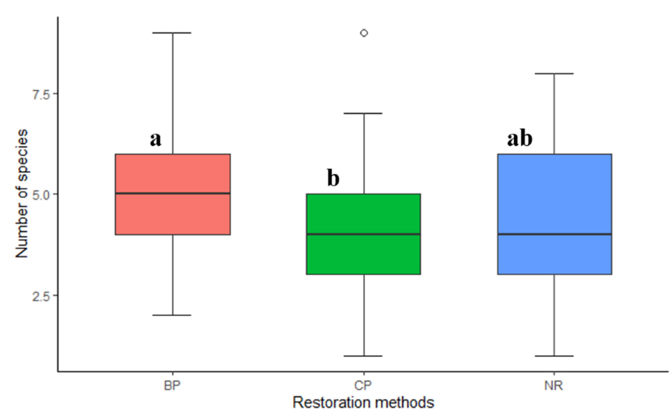

Figure 3 – Boxplot of the median and quartiles of the number of species among the different ecological restoration techniques*.
BP: number of species by the band planting technique; CP: number of species by the conventional planting technique; NR: number of species by the natural regeneration conduction technique; *same letters do not differ by Dunn's post-test with $p < 0.05$.

The Shannon-Weaver diversity index (H' = 3.03) and the Pielou's evenness index (J' = 0.76) were higher for the technique of NR (Table 2), and lower for CP of seedlings (H' = 2; J' = 0.48). The BP technique had intermediate values (H' = 2.56; J' = 0.62), as it is a technique

Table 2 – Values obtained for the indicators of the attributes of stability, resilience, and reliability of the restoration areas studied.

Attributes	Indicators	CP	NR	BP
Stability and resilience	**Species diversity**			
	H' (bits.ind^{1})	2.00	3.03	2.56
	Richness	55	47	55
	Density	4164	4300	4348
	J	0.48	0.76	0.62
	Ind/GE (%) - NP	55	33	51
	Ind/GE (%) – P	45	67	49
	Functional diversity			
	D(GE)(No. P)	25	31	27
	D(GE)(No. NP)	30	16	28
	IMA(m/ano)	-	-	-
	AB (m²) ha	7.72	0.22	5.06
	F (eco)	4	4	4
	EPI	0	0	0
	CIP	1	1	1
Reliability	**Control and Management**			
	CC (%)	88	38	65
	L (%)	-	-	-
	GRAM (%)	5	45	5.9
	Phum (+)	2	2	3
	Phum (-)	2	2	3
	Soil protection and Litter input			
	%herb	18	54	20.9
	%rege	37	10	23.75
	%mmort	58	58	76.3
	%ser	96	92	96.9
	H-ser	1.9	1.7	4.2

CP: conventional planting; BP: band planting; NR: area with the conduction of natural regeneration; H': Shannon's diversity index; S: species richness; d: density of individuals; Ind/GE: percentage of individuals/ecological group; J: Pielou's evenness index; D (Ge): diversity of ecological groups; AB: basal area; F (eco): diversity of ecological functions; Epi: epiphytes; CIP: creepers; CC: canopy cover; L: incidence of light; GRAM (%): presence of exotic grasses; Phum (-): negative human presence; Phum (+): positive human presence; % herb: percentage of herbaceous plants; % ser: percentage of litter; H-ser: litter height.

that mixes the planting of seedlings with the conduction of natural regeneration (Table 2).

Comparing these results with the indexes observed in a seasonal forest in the same state, in which the Shannon-Weaver index (H') was 2.66 and the Pielou's Evenness (J') index was 0.904 (Galetti et al., 2018), we found that the technique of conducting natural regeneration had the highest Shannon-Weaver index. Our results were lower than those found in recent studies on the diversity in seasonal forests, conducted in the states of Minas Gerais (Brazil), with H' = 3.94 (Torres et al., 2017) and Paraná, with H' = 3.35 (Souza et al., 2017); states adjacent to ours.

The density of individuals was close among the techniques; however, CP had the lowest density ($p < 0.05$) (Figure 4). BP had the highest density with approximately 4,348 individuals per hectare. Galetti et al. (2018) compared different restoration techniques with a seasonal forest area and observed that the techniques had higher diversity than the natural area. All the techniques evaluated in our study showed higher density than the seasonal forest area sampled by Galetti et al. (2018). Pinheiro et al. (2002) found a density of 7,488 individuals per hectare in a seasonal forest in the municipality of Bauru (86.4 km away from the study areas); however, the study area chosen by the authors had not been disturbed for more than 30 years, being a very well-preserved area.

Despite the diversity and evenness indices among the techniques are different, the densities were very close, so we realized that analyzing the parameters of richness, diversity, evenness, and density individually could mask the results of ecological restoration, through the inspection agencies that use these parameters as references (Fernandes et al., 2017).

Regarding functional diversity for the basal area indicator in the different techniques evaluated, we observed that all of them differed ($p < 0.01$), with BP being the technique that had the largest basal area, followed by CP, and the NR technique had the smallest basal area (Figure 5).

This fact can be attributed to the age of the conventional planting of seedlings, which is already five years old and has larger trees.

BP, although newer, had a basal area close to that of CP, whereas the area subjected to NR, despite being four years old, still does not have an arboreal structure forming a continuous canopy. The results for the basal area are still a long way from being similar to the ones found in preserved seasonal forest areas in the state of São Paulo, where values of 20.93 $m^2.ha^{-1}$ were found (Galetti et al., 2018) and Minas Gerais, with 20.019 $m^2.ha^{-1}$ (Torres et al., 2017), and some reforestation plantations in the same state, with a value of 15.05 $m^2.ha^{-1}$ (Melo and Durigan, 2007).

There were no significant differences in height between BP and the other techniques (Figure 6). However, there were differences between the CP and NR areas ($p > 0.01$), which had the lowest heights in the vertical stratum (Figure 6). Both the basal area and the height influence the shading of the community, since larger basal areas and greater heights can be correlated to larger individuals in the community (Francisco, 2020). Thus, we expected that both the CP of seedlings and BP would show greater canopy cover when compared to NR, corroborating our results.

Like height and basal area, canopy cover is related to shading, preventing exotic grasses from establishing themselves in the community, as they need a lot of light, thus favoring the process of restoration and ecological succession (Melo and Durigan, 2007; Galetti et al. 2018).

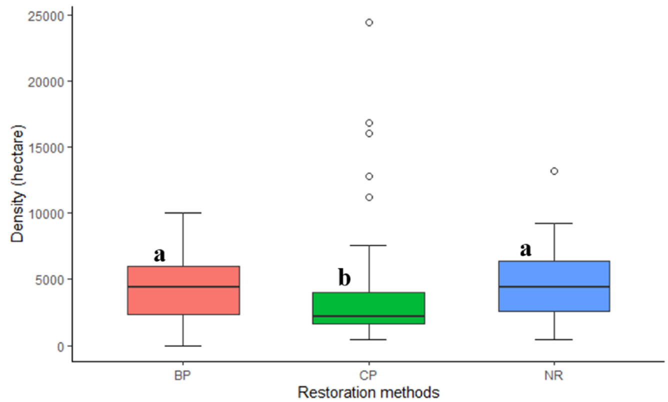

Figure 4 – Boxplot of the median and quartiles of the density of individuals among the different ecological restoration techniques*.
BP: number of species by the band planting technique; CP: number of species by the conventional planting technique; NR: number of species by the natural regeneration conduction technique; *same letters do not differ by Dunn's post-test with $p < 0.05$.

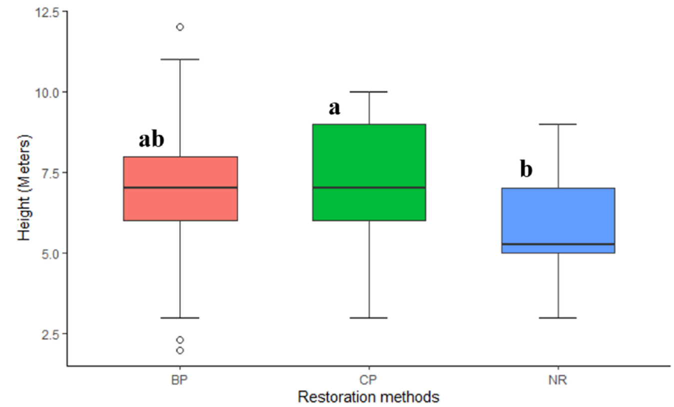

Figure 6 – Boxplot of median and quartiles of tree height between different ecological restoration techniques*.
BP: number of species by the band planting technique; CP: number of species by the conventional planting technique; NR: number of species by the natural regeneration conduction technique; *same letters do not differ by Dunn's post-test with $p < 0.05$.

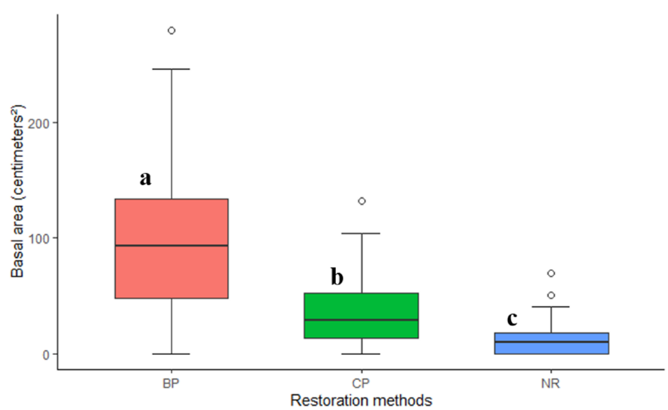

Figure 5 – Boxplot of the median and quartiles of the basal area between the different ecological restoration techniques*.
BP: number of species by the band planting technique; CP: number of species by the conventional planting technique; NR: number of species by the natural regeneration conduction technique; *same letters do not differ by Dunn's post-test with $p < 0.05$.

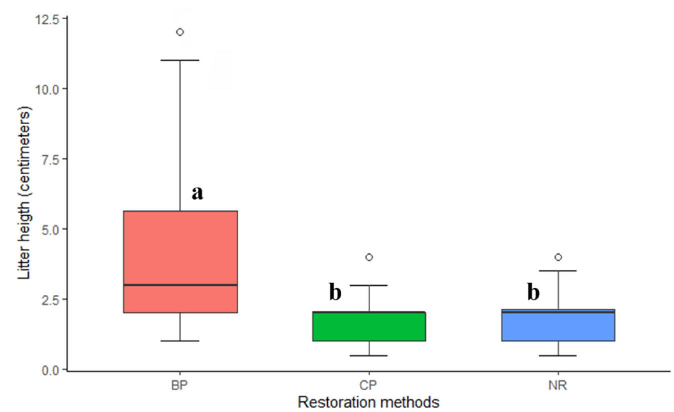

Figure 7 – Boxplot of median and quartiles of litter height among the different ecological restoration techniques*.
BP: number of species by the band planting technique; CP: number of species by the conventional planting technique; NR: number of species by the natural regeneration conduction technique; *same letters do not differ by Dunn's post-test with $p < 0.05$.

This may have contributed to the fact that the values for the cover indicator of exotic grasses in the control and management descriptor were much lower in the CP of seedlings (5% of exotic grasses) and BP (5.9% of exotic grasses). For NR, it was 45% of exotic grasses.

Regarding the soil protection and litter input descriptors, the BP technique showed better results concerning the number of indicators evaluated. There was a significant difference between litter height in BP ($p < 0.01$). This may be due to the presence of herbaceous, shrub, and tree species whose leaves and branches fall in the less favorable season or end up dying for being annual, as this technique mixes NR with planting seedlings (Figure 7).

Litter cover in restoration areas is very important because it plays several roles in the balance and dynamics of ecosystems, especially in tropical regions where most soils have low natural fertility, favoring nutrient cycling and the maintenance of tropical forests (Caldeira et al., 2020; Silva and Brandão, 2020).

The results of the stability and resilience and reliability indicators (Figures 8 and 9) showed that the BP restoration technique promoted similar and even superior conditions compared to the other restoration techniques evaluated in this study (Figure 8). There was a higher abundance and richness of pioneer species in NR. For BP (51% non-pioneer; 49% pioneer) and CP of seedlings (55% non-pioneer; 45% pioneer), there was a higher abundance of non-pioneer species as a result of the proportion used for planting (Table 2).

The factors that generated stability and resilience in the three restoration techniques evaluated were found based on the values of the

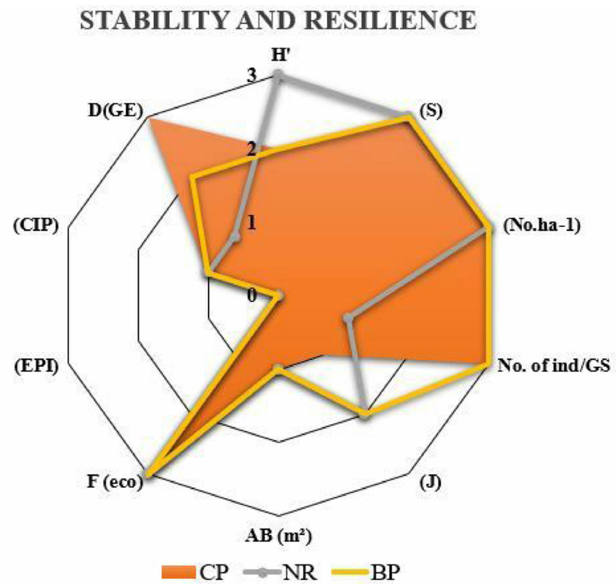

Figure 8 – Radar charts, with radii from 0 to 3, according to the parameters of Table 1, of the indicators of the restoration areas studies. Indicators of community and functional diversity.
CP: conventional planting; BP: band planting; NR: natural regeneration; H': Shannon's diversity index; S: species richness; d: density of individuals; Ind / GE: percentage of individuals / ecological group; J: Pielou's evenness index; D (Ge): diversity of ecological groups; AB: basal area; F (eco): diversity of ecological functions; Epi: epiphytes; CIP: creepers.

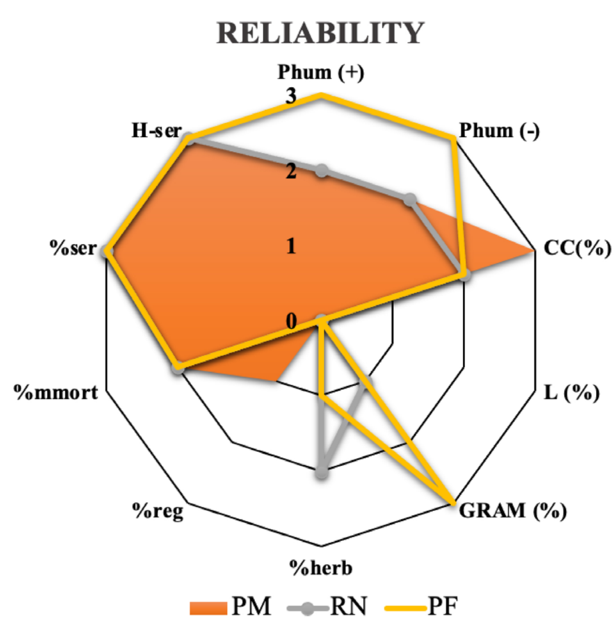

Figure 9 – Radar charts, with radii from 0 to 3, according to the parameters in Table 1, of the indicators of the studied areas of restoration. Indicators of control and management and protection of soil and litter input.
CP: conventional planting; BP: band planting; NR: natural regeneration; CC: canopy cover; L: incidence of light; GRAM (%): presence of exotic grasses; Phum (-): negative human presence; Phum (+): positive human presence; % herb: percentage of herbaceous plants; % ser: percentage of litter; H-ser: Litter height.

indicators diversity of ecological functions (F. (eco)) and development (presence of vines) equivalent (Figure 8). There was no record of the presence of vascular epiphytes in the areas; however, these conditions can be attributed to areas with little age of restoration. On the other hand, the factors associated with environmental sustainability over time (reliability) distinguished BP the most from other areas. (Figure 9).

BP proved to be efficient in recovering ecological functions capable of generating stability and resilience and maintaining ecological processes in conditions similar to fragments in the initial succession stage, with EFCI (Figure 10) higher than CP in the coverage and diversity models and NR conducted in the indicators of community diversity, and control and management.

As BP combines planting seedlings with NR, it uses a restoration approach of assisted natural regeneration, which aims to accelerate ecological succession by removing or reducing barriers to natural forest regeneration such as weed competition, improving favorable microclimatic conditions for native species, and higher seed dispersal by animals (Shono et al., 2007).

BP showed balance in most of the factors that provided ecological functionality, such as community diversity, plant density, as well as the increase in basal area, the number of non-pioneer species or even the density of individuals, which can contribute to ground cover, an important factor for system reliability (Galetti et al., 2018). In this way, BP can be applied in a wide variety of forest types and geographic areas, allowing its adaptation to meet different objectives, such as biodiversity conservation and income generation through a consortium with the production of firewood and timber and even non-timber forest products.

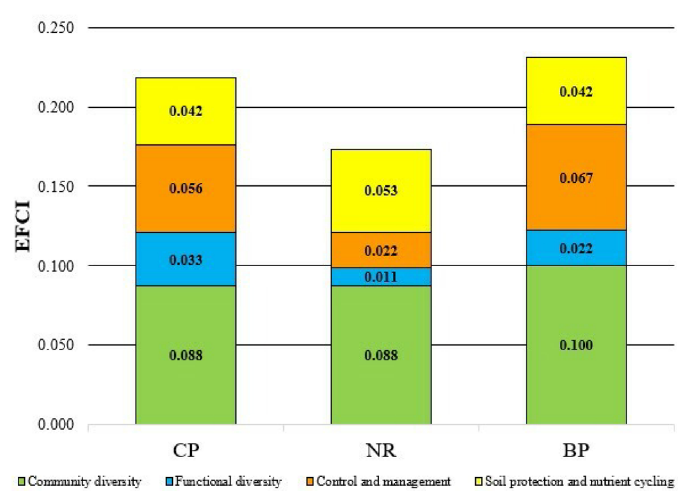

Figure 10 – Ecological functionality consolidation index (EFCI) values obtained for the stability and resilience attributes of the system represented by the diversity of species and functional and reliability, represented by the protection and litter input and the control and management in different techniques restoration.
CP: conventional planting; BP: band planting; NR: conduction of natural regeneration.

Conclusion

All the restoration techniques analyzed in this study had their benefits for ecological restoration and functional diversity in the NR model was strongly affected by the basal area of the community. The MESMIS method proved to be efficient in the evaluation of ecological functions for restoration. Based on the EFCI, we suggest the BP technique as an alternative to the CP of seedlings and NR techniques, as its characteristics derive from the other two techniques.

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