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INFLUENCE OF ECOLOGICAL GROUP COMPOSITION, PLANTATION SPACING AND ARRANGEMENT IN THE RESTORATION OF RIPARIAN FOREST ON RESERVOIR SHORES

INFLUÊNCIA DA COMPOSIÇÃO DE GRUPOS ECOLÓGICOS, ESPAÇAMENTO E ARRANJO DE PLANTIO NA RECUPERAÇÃO DE MATAS CILIARES EM MARGEM DE RESERVATÓRIO

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ABSTRACT

This work aimed to assess the effect of spacing, arrangement and ecological group composition of planted seedlings on the restoration process of artificial reservoir shores in southeastern Brazil. The assessments were performed 12 years after the settlement of the experiment in which five mixed stand models were tested. First, a general evaluation of the stand was performed when we surveyed the overstory and understory, seed bank and soil for chemical analysis.Then, the restoration indicators survival of planted trees, basal area and density of the tree community, litter accumulated on the soil and canopy closure index were utilized to compare the plantation models and to assess the influence the experimental factors on these parameters. In the general analysis, we found that the studied stand presents low diversity, poor regeneration, and seed bank dominated mostly by one planted exotic tree species and weeds, which may jeopardize the self-maintenance of the stand in the future. The factor that most influenced the models was the ecological group composition with the best performance found for models in which both pioneer and non-pioneer groups were used. Probably, the plantation arrangement and spacing did not have greater influence due to both plant mortality and natural regeneration that has developed to this age. Hence, it is not recommended the use of only pioneer species in the implantation of riparian forest and the proportion of 50% pioneers and 50% non-pioneers using as much species as possible is indicated for areas that might present constraints for the natural regeneration.
Keywords: Environmental afforestation; restoration indicators; hydroelectric power plants.

RESUMO

Este trabalho teve como objetivo avaliar o efeito do espaçamento, arranjo e composição de grupos ecológicos das mudas plantadas no processo de restauração de margem de reservatório artificial no sudeste do Brasil. As avaliações foram realizadas 12 anos após a implantação do experimento em que cinco modelos de plantios mistos foram testados. Primeiramente, fez-se uma avalição geral do povoamento por meio de levantamentos do estrato arbóreo, regenerante, banco de sementes e de análise química e textural do solo. Em seguida, lançou-se mão dos indicadores de recuperação sobrevivência das árvores plantadas, área basal e densidade da comunidade arbórea, acúmulo de serapilheira sobre o solo e índice de fechamento do dossel para comparar os modelos e checar a influência dos fatores experimentais nestes parâmetros. Como resultado da análise geral, obteve-se que o povoamento encontra-se em situação de baixa diversidade, com regeneração deficiente e banco de sementes dominado majoritariamente por uma espécie arbórea exótica

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utilizada no plantio e espécies herbáceas invasoras, o que pode comprometer a automanutenção do povoamento no futuro. O fator que mais influenciou os modelos foi a composição de grupos ecológicos com os melhores resultados apresentados pelos modelos em que se usaram ambos os grupos das pioneiras e não pioneiras. Provavelmente, o arranjo e o espaçamento de plantio não tiveram muita influência devido à mortalidade das mudas e à regeneração natural que se desenvolveu até esta idade. Assim, recomenda-se que na implantação de povoamentos para reconstituição de matas ciliares não sejam utilizadas apenas espécies pioneiras e sugere-se que a proporção de 50% de espécies pioneiras e 50% de não pioneiras, com o maior número possível de espécies, seja utilizada em áreas com deficiência da regeneração natural.
Palavras-chave: Reflorestamentos ambientais; indicadores de recuperação; usinas hidrelétricas.

INTRODUCTION

Ensuring the integrity of the margins of artificial reservoirs, the concomitant creation of an environment suitable for the recovery of local biodiversity and the perpetuation of the ecosystem functions are the main objectives of the establishment of riparian vegetation on the shores of *hydroelectric power plant reservoirs.*

Botelho and Davide (2002) warn that, unlike the natural riparian environments, the margins of artificial reservoirs are usually areas of natural occurrence of other types of vegetation not characteristic of the margins of natural water bodies. Thus, they do not have the typical soil attributes of riparian areas with physical, chemical and structural characteristic quite diverse, as well as the relief. Moreover, these authors also state that these areas are often sites of former anthropic use, and then, display a certain degree of degradation that becomes another barrier to be overcome.

Mainly from the 1980s, with the intensification of research regarding mixed stands implantation for the recovery of degraded areas, various methodologies have been proposed and improved (RODRIGUES et al, 2009). Among them, stands can be formed based on plantation models, which are designed by the combination of spacing, arrangement and composition of species or ecological/functional groups. In the development of plantation models, several objectives must be targeted. The spacing must be such that provides a faster coverage of the soil, avoiding erosion and controlling weed competition. The arrangement, defined as the distribution of plants in the field, is determined to optimize plant growth especially when species of different successional stages are used. Using species from different ecological/functional groups comes from the ecological succession as the basis of mixed forest plantation, i.e., an attempt to give the artificial regeneration a model following the conditions under which it occurs naturally (RODRIGUES; LEITÃO FILHO, 2004).

In order to evaluate and monitor the success of an environmental reforestation, several restoration indicators have been proposed (RODRIGUES; GANDOLFI, 2004; ALMEIDA; SÁNCHEZ, 2005; REIS, 2008) which assess attributes and/or processes of a given area, making it possible to monitor trends of environmental changes or diagnose causes of an environmental problem (DALE; BEYELER, 2001).

Thus, the objective of this work is to evaluate five riparian-forest plantation models on artificial reservoir shore through the analysis of restoration indicators. We aim to investigate whether the factors planting spacing, arrangement and composition of ecological influence the process of restoration of riparian forests on artificial reservoir shore to the age of 145 months. In addition, we evaluated the structure and diversity of the stand as a whole in order to assess the current successional state in which the stand is found.

MATERIAL AND METHODS

Study area and characterization of the experiment

The study area is located in the city of Igarapava, São Paulo state, Brazil, at the coordinates 19°59’37 S” and 47º41’53” W, and altitude of 520 meters. The experiment was established on the shore of the Igarapava Hydroelectric Power Plant reservoir, formed by the dam of the Rio Grande River. The area had been used for about 30 years for cultivation of sugar cane. With the reservoir formation, the shores were destined to be reforested to comply with the legislation as a permanent conservation area. Adjacent areas are still occupied by the afore mentioned culture.

The climate is tropical wet with dry winter (Aw from Köppen classification). The annual mean temperature and precipitation are 23.3°C and 1525.2 mm, respectively, being from October to March the period with the greatest precipitation (CENTRO DE PESQUISAS METEOROLÓGICAS E CLIMÁTICAS APLICADAS À AGRICULTURA, 2010). The natural vegetation of the region is transitional between Atlantic Forest and Cerrado (BRASIL, 1983). Specifically, the area covered by the experiment was occupied by tropical semideciduous forest. The predominant soil type in the region is oxisol (EMBRAPA, 2006).

Five plantation models were tested varying the factors: spacing, arrangement and proportion of ecological groups. For the latter, species were grouped into pioneer and non-pioneer as suggested by Kageyama and Gandara (2004).

The treatments were: M1) 3x2m spacing, quincunx arrangement with pioneer lines interspersed with non-pioneer lines, 50% pioneer and 50% non-pioneer composition (50P:50NP); M2) 3x2 spacing, quincunx arrangement, 100% pioneers composition (100P); M3) 3x2 spacing, regular arrangement with pioneers and pioneers interspersed in all lines, (50P-50NP); M4) 3x3 spacing, regular arrangement, 100P; and M5) 3x3 spacing, regular arrangement with even rows containing only pioneer species and odd rows with both ecological groups interspersed, 75% pioneer and 25% non-pioneer composition (75P-25NP). The experiment was implemented in a randomized block design with four replications, each plot composed of 15 rows with eight plants.

Thirteen species were planted: the pioneers *Croton floribundus*, *Guazuma ulmifolia*, *Muntingia calabura*, *Schinus terebinthifolius* and *Trema micrantha*; and the non-pioneer: *Cedrela fissilis*, *Clitoria fairchildiana*, *Enterolobium contortisiliquum*, *Handroanthus impetiginosus*, *Morus nigra*, *Myrsine umbellata* and *Peltophorum dubium*. Description of silvicultural operations such as soil preparation, fertilization and weed control are described in Moreira (2002).

General Stand characterization

Twelve years and four months after plantation, we surveyed the overstory and understory vegetation, seed bank, and performed soil analysis in order to characterize the stand as a whole.

Overstory

The overstory structure and diversity was assessed through census of the trees with circumference at 1.30m (CBH) greater than or equal to 15.7 cm. The CBH was obtained using a tape measure, later converted to diameter (DBH), and height was inferred in comparison with a 13-meter telescopic ruler pole. This way, both groups, planted and natural regenerated trees, were measured. All these trees were tagged and identified to the species level according to the APG III (ANGIOSPERM PHYLOGENY GROUP, 2009).

Understory

Forty 5x5 m plots were settled to assess understory vegetation, two in each replication of the models. The identification, height and DBH were obtained from the plants within the inclusion criterion 1 cm < DBH < 5 cm. Additionally, we considered the planted trees that met this inclusion criterion, even if they were located out of these plots.

Seed bank

The mix of soil-litter was collected to a depth of 5 cm in the soil using a metal frame with dimensions of 0.25 x 0.25 m in the intensity of two samples, 15 m apart from each other, subsequently forming one composite sample for each treatment replication. The material was placed to germinate in 44 cm × 27.6 cm × 7.6 cm plastic trays, which were kept inside a greenhouse to avoid contamination with external propagules. Five additional trays with sterilized sand were kept in the greenhouse as a control to detect possible inside contamination.

In the first week of installation, we performed daily irrigation. The frequency of irrigation changed along time to every two or three days depending on the moisture accumulated in the trays.

All the plants that emerged from the material were counted and identified to species level. Evaluations were performed every two weeks for 136 days. The very young seedlings and/or seedlings which had no characteristics that would enable their identification were marked and kept in the trays until it was possible to recognize them.

Soil analysis

Twenty composite samples were collected at 0-20 cm depth in the soil. Each composite sample was obtained by the homogenization of three simple samples taken in each plot. This material was subjected to analysis of texture, fertility, pH and organic matter content. The result was compared with that obtained by Moreira (2002) at 34 months age in the same experimental area.

Processing and data analysis

For the characterization of the overstory and understory, we calculated the structural parameters density, frequency, dominance (absolute and relative forms), importance value (IV), and the diversity indices of Shannon-Weaver and Pielou's Evenness. The species were also classified according to the successional group (SWAINE; WHITMORE, 1988) following the classifications found in literature. When contradictions were found, we chose to adopt the classification most used in the references.

Plantation models analysis

Plant Density and basal area

For the analysis of density (ind ha^{-1}) and basal area (m^2 ha^{-1}) we used the data from the overstory vegetation survey. We first performed the analyses separating the plants into planted trees, natural regeneration and tree community (that is, planted trees + natural regenerated ones).

For the indicator density, we analyzed the natural regeneration and tree community, whereas for the basal area, the analyses were done using the planted trees and natural regeneration.

Litter accumulated on the soil

In May, 2011, four samples of litter accumulated on the ground were collected per plot, 15 m distant from each other and perpendicular to the reservoir shore, using a 1x1 m PVC frame. These samples were put together forming a compound sample for each treatment replicate, totalizing a sampling area of 4 m^2 per replicate. The material was oven dried at 70° C for at least 72 hours. Subsequently, we obtained measurements of dry weight using an analytical scale accurate to three decimal places. The values obtained were converted into tons per hectare (t ha^{-1}).

Canopy closure

Along with the collection of litter, canopy photographs were taken using a Nikon Coolpix P80 digital camera. The lens was positioned parallel to the canopy, 1 m height from the ground on a leveled tripod. The images, with a resolution of 3648 x 2736 pixels, were obtained in automatic mode, on clear days, under diffuse light, avoiding high solar radiation. We sampled five points per plot in its central part, about 7 m apart from each other.

In image processing, we first used the software Adobe Photoshop CS3, treating the image in order to contrast the vegetation in relation to the openings in the canopy and to correct any reflections on the trunks, branches and leaves. The image was, then, converted to gray scale and processed in the software Sidelook 1.1.1, when the gray scale was converted to black-and-white and the pixels were counted. Thus, the Canopy Closure Index (CCI) was calculated for each plot as the ratio between the number of pixels representing the canopy (black pixels) and the total number of pixels in the image.

Statistical analysis

We performed ANOVA for all the indicators, followed by Scott-Knott test when significant difference was found. In addition, we also performed non-orthogonal contrast analyses using the Scheffé test in which the contrasts were defined by grouping homogeneous treatments in order to isolate the factors that could influence the mean as follows: i) Contrast 1 (C1) = treatments M1 and M2 vs. treatments M3, M4 and M5; ii) C2 = treatments M1, M2 and M3 vs. treatments M4 and M5; iii) C3 = treatments M1 and M3 vs. treatments M2 and M4; iv) C4 = treatment M1 vs. treatment M2; v) C5 = treatment M1 vs. treatment M3; vi) C6 = treatment M2 vs treatment M4.

Therefore, the proposed contrasts compared: C1- different arrangements; C2- different spacings, C3-100% pioneers (100P) vs. 50% pioneers: 50% non-pioneers composition (50P:50NP); C4- 100P vs. 50P:50NP compositions in same spacing and arrangement; C5- different arrangements in the same spacing and composition; and C6- arrangements and spacings in 100P composition. Statistical analyses were performed using the software R 2.12.2 (R DEVELOPMENT CORE TEAM, 2011).

We tested the statistical assumptions of normality and homoscedasticity by the Shapiro-Wilk and Bartlett tests, respectively. In the cases where these assumptions were not met, we proceeded to transform the data by the √x and log(x) transformations. If even after transformation, the assumptions were not met, we used the nonparametric Friedman test (SOKAL; ROHLF, 1995) with Wilcoxon-Nemenyi-McDonald-Thompson post hoc test (HOLLANDER; WOLFE, 1999) when Friedman test was significant. All tests were based on a significance level of 5%.

RESULTS AND DISCUSSION

General Stand characterization

The soil is classified as clay soil showing, on average, 53.3% clay, 26.90% silt and 19.80% sand. There was improvement of the characteristics of the soil (Table 1) since 2002, given that most of the parameters of the analysis were found adequate (ALVAREZ VENEGAS, 1999), except by phosphorus (P) that presented VERY LOW level, but in 2011, it rose to the level of LOW. In addition to P, two other parameters changed their levels in the interpretation of the analysis: Cation exchange capacity, from GOOD to VERY GOOD, and organic matter content, from MEDIUM to GOOD.

The only negative result obtained in the comparison between the analyzes carried out at 34 and 145 months was a decrease of 38% in the amount of potassium, even though it still was classified as “good”.

Soil fertility tends to increase as the established vegetation covers the soil providing protection against the development of erosive processes maintaining in the area most part of the nutrients cycled by the vegetation. Jiao, Wen and An (2011) showed that the establishment and development of vegetation succession resulted in improvement of soil fertility. This author studied the characteristics of the soil from 5 to 45 years of recovery and found that, from the age of 20 years on, there was significant improvement in the levels of organic matter (8 $g.kg^{-1}$ to 13 $g.kg^{-1}$), nitrogen (33 $mg.kg^{-1}$ to 58 $mg.kg^{-1}$), phosphorus (0.7 $mg.kg^{-1}$ to 1.3 $mg.kg^{-1}$) and potassium (65 $mg.kg^{-1}$ to 115-mg. kg^{-1}).

After 145 months of the plantation, 845 individuals (489 $ind.ha^{-1}$) belonging to 32 species, 29 genera and 22 families were found in the overstory. The lists of the species found in the

TABLE 1: Soil analysis carried out at 34 and 145 months after plantation in a riparian forest restoration trial in Igarapava, SP state, Brazil.

TABELA 1: Análises de solo procedidas aos 34 e aos 145 meses após o plantio em um experimento de recuperação de matas ciliares em Igarapava - SP, Brasil.

Parameters	Unit	Age (months)		Interpretation[1] at 145 months
		34	145	
pH in water		6.10	6.33	Weak acidity
Phosphorus Mehlich I	mg/dm^3	4.00	5.51	Low
Potassium Mehlich I	mg/dm^3	119.00	73.50	Good
Calcius	$cmolc/dm^3$	6.10	8.99	Very good
Magnesium	$cmolc/dm^3$	1.10	1.34	Good
Aluminum	$cmolc/dm^3$	0.00	0.10	Very low
H + Al (Potential acidity)	$cmolc/dm^3$	2.60	3.41	Medium
Sum of bases	$cmolc/dm^3$	7.50	10.50	Very good
Effective CEC	$cmolc/dm^3$	7.50	10.60	Very good
CEC at pH 7,0	$cmolc/dm^3$	10.10	13.94	Good
Aluminum saturation	%	0.00	1.05	Very low
Base saturation	%	74.30	74.32	Good
Organic matter content	dag/Kg	3.40	4.16	Good

Where in: [1]= interpretation given by Alvarez Venegas (1999); CEC= cation exchange capacity.

surveys of overstory, understory and seed bank and their respective structural parameters are presented by Soares (2012).

The species richness found in this work is in the range of studies in riparian reforestation areas in the same region (FERREIRA, 2009; REIS, 2008). However, the richness found in these can be considered below the natural pattern which presents, on average, 80 species according to 43 surveys reviewed by Rodrigues and Nave (2004). Unlike richness, for the density, the mean value was also low even in cases of reforestation (FERREIRA, 2009; REIS, 2008).

The species *Guazuma ulmifolia*, *Muntingia calabura* and *Schinus terebinthifolius* were responsible for 75% of the number of individuals, each one containing 221, 206 and 205 plants, respectively. This, and the small number of species, led to the Shannon index of 1.97 nats ind^{-1} and Pielou's evenness of 0.58, both considered low (FERREIRA, 2009; REIS, 2008), reflecting the dominance of the three species mentioned above.

It is noteworthy that *Muntingia calabura* is an exotic species and behaved as dominant in some areas of the stand, especially in the repetitions of the 100P models. Its invasive characteristic had been described in previous studies (FLEMING et al., 1985; FIGUEIREDO et al., 2008). This did not occur, however, with *Guazuma ulmifolia* and *Schinus terebinthifolius*, which, despite the number of individuals, are mixed with the rest of the community.

The average height and diameter of the trees were 8.0 m (standard deviations (sd) = 2.81m) and 16.3 cm (sd=10.63cm), respectively. The overstory basal area was 14.45 m² ha^{-1}, far below the averages found for native riparian ecosystems in southeastern Brazil, which, in general, are greater than 20 m² ha^{-1} (SOUZA, 2003; PEREIRA, 2003; FERREIRA, 2009).

The species of greatest IV were in this order: *Guazuma ulmifolia*, *Clitoria fairchildiana*, *Schinus terebinthifolius*, *Muntingia calabura* and *Peltophorum dubium*, and all other IV's were less than 10. The position of *Clitoria fairchildiana* as the second in importance is mainly due to its basal area (5.12 m² ha^{-1}) only exceeded by *Guazuma ulmifolia* (5.52 m² ha^{-1}). Most individuals of this species are large (height>10 m and dbh>25 cm), and only three were not planted, i.e., regenerated from the dispersion of planted trees. This indicates that, unlike *Muntingia calabura*, *Clitoria fairchildiana* does not have invasive characteristics. Hence, despite native from the Amazon rainforest *dominium,* the use of this species to compound stands for environmental reforestation may be suggested given its rapid diameter, height and crown growth, covering the soil; given the fact that it is unlikely to become a problem in terms of behaving as invasive species and due to its ability to fix nitrogen.

In the understory, 157 individuals were found (3140 ind ha^{-1}) belonging to 20 families, 22 genera and 23 species. These values are low compared to other studies of natural regeneration in riparian forests. For example, Oliveira and Felfili (2005) studying gallery forests in central Brazil, found 51 families, 104 species, and the density of 6.407 ind ha^{-1}.

The diversity and evenness indices were, respectively, 2.37 nats ind^{-1} and 0.75, below those found by the author mentioned above. Although this *stratum* has fewer species than the other one, these indices were higher due to the dominance of three species in the overstory, which did not occur in the understory. The species with the highest number of individuals were *Piper gaudichaudianun* (n=38), followed by *Schinus terebinthifolius* (n=30), *Handroanthus impetiginosus* (n=28), *Muntingia calabura* (n=18) and *Peltophorum dubium* (n=12), and out of these, only *Piper gaudichaudianum* was not planted. All *Handroanthus impetiginosus* found are remnants of the plantation and in the case of *Peltophorum dubium*, four plants regenerated naturally. Of the *Schinus terebinthifolius* and *Muntingia calabura* plants found, 19 and 12 came from natural regeneration, respectively. Overall, 34% of plants measured were planted. Eighteen species were found in both overstory and understory, out of which 10 species were used in the plantation which means that eight species regenerated by natural dispersion and were able to establish and develop to the overstory inclusion criterion. These species are: *Casearia commersoniana*, *Cecropia pachistachia*, *Landenbergia cuyabensis*, *Piper arboreum* and *Piper gaudichaudianum*, *Ramnidium elaeocarpus*, *Zanthoxylon riendelianum and Ricinus communis*, being the latter the only exotic plant.

The low values of diversity and phytosociological parameters found for this stand possibly occurred due to lack of propagules and the dispersal source in the area since the landscape is occupied almost entirely by cultivation areas of sugar cane. The few existing forest patches are sparse, very disturbed, and the nearest one, of considerable size and structure, is located on the opposite side of the reservoir more than 3 km distant. This landscape is very characteristic of southeastern Brazil, whose degradation was so intense that, in many areas, there is no regeneration or seed bank of tree species or near forest fragments that would allow an effective dispersion (GANDOLFI et al., 2007). In highly fragmented landscapes, the arrival of alien propagules promoted by abiotic agents (i.e. anemochory, autochory, hydrochory) is hampered by the distance of the fragments (PARROTTA et al., 1997; HOLL, 1999). Furthermore, the proximity of urban centers and the presence of productive activity, with frequent traffic of machines and vehicles, is a factor that may be inhibiting the presence of disperser fauna at these sites.

Considering the results of these analyses, this stand is likely to present problems regarding its future structural and functional maintenance. The evidence found in this experiment confirms the need for more diverse plantations mainly in regions where the matrix is comprised of intense agricultural production and lacks connectivity elements.

In relation to the seed bank, a number of 2883 plants germinated in of litter-soil samples were taken from the experimental area along 136 days. These individuals were distributed in 35 species and 19 families.

The most abundant species was the *Muntingia calabura* with 2500 individuals germinated corresponding to 86.71% of the total. This species produces fruits in abundance all months of the year and presents self-compatibility which causes it to produce large quantities of seeds even in degraded areas deficient in dispersing agents (FIGUEIREDO et al., 2008). For this reason, the number of plants of tree species germinated (n= 2661) was higher than the herbs (n= 222). Seven tree species were identified and the herbaceous component presented 28 species, six of which were not identified. Many studies report the predominance of herbaceous species in the seed bank (SORREANO, 2002; SOUZA et al., 2006; GASPARINO et al., 2006; TRES et al., 2007). In our case, if *Muntingia calabura* was disregarded, the number of herbaceous plants would be greater, in agreement with the studies cited above.

Of the tree species found, only *Solanum aculeatissimum* and *Solanum sp*. were not planted, which reinforces the finding in the phytosociological surveys that there are deficiencies in quantity and diversity of the natural regeneration. Gandolfi et al. (2007) warn that, although the dispersion is a process that is actually useful in restoring degraded areas, it does not always occur in the expected intensity and diversity. Its failure, in some cases, may be associated with different factors such as the low availability of seeds in the restoration site or in fragments present in the neighborhood, lack of dispersing animals, the presence of barriers between the source of propagules and the area to receive them, the imbalance between predators and seeds, etc.

Another concernment regarding the seed bank is that most herbaceous plants identified are considered weeds. Subsequently, as gaps are created due to natural death of trees, these invasive species are likely to infest the area given that the area lacks of abundant and diverse understory that would allow for canopy recovery. This has already been detected in some locals within this stand especially due to the mortality of pioneer species.

Plantation models

Plant density

The density of natural regeneration had an average of 146.99 ind ha^{-1} (sd =70.55). Although there was a significant difference between the models (p-value = 0.0349), the Scott-Knott test was not able to differentiate the means at 5% probability. It was decided, then, to maintain the level of significance and utilize the Tukey's test in order to check this difference (Table 2).

A clear difference was detected between models M1 and M4, which represent two extremes of the variation in experimental factors. By observing the means of the models, despite the three intermediate values did not differ from themselves or in relation to the aforementioned ones, it is possible to detect a trend of increase in the density of natural regeneration as the of pioneer species increased.

In the analysis of contrasts, only the contrast C3, which compared the compositions 50P:50NP and 100P was statistically different (p-value = 0.04). Thus, the composition of ecological groups can be considered the most important factor affecting this indicator.

The density of the regeneration, however, is an indicator that requires care in its interpretation. For example, in the first years after implantation of an environmental afforestation, the number of trees and shrubs regenerating is itself a good

TABLE 2: Mean values of the restoration indicators followed by its standard errors and results of the Scott-Knott test at 5% significance level in a trial of riparian forest restoration models.

TABELA 2: Médias e desvios dos indicadores de recuperação e resultados do teste Scott-Knott a 5% de significância em um teste de modelos de implantação de matas ciliares.

Indicators	Models									
	M1		M2		M3		M4		M5	
BAPT[1]	19.02 (4.49)	c	8.93 (2.98)	a	18.32 (3.13)	c	9.41 (0.78)	a	13.76 (1.77)	b
BANR[2]	0.29 (0.17)	a	1.38 (0.92)	a	1.71 (1.50)	a	1.62 (0.86)	a	1.19 (0.80)	a
DTC[1]	427.08 (130.96)	a	565.97 (82.06)	a	465.28 (64.64)	a	567.13 (133.19)	a	423.61 (76.86)	a
DRN[3]	65.97 (53.64)	a	184.03 (62.50)	ab	100.69 (23.71)	ab	238.43 (99.83)	b	145.83 (66.50)	ab
LDMAS[1]	11.11 (2.16)	a	6.88 (1.59)	a	15.69 (7.00)	b	6.79 (1.10)	a	8.94 (3.01)	a
CCI[1]	73.60 (12.08)	a	73.67 (4.57)	a	84.07 (1.88)	a	82.50 (6.48)	a	77.66 (9.71)	a

Where in: Mean values followed by the same letters in the line do not differ statistically from each other.; BAPT = basal area of the planted trees (m^2); BANR = basal area of natural regeneration (m^2); DTC = density of tree community (ind ha^{-1}); DNR = density of natural regeneration (ind ha^{-1}); LDMAS = litter dry matter accumulated on the soil (t ha^{-1}); CCI = canopy closure index (%);()= standard deviation; [1] analysis by Scott-Knott-test (5%) ; [2] analysis by Friedman test (5%); [3] analysis by Tukey test (5%).

indicator, since it infers about the potential for soil protection in addition to serving to attract and shelter dispersing fauna. Nevertheless, over time, besides the quantitative aspect, the composition of the regeneration should be taken into consideration. Factors such as the number of species, ecological/ functional group, dispersion guild, among others, are important in determining the successional stage of the stand (SOCIETY FOR ECOLOGICAL RESTORATION, 2004). Thus, it is expected that, at a later age, the implanted forest be at higher richness and diversity in regeneration and with predominance of species of late successional stages, no longer of pioneers. For example, Oliveira-Filho et al. (2004), studying areas of secondary forests exploited in southeastern Brazil, found that areas in the early stages had a higher density of individuals and a majority of light demanding species than later-succession stands.

Following this thought, the most abundant regeneration in 100P models should not be interpreted as a positive indicator, since pioneer species were predominant. Of the 267 trees throughout the experiment, at least 235 belong to the group of pioneers being that eleven species were classified as pioneers, 10 as light demanding climax, 3 as shade-tolerant climax and 2 without characterization of ecological group. *Muntingia calabura* (n = 167), *Piper gaudichaudianun* (n = 27) and *Cecropia pachistachia* (n=16) were the three species with most abundant natural regeneration.

Parrotta, Knowles and Wunderle Junior (1997) warn that, despite the rapid growth and ground cover provided by pioneers, plant mortality in a stand dominated by them would lead to the early reopening of the area, due to their short life cycle, giving chance for the establishment of invasive plants and increasing the chance of fire. Rodrigues et al. (2009) give an example of an area of seven years of age where only pioneer species were used species, being detected invasion by weeds and lack of natural regeneration after the senescence of the planted trees.

In the analysis of the tree community, a mean density of 489.15 ind ha^{-1} (sd = 107.75) was obtained. Although the treatments did not differentiate significantly (p-value = 0.198), the 100P models showed a trend to have higher density of at least 100 ind.ha^{-1} more than the other ones. There was also no difference between the proposed contrasts.

Basal area

Regarding the basal area of the planted trees, a mean value of 13.88 m^2 ha^{-1} (sd = 2.75) was found. There was significant difference between the models (p-value = 0.0004) with higher mean basal area found in models M1 (19.01 m^2 ha^{-1}) and M3 (18.32 m^2 ha^{-1}) followed by the model M5 (13.76 m^2 ha^{-1}), and finally, the models M2 (8.93 m² ha^{-1}) and M4 (9.40 m² ha^{-1}) as shown in Table 2. That is, models with the same compositions of ecological groups were statistically equal to each other. In the contrast analysis, C3 (p-value < 0.001) and C4 (p-value = 0,005), which confronts the compositions 100P against 50P-50NP, were the only significant.

The factor that mostly affected the basal area was the composition of ecological groups, with greater basal area for greater proportion of planted non-pioneer species individuals. We highlight that the models in which non-pioneer species were planted had their basal area strongly influenced by the species *Clitoria fairchildiana,* which had the highest average basal area (0.1322 m²) among all others. For comparison, the two species that had the highest basal area out of the planted trees were *Guazuma ulmifolia* and *Clitoria fairchildiana*, with values of 9.44 m² and 8.59 m², respectively, the former presenting 216 individuals and the latter only 65.

In relation to the naturally regenerated trees, a mean basal area of 1.23 ha^{-1} (sd = 0.92) was found. For this group, the non-parametric test was performed due to the non-compliance of the assumption of normality (W = 0.8958, p-value = 0.0344) and due to the inefficiency of the transformation √(x) and ln(x).

The Friedman test found no significant difference between the treatments (χ^2= 6.8, p-value = 0.0851).

Litter accumulated on the soil

An overall average of 9.88 t ha^{-1} (sd = 3.19) of dry matter of the litter accumulated on the soil was obtained. For this variable, assumptions required by the analysis of variance model were not met with p-values for the Shapiro-Wilk and Barttlet test of 0.0005 (W = 0.7883) and 0.0262 (K² = 11.02), respectively. We also tested the transformation √(x) and ln(x) with no effect, proceeding, then, with the non-parametric analysis.

The Friedman test was significant (χ^2= 11.40; p-value = 0.0224) and the *post hoc* test, although not significant, indicated that the significance of the Friedman test is due mainly to comparisons M3 vs. M4 (p-value = 0.0652) and M3 vs. M2 (p-value = 0.0761) given the proximity of the p-values with the significance level.

Even without meeting the statistical assumptions, in addition, we carried out the analysis of variance and analysis of contrasts in order to explore the possible differences between the treatments. Thus, significant differences were detected between treatments (p-value = 0.0104). The model M3 was the only one to differentiate statistically, with the largest value of litter accumulation (Table 2).

For the tested contrasts, only the contrast C3 was significant (p-value = 0.02). Therefore, as it was revealed for the previous indicators, composition of ecological groups was the most important factor involved in the production of litter with the 50P:50NP models accumulating the largest amounts. The treatment means showed a trend of models composed by only pioneer species (or by higher proportion of them, which is the case of M5) to display the lowest averages.

The amount of litter found here was consistent with studies in the literature (PATRICIA; MORELLATO, 1992; REIS, 2008), remarking the fact that the production of litter is highly variable (VITOUSEK, 1984).

Scherer-Lorenzen et al. (2007), found a positive correlation between litterfall and tree basal area. Nunes and Pinto (2007) and Schittler et al. (1993) found higher deposition on areas where there were larger individuals. These authors state that larger individuals have greater primary productivity and greater canopy making them produce more litter. As seen, the 50P:50NP models tended to have lower densities, greater basal areas and presented greater quantity of litter, which corroborates the results found by these authors.

Once it is known that litter is characterized as the main way of nutrient return to the soil in forest ecosystems (GOLLEY, 1978), the fact that no deficiency was found in this indicator may have contributed to the improvement of the soil fertility and organic matter characteristics as previously described.

Canopy closure index

We found a mean canopy closer of 78.29% (sd = 8.54). There were no significant differences either between the models or for the proposed contrasts (Table 2).

One of the most important features desired in environmental reforestations is the protection of the soil promoted mainly by the crown coverage. This feature, essential in the early years, must be maintained over time so that the soil does not remain exposed, susceptible to erosion and weed infestation, especially grasses used for pasture which are very aggressive and difficult to remove.

The results of this indicator can be considered within the range found by other authors (MEIRA-NETO et al., 2005; GARCIA et al., 2007; GÊNOVA et al., 2007). This was expected due to the age of the stand and the lack of frequent disturbances such as logging, cattle access. Therefore, the different plantation models did not influence the canopy closure at the age of 145 months, probably because some of the non-pioneer species reached great dimensions and the established natural regeneration, despite poor, helped fill in the canopy.

CONCLUSIONS

The composition of ecological groups was the factor that most influenced, at the age of 145 months, the indicators density, basal area and litter accumulation on the ground so that models in which species of both ecological groups were used showed the best indicators. Different arrangements and spacings, at this age, no longer exert influence on the recovery indicators. The canopy closure was not related to the plantation models, possibly due to the age of the stand.

As a consequence of the landscape in which it is inserted, the stand as a whole presents low diversity, poor regeneration, and seed bank mostly dominated by one planted exotic tree species and invasive herbaceous species, which may compromise the stand self-maintenance in the future.

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REFERENCES

ALMEIDA, R. O. P. O.; SÁNCHEZ, L. E. Revegetação de áreas de mineração: critérios de monitoramento e avaliação de desempenho. **Revista Árvore**, Viçosa, MG, v. 29, n. 1, p. 47-54, jan./fev. 2005.

ALVAREZ VENEGAS, V. H. et al. Interpretação dos resultados das análises de solo. In: RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ-VENEGAS, V. H. (Ed.). **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais**: 5ª aproximação. Viçosa, MG: UFV, 1999. p. 43-60.

ANGIOSPERM PHYLOGENY GROUP. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. **Botanical Journal of the Linnean Society**, London, v. 161, n. 1, p. 105-121, 2009.

BOTELHO, S. A.; DAVIDE, A. C. Métodos silviculturais para recuperação de nascentes e recomposição de matas ciliares. In: SIMPÓSIO NACIONAL DE RECUPERAÇÃO DE ÁREAS DEGRADADAS, 5., 2002, Belo Horizonte. **Anais...** Lavras: UFLA, 2002. v. 1, p. 123-145.

BRASIL. Ministério das Minas e Energia. **Projeto RADAM/BRASIL:** Goiânia: geologia, geomorfologia, pedologia, vegetação e uso potencial da terra. Rio de Janeiro: Ministério de Minas e Energia, 1983. 768 p. (Levantamento de Recursos Naturais, 31).

CENTRO DE PESQUISAS METEOROLÓGICAS E CLIMÁTICAS APLICADAS À AGRICULTURA. **Clima dos municípios paulistas**. [2010]. Disponível em: <http://www.cpa.unicamp.br/outras-informacoes/clima_muni_232.html>. Acesso em: 28 out. 2010.

DALE, V. H.; BEYELER, S. C. Challenges in the development and use of ecological indicators. **Ecological Indicators**, Amsterdam, v. 1, p. 3-10, 2001.

EMBRAPA. Centro Nacional de Pesquisa de Solos. **Sistema brasileiro de classificação de solos**. Brasília: Embrapa, 2006. 412 p.

FERREIRA W. C. **Stock of biomass and carbon and restoration indicators in riparian forest**. 2009. 163 f. Thesis (D.Sc. in Forestry) - Universidade Federal de Lavras, Lavras, 2009.

FIGUEIREDO, R. A. et al. Reproductive ecology of the exotic tree Muntingia calabura L. (Muntingiaceae) in Southeastern Brazil. **Revista Árvore**, Viçosa, MG, v. 32, n. 6, p. 993-999, nov./dez. 2008.

FLEMING, T. H. et al. Phenology, seed dispersal, and colonization in *Muntingia calabura*, a neotropical pioneer tree. **American Journal of Botany**, St. Louis, v. 72, p. 383-391, 1985.

GANDOLFI, S.; MARTINS, S. V.; RODRIGUES, R. R. Theoretical bases of the forest ecological restoration. In: RODRIGUES, R. R.; MARTINS, S. V.; GANDOLFI, S. (Org.). **High diversity**

forest restoration in degraded areas: methods and projects in Brazil. New York: J. Wiley, 2007. p. 24-45.

GASPARINO, D. et al. Quantificação do banco de sementes sob diferentes usos do solo em área de domínio ciliar. **Revista Árvore**, Viçosa, MG, v. 30, n. 1, p. 1-9, jan./fev. 2006.

GÊNOVA, K. B.; HONDA, E. A.; DURIGAN, G. Processos hidrológicos em diferentes modelos de plantio de restauração de mata ciliar em região de cerrado. **Revista do Instituto Florestal**, São Paulo, v. 19, p. 189-200, 2007.

GOLLEY, F. B. et al. **Ciclagem de minerais em um ecossistema de floresta tropical úmida**. São Paulo: EDUSP, 1978. 256 p.

HOLL, K. D. Factors limiting Tropical Rain Forest regeneration in abandoned pasture: seed rain, seed germination, microclimate, and soil. **Biotropica,** Oxford, v. 31, p. 229-242, 1999.

HOLLANDER, M.; WOLFE, D. A. **Nonparametric statistical methods**. 2nd ed. New York: J. Wiley, 1999. 787 p.

JIAO, F.; WEN, Z. M.; AN, S. S. Changes in soil properties across a chronosequence of vegetation restoration on the Loess Plateau of China. **Catena**, Amsterdam, v. 86, n. 2, p. 110-116, jan. 2011.

KAGEYAMA, P. Y.; GANDARA, F. B. Recuperação de áreas ciliares. In: RODRIGUES, R. R.; LOURENÇO FILHO, H. F. (Ed.). **Matas ciliares**: conservação e recuperação. São Paulo: USP/FAPESP, 2004. p. 249-270.

MEIRA-NETO, J. A. A.; MARTINS, F. R.; SOUZA, A. L. Influência da cobertura e do solo na composição florística do sub-bosque em uma Floresta Estacional Semidecidual em Viçosa, MG, Brasil. **Acta Botanica Brasílica**, Brasília, v. 19, n. 3, p. 473-486, 2005.

MOREIRA, M. A. **Modelos de plantio de florestas mistas para recomposição de mata ciliar**. 2002. 99 f. Dissertação (Mestrado em Engenharia Florestal) - Universidade Federal de Lavras, Lavras, 2002.

NUNES, F. P.; PINTO, M. T. C. Produção de serapilheira em mata ciliar nativa e reflorestada no alto São Francisco, Minas Gerais. **Biota Neotropica**, Campinas, v. 7, n. 1, p. 97-102, 2007.

OLIVEIRA, E. C. L.; FELFILI, J. M. Estrutura e dinâmica da regeneração natural de uma mata de galeria no Distrito Federal, Brasil. **Acta Botanica Brasilica**, Porto Alegre, v. 19, n. 4, p. 801-811, 2005.

OLIVEIRA-FILHO, A. T. et al. Diversity and structure of the tree community of a fragment of tropical secondary forest of the Brazilian Atlantic Forest domain 15 and 40 years after logging. **Revista Brasileira de Botânica**, São Paulo, v. 27, n. 4, p. 685-701, jul./ago. 2004.

PARROTTA, J. A., KNOWLES, O. H.; WUNDERLE JUNIOR, J. M. Development of floristic diversity in 10-year-old restoration Forest on a bauxite mined site in Amazonia. **Forestry Ecology and Management**, Amsterdam, v. 99, p. 21-42, 1997.

PATRICIA, L.; MORELLATO, C. Nutrient cycling in two south-east Brazilian Forests: I- Litterfall and litter standing crop. **Journal of Tropical Ecology**, Cambridge, v. 8, p. 205-215, 1992.

PEREIRA, J. A. A. **Efeitos dos impactos ambientais e da heterogeneidade ambiental sobre a diversidade e estrutura da comunidade arbórea de 20 fragmentos de florestas semidecíduas da região do Alto Rio Grande, Minas Gerais**. 2003. 158 f. Tese (Doutorado em Engenharia Florestal) - Universidade Federal de Minas Gerais, Belo Horizonte, 2003.

R DEVELOPMENT CORE TEAM. **R: a language and environment for statistical computing**. Vienna: R Foundation for Statistical Computing, 2011. (Software)

REIS, D. N. **Desenvolvimento de um índice para avaliação da recuperação de ecossistemas ciliares**. 2008. 179 f. Dissertação (Mestrado em Engenharia Florestal) - Universidade Federal de Lavras, Lavras, 2008.

RODRIGUES, R. R. et al. On the restoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. **Biological Conservation**, Amsterdam, v. 142, p. 1242-1255, 2009.

RODRIGUES, R. R.; NAVE, A. G. Heterogeneidade florística de matas ciliares. In: RODRIGUES R. R., LEITÃO FILHO H. F. (Ed.). **Matas ciliares**: conservação e recuperação. São Paulo: EDUSP/FAPESP, 2004. p. 43-60.

RODRIGUES, R. R.; GANDOLFI, S. Conceitos, tendências e ações para a recuperação de florestas ciliares. In: RODRIGUES, R. R.; LEITÃO FILHO, H. (Ed.). **Matas ciliares:** conservação e recuperação. São Paulo: EDUSP, 2004. p. 235-247.

RODRIGUES, R. R.; LEITÃO FILHO, H. F. **Matas ciliares:** conservação e recuperação. 3. ed. São Paulo: EDUSP/FAPESP, 2004. 320 p.

SCHERER-LORENSEN, M.; BONILLA, J. L.; POTVIN, C. Tree species richness affects litter production and decomposition dynamics in a tropical biodiversity experiment. **Oikos**, Buenos Aires, v. 116, n. 12, p. 2108-2124, dec. 2007.

SCHLITTLER, F. H. M.; MARINIS, G.; CÉSAR, O. Produção de serapilheira na floresta no Morro do Diabo, Pontal do Paranapanema, SP. **Naturalia**, São Paulo, v. 18, n. 12, p. 135-147, 1993.

SOCIETY FOR ECOLOGICAL RESTORATION. **The SER international primer on ecological restoration**. Tucson: SER, 2004. Disponível em: <https://www.ser.org/pdf/SER_Primer_Portuguese.pdf>. Acesso em: 12 nov. 2011.

SOARES, A. A. V. **Modelos de implantação de matas ciliares em margem de reservatório**. 2012. 84 f. Dissertação (Mestrado em Engenharia Florestal) - Universidade Federal de Lavras, Lavras, 2012.

SOKAL, R. R.; ROHLF, F. J. **Biometry**: the principles and practice of statistics in biological research. New York: Freeman, 1995. 887 p.

SORREANO, M. C. M. **Avaliação de aspectos da dinâmica de florestas restauradas, com diferentes idades**. 2002. 145 f. Dissertação (Mestrado em Ciências Florestais) - Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, 2002.

SOUZA, J. S. et al. Análise das variações florísticas e estruturais da comunidade arbórea de um fragmento de floresta semidecídua às margens do rio Capivari, Lavras, MG. **Revista Árvore**, Viçosa, MG, v. 27, n. 2, p. 185-206, mar./abr. 2003.

SOUZA, P. A. et al. Avaliação do banco de sementes contido na serapilheira de um fragmento florestal visando recuperação de áreas degradadas. **Cerne**, Lavras, v. 12, n. 1, p. 56-67, jan./mar. 2006.

SWAINE, M. D.; WHITMORE, T. C. On the definition of ecological species groups in tropical rain forests. **Vegetatio**, The Hague, v. 75, n. 1, p. 81-86, feb. 1988.

TRES, D. R. et al. Banco de sementes como indicadores para a restauração ecológica de matas ciliares. **Revista Brasileira de Biociências**, Porto Alegre, v. 5, n. 1, p. 309-311, 2007.

VITOUSEK P. M. Litterfall nutrient cycling and nutrient limitation in tropical forests. **Ecology**, Washington, v. 65, p. 285-298, 1984.