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ASSESSING PASSIVE RESTORATION OF AN ATLANTIC FOREST SITE FOLLOWING A *Cupressus lusitanica* MILL. PLANTATION CLEARCUTTING

AVALIAÇÃO DA RESTAURAÇÃO PASSIVA DE UMA ÁREA DE MATA ATLÂNTICA APÓS O CORTE RASO DE UMA PLANTAÇÃO DE *Cupressus lusitanica* MILL

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ABSTRACT

Cupressus lusitanica has a relatively low potential for fostering colonization of native species beneath the forest canopy. However, following the clearcut of a *Cupressus lusitanica* plantation in the State Forest of Avaré (SFA), southeastern Brazil, a vigorous regeneration of Atlantic forest tree and shrub species was observed. We evaluated the passive restoration of this site by comparing its regenerating vegetation to the vegetation established in man-made gaps in Atlantic forest in the State Park of Cantareira (SPC), southeastern Brazil. The frequency distribution of dispersal syndromes for species and the rate of reduction in abundance of pioneer species in a rank/abundance plot did not differ between the two areas. The rarefaction curves for species richness and diversity of the SPC fall below the corresponding curves of the SFA. The proportions of non-pioneer species and of individuals of non-pioneer species were greater in the SFA. The frequency distribution of dispersal syndromes for individuals differed between the two areas due mainly to a more conspicuous predominance of zoochory in the SFA. The rate of reduction in abundance of non-pioneer species in a rank/abundance plot was smaller in the SFA. We concluded that passive restoration may successfully recover native vegetation attributes following the clearcut of forest plantations without conspicuous regeneration of native species beneath the forest canopy. However, this phenomenon may be influenced by particular properties of the forest species, logging practices and faunal seed dispersal integrity.
Keywords: forest recovery; forest succession; functional groups; natural regeneration.

RESUMO

Cupressus lusitanica Mill. possui um potencial relativamente baixo para promover a regeneração de espécies nativas sob o dossel da floresta. Entretanto, após o corte raso de uma plantação de *Cupressus lusitanica* na Floresta Estadual de Avaré (FEA), sudeste do Brasil, uma vigorosa regeneração de espécies arbustivo-arbóreas da floresta Atlântica foi observada. Avaliou-se a restauração passiva desse sítio comparando sua vegetação com a vegetação estabelecida em clareiras artificiais abertas em floresta secundária no Parque Estadual da Cantareira (PEC), sudeste do Brasil. A distribuição de frequência de síndromes de dispersão para espécies e a taxa de redução da abundância das espécies pioneiras em um gráfico de rol de abundância não diferiram entre as duas áreas. As curvas de rarefação para riqueza de espécies e diversidade do PEC ficaram abaixo das curvas correspondentes da FEA. As proporções de espécies não pioneiras e de indivíduos de espécies não pioneiras foram maiores na FEA. A distribuição de frequência de síndromes de dispersão para indivíduos diferiu entre as duas áreas devido a uma predominância mais acentuada de zoocoria na FEA. A taxa de redução da abundância das espécies não pioneiras em um gráfico de rol de abundância foi menor na FEA. Concluiu-se que a restauração passiva pode recuperar atributos da vegetação nativa após o corte raso de plantações florestais desprovidas de conspícua regeneração de espécies nativas no sub-bosque. No entanto, esse fenômeno pode ser influenciado por propriedades particulares da espécie florestal, práticas

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de exploração e integridade da dispersão de sementes pela fauna.
Palavras-chave: grupos funcionais; regeneração natural; recuperação florestal; sucessão florestal.

INTRODUCTION

Ecosystem restoration allows for different levels of management efforts depending on the degradation intensity and the surrounding environmental conditions (SUDING et al., 2004; GANDOLFI; RODRIGUES; MARTINS, 2007; CHAZDON, 2008). The lowest intervention level occurs when no management action is taken, beyond releasing the restoration site from stressors, which impair the spontaneous ecosystem recovery, in such a way that the site can undergo a passive restoration. Passive restoration may foster plant and animal communities' recovery (AIDE et al., 2000; MCIVER; STARR, 2001; GUERRERO; ROCHA, 2010; MORRISON; LINDELL, 2011) when the level of degradation is relatively low and given that there are sources of colonizers and faunal dispersal agents nearby (WUNDERLE, 1997; GUARIGUATA; OSTERTAG, 2001; CHAZDON, 2008). However, there is a degradation threshold, beyond which recovery is not possible without intensive intervention (SUNDING et al., 2004). There is also a threshold beyond which moderate interventions such as tree planting can accelerate recovery, but it is very difficult to identify this threshold (CHAZDON, 2008). Thus, it is convenient to evaluate passive restoration in its initial stages, when a decision concerning a possible intervention is particularly important. Passive restoration has a great economic appeal, especially in developing countries, due to the relatively high costs of active restoration. For the Atlantic forest such costs can vary between \$3,315 and \$5,216 per ha (CALMON et al., 2009).

Some studies assessed passive restoration in tropical forest sites comparing secondary and mature forests (e.g. AIDE et al., 2000; LIEBSCH; MARQUES; GOLDENBERG, 2008). Other research compared the vegetation arising from passive and active restoration (e.g. SAMPAIO; HOLL; SCARIOT, 2007; MORRISON; LINDELL, 2011). In general, these studies were carried out in abandoned pastures. Studies addressing forest plantations, in general, evaluated the spontaneous regeneration of native species beneath the forest canopy (e.g. PARROTTA, 1992; LEMENIH; GIDYELEW; TEKETAY, 2004; SOUZA et al., 2007; ABREU et al., 2011). Native species regeneration may be catalyzed beneath the canopy of plantation forests but this phenomenon relies on several variables, including the plantation species (BROCKERHOFF et al., 2008; VIANI; DURIGAN; MELO, 2010). For instance, Lemenih, Gildyelew and Teketay (2004) found no native woody species with DBH above 1 cm regenerating beneath the canopy of 31 year-old *Cupressus lusitanica* Mill. plantation in southern Ethiopia. Lemenih, Gildyelew and Teketay (2004) argued that the soil in this plantation was more shaded and colder than the soil in plantations of other species, which might impair native woody species colonization. In general, the regeneration of native wood species is considerably scarce beneath the canopy of conifer species plantations relative to the regeneration beneath the canopy of broad-leaved species plantations (FEYERA; BECK; LÜTTGE, 2002; LEMENIH; GIDYELEW; TEKETAY, 2004).

Information from literature concerning species that do not allow for the development of a species-rich understory, remaining as tree monocultures throughout their entire management cycle (e.g. LUGO, 1997), gave rise to concerns about the success of passive restoration in recovering species richness, diversity, dispersal syndromes and functional groups composition following the forest plantation clearcutting. Here, we address this issue by investigating the possible negative residual influences of *Cupressus lusitanica* upon native forest recovery.

Passive restoration can be defined as the spontaneous return of an ecosystem to a desirable status or trajectory (ARONSON; DURIGAN; BRANCALION, 2011). For the purposes of evaluation of passive restoration beneath the canopy of forest plantations, the desirable status or trajectory can be represented by the natural regeneration observed beneath the canopy of native forests nearby (SENBETA; TEKETAY; NÄSLUND, 2002; LEMENIH; GIDYELEW; TEKETAY, 2004; SOUZA et al., 2007). However, natural regeneration after the forest plantation clearcutting faces light conditions different to those encountered beneath a forest canopy. Evaluation of passive restoration after the forest plantation clearcutting requires a system with comparable light conditions. Comparison with natural forest gaps may be inappropriate because we may not be able to determine the precise age of these gaps. Furthermore, a forest recovering in natural gaps is strongly influenced by those seedlings and saplings that remained (MARTÍNEZ-GARZA; HOWE, 2003), which may not be true for native forest recovery following the forest plantation clearcutting, especially concerning plantation species which were refractory to native species colonization in its understory. On the other hand, comparison with man-made forest gaps may be a good alternative because in these gaps all vegetation is removed and one can know the age of the regenerating vegetation. Because studies evaluating regeneration in man-made forest gaps are relatively uncommon, it would be necessary to use information from reference sites relatively far away from the restoration site, so the search for closeness in light conditions can result in distinctiveness in other environmental conditions. However, understanding this distinctiveness can help to assure the value of the reference information gathered from those reference sites (WHITE; WALKER, 1997).

The objective of this study was to assess passive restoration in an Atlantic forest site following a *Cupressus lusitanica* plantation clearcutting by means of a comparison between the natural regeneration found in this site and the regeneration found in man-made forest gaps. The issue underpinning this objective refers to the effectiveness of passive restoration in recovering species richness, diversity, dispersal syndromes and functional groups composition in the restoration site. We hypothesized that this effectiveness might be low and consequently we would find significant differences between the regenerating vegetation in our study area and in the man-made gaps, with relation to the afore-mentioned attributes.

MATERIAL AND METHODS

Study area

The State Forest of Avaré (SFA) comprises 95.3 ha and is located in the municipality of Avaré, in the southeast region of Brazil (23º 05' 57" S and 48º 54' 44" W, 770 m a.s.l.). The mean annual temperature is 20.3º C and the mean annual rainfall is 1,274 mm (SENTELHAS et al., 1999). From the second half of the 20th century onwards, several forest plantations were established in the SFA, essentially of exotic species. The area occupied by forest plantations comprises about 64 ha. Additionally, in parts of the SFA, plantations of indigenous species were established or natural forest was allowed to recover resulting in secondary forests predominantly covering the margins of the main local stream and comprising about 10 ha. The secondary forests can be classified as seasonal semi-deciduous forest (IBGE, 2012), one of the two main Atlantic forest subtypes (OLIVEIRA-FILHO; FONTES, 2000). In the SFA region the native forest cover is highly fragmented (KRONKA et al., 2005). In a radius of 10 km around the SFA the forest cover comprises 1,841 ha distributed among 224 forest fragments of which 46 are larger than 10 ha and only one is larger than 100 ha (INSTITUTO FLORESTAL, 2013). Only 33% of that forest cover is composed of more diversified and tall forests (INSTITUTO FLORESTAL, 2013).

Cupressus lusitanica is a coniferous tree indigenous to the mountain regions of Mexico, Guatemala, El Salvador and Honduras, extensively cultivated in temperate and tropical regions (LAMPRECHT, 1990; LORENZI et al., 2003). In the SFA an area comprising 4.25 ha was occupied until 2009 by a *Cupressus lusitanica* forest established between 1956 and 1959. The plantation was established with an initial density of 1,600 stems ha^{-1} and was hewed during the cultivation period reaching a final density of about 625 stems ha^{-1}. The trees reached a mean diameter of 30 cm at breast height and a mean height of 35 m. The *Cupressus lusitanica* forest came to be known as the dark forest by local people due to its dull appearance and the almost complete absence of natural regeneration beneath the canopy (personal observation), thus corroborating the information from literature concerning the low potential for native species regeneration in plantations of this species. However, following clearcutting and the dark forest site's abandonment in March 2009, a visually conspicuous native tree and shrub species regeneration took place without any deliberate management action being taken in order to foster regeneration. A prior assessment reveals that the regenerating species pertain to the flora of the seasonal semi-deciduous forest.

Data collection

In a 2.25 ha area, namely the plot sampling area, we installed 64 circular plots with a diameter of 3 m, representing a sampled area of 0.0452 ha in total. The soil of this area is Red Oxisols (EMBRAPA, 2006). The plots were positioned along six transects, 20 m apart. The distance between two adjacent plots in transect was about 10 m. Inside the plot, we identified, counted and measured all plants with a minimum diameter of at least 1 cm at a height of 0.8 m above the soil. The botanical identification was made by comparing them to the Dom Bento José Pickel (SPSF) and Irina Delanova Gemtchynicov (BOTU) herbaria. Voucher material was logged at SPSF herbarium. The botanical nomenclature follows the APG III system (APG III, 2009). The botanical synonyms were checked by consulting the data bank compiled by the Rio de Janeiro Botanical Garden (JARDIM BOTÂNICO DO RIO DE JANEIRO, 2012).

For each species found in the plots, we searched the literature for information relating to: the functional groups (pioneer or non-pioneer) (*sensu* WHITMORE, 1989); and dispersal syndrome (zoochory, anemochory and autochory) (*sensu* Pijl, 1982). For the majority of the species we obtained the information from the data bank available in São Paulo (2007). For species which were not found in this reference tool, other sources were used (MORELLATO; LEITÃO-FILHO, 1992; GANDOLFI; LEITÃO-FILHO; BEZERRA, 1995; LORENZI, 2000; FORERO; COSTA, 2002; MARTINS; RODRIGUES, 2002; SOUZA; ESTEVES, 2002; KIYAMA; BIANCHINI, 2003; PULITANO; DURIGAN; DIAS, 2004; BERNACCI et al., 2006; CARPANEZZI; CARPANEZZI, 2006; MEDEIROS, 2006; SOUZA et al., 2007; YAMAMOTO; KINOSHITA; MARTINS, 2007; BARDELLI; KIRIZAWA; SOUSA, 2008; LEITE; RODRIGUES, 2008; LORENZI, 2009; BORGO, 2010; DAN; BRAGA; NASCIMENTO, 2010; PEREIRA et al., 2010; SILVA, 2010). In consulting these references, we adopted the criterion employed in São Paulo (2007) and treated the earlier secondary functional group as pioneer and the later secondary functional group as non-pioneer.

The list of the species found in the plot sampling area of the SFA, along with the number of individuals found for each species, the voucher number at the Dom Bento José Pickel herbarium and the classifications concerning functional group and dispersal syndrome, is part of other paper (CIELO-FILHO; SOUZA; FRANCO, 2013) and can be obtained from the authors upon request.

Reference area

For assessing the passive restoration in our study area we compared its regenerating vegetation with the vegetation resulting from secondary succession in man-made gaps in native secondary forest in the State Park of Cantareira (SPC). In those gaps the forest cover was entirely suppressed and the vegetation established was described by Arzolla (2011). The SPC is located in the municipality of São Paulo, southeastern Brazil (23° 26’ 40” S and 46° 38’ 39”, 885 m a.s.l.). The mean annual temperature in the SPC region is 18.5º C and the mean annual rainfall is 1.495 mm (SÃO PAULO, 2010). The SPC is a protected area of 7,916 ha covered predominantly by secondary forest which has been recovered since the first half of the XX century (ARZOLLA et al., 2010) and which can be classified as rain forest (IBGE, 2012), the other main subtype of Atlantic forest (OLIVEIRA-FILHO; FONTES, 2000). The SPC encompasses a continuous forest cover of about 7,481 ha (SÃO PAULO, 2010), which is almost entirely composed of diversified and tall forests (INSTITUTO FLORESTAL, 2013).

In July 2006, 11 gaps were opened in the secondary forest for the installation of power transmission towers resulting in the complete removal of the vegetation covering (ARZOLLA et al., 2010). The gaps are irregularly spaced along a 4.3 km transect and vary in size from 106 m^2 to 286 m^2 (mean of 180 m^2) totaling 0.2 ha (ARZOLLA et al., 2010). Between January and May 2010 Arzolla (2011) identified, counted and measured the diameter at a height of 1.3 m above the soil level of all plants with a height of more than 1.3 m. By excavating the soil around the stems it was possible to determine whether the plants had been established through seed or sprouting (ARZOLLA, 2011). The plants established through seed totaled 1,309 individuals pertaining to 82 species, while the plants established through sprouting totaled 343 individuals pertaining to 74 species. Considering the two modes of establishment, 1,652 individuals pertaining to 137 native species were recorded in the gaps (ARZOLLA, 2011). For the purposes of comparison with the SFA vegetation, we considered only plants established through seed and revised the classification of the species according to the functional groups made by Arzolla (2011) in order to match the criteria adopted for the attribution of functional groups for the species of the SFA vegetation.

Assessing passive restoration

The vegetation attributes considered for comparison were: species richness; diversity; proportion of non-pioneer species; proportion of individuals of non-pioneer species; frequency distribution of dispersal syndromes for species; and frequency distribution of dispersal syndromes for individuals.

We constructed rarefaction curves with 95% confidence intervals for species richness (*S*) and Shannon diversity index (*H'*) (MAGURRAN, 2004) for the SPC vegetation. Rarefaction curves for the same parameters were calculated for the vegetation in the SFA enabling a comparison between the vegetation regenerating in the two areas (MAGURRAN, 2004). The curves were obtained by means of resampling without reposition (10,000 iterations) of individuals using the EcoSim software (GOTELLI; ENTSMINGER, 2001). For the SFA vegetation, a second rarefaction curve was calculated for *S* and *H'* resampling plots instead of individuals to capture the influence of the spatial structure of the vegetation upon the alpha-diversity estimators (GOTELLI; ENTSMINGER, 2001).

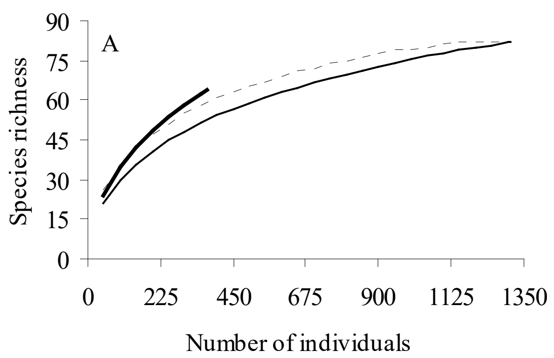
The comparison of the proportion of non-pioneer species and of individuals of non-pioneer species between the two areas was made through binomial tests (ZAR, 1999). The frequency distributions of dispersal syndromes for species and for individuals in the two areas were compared by applying a Chi-square test (ZAR, 1999). Where we encountered significant differences in dispersal syndrome frequency distributions, we partitioned the respective contingency table in order to assess which dispersal syndrome(s) gave rise to the difference (AYRES et al., 2007). Finally, we compared the slope of the curves of the rank/log-abundance plots considering only the ten most abundant pioneer species between the two areas by means of an analysis of covariance (ZAR, 1999). The same comparison was also applied to the non-pioneer species. All statistical tests were carried out using the BioEstat software (AYRES et al., 2007).

RESULTS AND DISCUSSION

We found 366 tree and shrub plants fitting the criterion for inclusion in the sample, totaling 64 species. The mean diameter of those plants was 2.9 cm (SD = 2.2 cm) and the mean height was 3.6 m (SD = 1.9 m). The stem density was 8,090 individuals ha^{-1} and the basal area was 8.6 m^2 ha^{-1}. After 29 months of passive restoration in the SFA the structural attributes of the vegetation are comparable to those observed after 41 months in the SPC where Arzolla (2011), analyzing plants established through seed and sprouting, found a stem density of 8,660 individuals ha^{-1}, a basal area of 7 m^2 ha^{-1}, a mean diameter of 2.5 cm (SD = 2.1 cm) and a mean height of 3.6 m (SD = 2.4 m). From a structural perspective, the vegetation that colonized the study area after clearcutting of *Cupressus lusitanica* plantation in the SFA is comparable with the vegetation colonizing man-made gaps in the SPC. However, in the present evaluation we are concerned with vegetation attributes beyond structure.

The species richness in the SFA was significantly greater than the species richness in the SPC from an abundance level of 140 individuals onwards, taking into account the resampling of individuals and from an abundance level of 160 individuals onwards, considering the resampling of plots (Figure 1A). The diversity in the SFA significantly surpassed that of the SPC from 100 individuals onwards, and from 115 individuals onwards, considering the resampling of individuals and plots, respectively (Figure 1B). Due to the fact that differences between the two resampling procedures were small, only individuals resampling curves were shown. Assessing the regenerating vegetation beneath the canopy of a 31-year old *Cupressus lusitanica* plantation in the south of Ethiopia, Lemenih, Gidyelew and Teketay (2004) found stem density and species richness significantly smaller than that observed in the regenerating vegetation beneath the canopy of a native forest nearby. Our results, concerning richness and diversity, showed that, after clearcutting the forest, the regenerating vegetation in areas previously occupied by a *Cupressus lusitanica* plantation may display different trends in relation to those reported by Lemenih, Gidyelew and Teketay (2004).

Lemenih, Gidyelew and Teketay (2004) attributed the relatively low value of species richness in the vegetation beneath *Cupressus lusitanica* forest canopy to the intense shade and lower temperature of the soil which could impair colonization by native plants. However, even taking into account the complete suppression of the above mentioned restrictive factors, the results



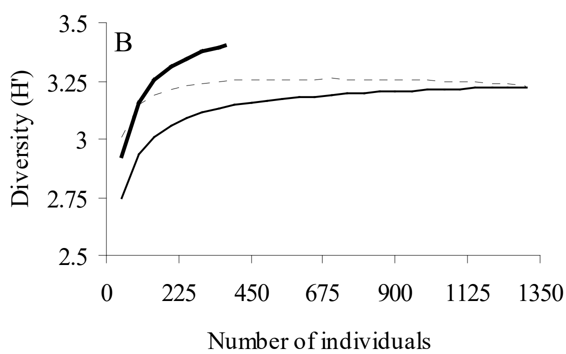


FIGURE 1: Rarefaction curves for species richness (A) and Shannon diversity index (B) in the State Forest of Avaré (thick line) and in the State Park of Cantareira (thin line). Dotted lines are the 95% upper confidence limit for the State Park of Cantareira curves.

FIGURA 1: Curvas de rarefação para riqueza de espécies (A) e índice de diversidade de Shannon (B) na Floresta Estadual de Avaré (linha grossa) e no Parque Estadual da Cantareira (linha fina). As linhas pontilhadas são o limite superior do intervalo de confiança a 95% para as curvas do Parque Estadual da Cantareira.

found in the SFA passive restoration area were unexpected because of the hypothesized negative residual influences of *Cupressus lusitanica* and, additionally, due to a further six reasons related to the way one can understand distinctiveness between the reference and restoration areas: 1 (distinction in relation to forest types) - the subtype of Atlantic forest found in the SFA, semi-deciduous forest, is well known for having a lower diversity than the subtype found in the SPC, rain forest (OLIVEIRA-FILHO; FONTES, 2000), which could result in a smaller species pool of potential colonizers in the SFA; 2 (distinction in relation to aging) - the regenerating vegetation in the SFA is 12 months younger than in the SPC, that is, there is at least one less fructification peak of potential colonizer species in the SFA (MORELLATO; LEITÃO-FILHO, 1992); 3 (distinction in relation to the scales of observation) - the scale extent of the sampling area in the SFA is smaller than that of the gaps transect in the SPC, which should result in a better representation of the beta diversity in the latter area and, ultimately, in a greater diversity in the set of gaps as a whole; 4 (distinction in relation to inclusion criteria) - the size criterion for inclusion of plants in the SFA plot sampling area is likely to be more restrictive than the one used in the SPC gaps, which should result in the inclusion of a wider spectrum of plant sizes (and hence, in a greater diversity) in the latter area; 5 (distinction in relation to distances from seed sources) - the mean distance among potential colonization micro-sites and the seed source (the secondary forest nearby) in the study area of the SFA is greater than in the gaps of the SPC and it is well known that seed rain and forest recovery potential decrease as the distance from the seed source becomes greater (HOLL, 1999; WIJDEVEN; KUZEE, 2000; GUARIGUATA; OSTERTAG, 2001); 6 (distinction in relation to landscape contexts) - the forest cover in the landscape surrounding the study area, which could influence the seed rain, is smaller, more fragmented and of a lower conservation status than the forest cover surrounding the reference area.

It is worth recognizing the potential methodological limitations represented by the use of a unique and, in some aspects, distinct reference site. This approach, imposed by a lack of studies similar to that of Arzolla (2011), overlooks the multiplicity of trajectories and stable states (SUDING; GROSS, 2006) that could be found in the secondary succession of Atlantic forests. On the other hand, as previously mentioned, similar light conditions and known regeneration age were considered pre-requisites for the kind of evaluation carried out here. Furthermore, it would be argued that the points enumerated in the preceding paragraph could justify the treatment of the reference area used in this study (for most of the possible trajectories or stable states) as a challenger task to be reached by the vegetation of our restoration site concerning the attributes compared. This reduces the probability of erroneous conclusions related to the lack of replication in gathering the reference information and to the distinctiveness between the restoration and the reference site.

Reasons 1 and 2 above would lead us to expect zoochory and non-pioneering to be better represented in the SPC, since the wetter climate and the greater aging of this area might be associated with a higher frequency of zoochoric and non-pioneer species and individuals (HOWE; SMALLWOOD, 1982; LIEBSCH; MARQUES; GOLDENBERG, 2008), but again our results did not match these expectations. For instance, the frequency distribution of dispersal syndromes for the species in the SFA did not differ significantly from the distribution in the SPC (χ^2 = 0.18, DF = 2, p = 0.915) (Figure 2A). Furthermore, we found a significant difference between the two areas with reference to the frequency distribution of dispersal syndromes for individuals (χ^2 = 80.69, DF = 2, p < 0.0001) (Figure 2B); and the partition of the corresponding contingency table shows that the proportion of zoochoric individuals in the SFA was significantly higher than the proportion of zoochoric individuals in the SPC (χ^2 = 76.09, DF = 1, p < 0.0001). Additionally, the proportion of non-pioneer species observed in the SFA (51%) was significantly greater than in the SPC (21%) (z = 3.7, p = 0.0002) (Figure 3) and the proportion of individuals of non-pioneer species in the SFA (24%) also was significantly greater than in the SPC (16%) (z = 3.5, p = 0.0005) (Figure 3).

The exclusion of the plants established through sprouting in the SPC probably had some influence on our results, but the whole set of regenerating plants in the gaps of the SPC would not be a good reference for evaluation of the passive restoration of the study area in the SFA, where we assumed a negligible sprouting establishment due to the forest conditions previous to the *Cupressus lusitanica* plantation clearcutting. This assumption is supported by personal observations and by other works that assessed the regeneration of native species underneath *Cupressus lusitanica* plantations (CHAPMAN; CHAPMAN, 1996; FIMBEL; FIMBEL, 1996; FEYERA; BECK; LÜTTGE, 2002; LEMENIH; GIDYELEW; TEKETAY, 2004; YIRDAW, 2001). It is worth asking whether the plants established through sprouting would have a negative effect on the diversity of species established through seed in the SPC, by competitive exclusion of the later. However, we note that most of the sprouting established plants pertained to rare species. Based on the assumption that the relative abundance is a good surrogate of the species competitive ability (MAGURRAN, 2004), it is likely that the plants established through sprouting in the SPC have limited competitive ability and for this reason, they could not have restricted significantly the richness

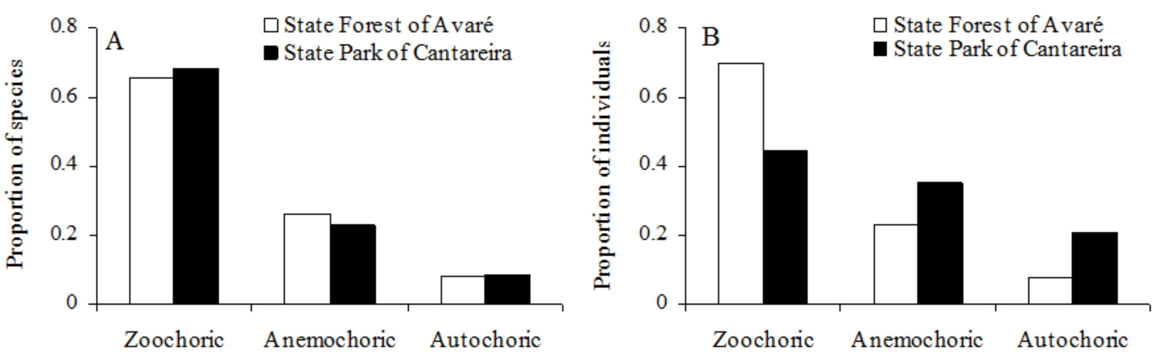


FIGURE 2: Frequency distribution of dispersal syndromes for species (A) and for individuals (B) in the State Forest of Avaré (SFA) and State Park of Cantareira (SPC). The global Chi-square was statistically significant only for individuals and the partition of the corresponding contingency table reveals that the proportion of zoochoric individuals in the SFA was significantly higher than the proportion of zoochoric individuals in the SPC.

FIGURA 2: Distribuição de frequência de síndromes de dispersão para espécies (A) e para indivíduos (B) na Floresta Estadual de Avaré (SFA) e no Parque Estadual da Cantareira (SPC). O valor do Qui-quadrado global foi estatisticamente significativo apenas para indivíduos e a partição da tabela de contingência correspondente revelou que a proporção de indivíduos zoocóricos na SFA foi significativamente mais alta que a proporção de indivíduos zoocóricos no SPC.

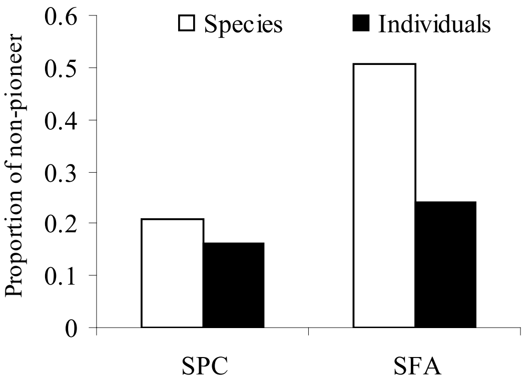


FIGURE 3: Proportion of non-pioneer species and proportion of individuals of non-pioneer species in the State Forest of Avaré (SFA) and State Park of Cantareira (SPC). For both proportions, of species and of individuals, the proportion of non-pioneers was significantly higher in the SFA than in the SPC according to the binomial test.

FIGURA 3: Proporção de espécies não pioneiras e proporção de indivíduos de espécies não pioneiras na Floresta Estadual de Avaré (SFA) e no Parque Estadual da Cantareira (SPC). Para ambas as proporções, de espécies e de indivíduos, a proporção de não pioneiras foi significativamente mais alta na SFA do que no SPC de acordo com o teste binomial.

of the species established through seed. Thus, how could the performance of the passive restoration in the SFA be explained? We consider three possible, not mutually exclusive, explanations.

Contrary to our working hypothesis, one of the explanations refers to a positive, rather than negative, residual influence *Cupressus lusitanica* that may favor the natural regeneration after clearcutting. For instance, Lemenih, Olssonb and Karltun (2004) found, for a 15-year old stand of *Cupressus lusitanica*, that one of the properties of this species is that it improves the fertility status of the soil. Favorable soil condition is one of the main factors responsible for the success of passive restoration in tropical forests (AIDE et al., 2000; GUARIGUATA; OSTERTAG, 2001). The influence of *Cupressus lusitanica* on soil fertility deserves further study and points to the possibility of methodological developments in restoration ecology centered on the conversion of *Cupressus lusitanica* plantations to natural forests. This species is considered to be a good alternative for timber production as long as adequate progenies are used and appropriate climate conditions are observed (SHIMIZU et al., 2006). Thus, passive restoration following *Cupressus lusitanica* plantation clearcutting may represent an important economic alternative to the expensive active restoration of the Atlantic forest.

Another possible explanation refers to the influence of the piles of branches left in the study area after the clearcutting. These piles constitute shelter and foraging sites for birds, mammals and reptiles which deposit seeds of native species fostering the recovery of natural vegetation in tree plantation lands after clearcutting (REIS; BECHARA; TRES, 2010). The fact that the State Forest of Avaré is a protected area certainly contributes to the beneficial influences of animal seed dispersers.

Finally, it is worth noting the presence in the study area of a water tunnel with a width of approximately 1 m, a height of 2 m and a length of 12 m, known to local people as the bat tunnel. Frugivorous bats which are abundant in forest restorations sites such as *Artibeus lituratus* (OLFERS, 1818) and *Carollia perspicillata* (LINNAEUS, 1758; SILVEIRA et al., 2011) are also commonly found in shelters similar to tunnels, such as caves (TRAJANO, 1984). Among the ten most abundant species in the study area, two are dispersed by the bats mentioned above: *Maclura tinctoria* (L.) D.Don ex Steud. and *Cecropia pachystachya* Trécul (MIKICH, 2002; SILVEIRA et al., 2011). Additionally, Solanaceae fruit, an expressive family in the study area concerning number of species and individuals, are especially appreciated by bats of the genus *Sturnira* (MARINHO-FILHO, 1991). Thus, we suggest that the conditions favorable for the presence of bats in the study area may also have contributed to the actual success of the passive restoration of this area.

The above explanations emphasize the influence of the seed rain, but, alternatively, the soil seed bank could also be evoked to explain the passive restoration of the area. However, studies focusing on the soil seed bank underneath forest plantations (including *Cupressus lusitanica* plantations) have shown that native wood species are scarcely represented in such seed banks (e.g. SENBETA; TEKETAY; NÄSLUND, 2002; LEMENIH; TEKETAY, 2005). This scarcity may be attributed to the transient nature of tropical woody species seeds, especially of the late successional species (LEMENIH; TEKETAY, 2005; PUIG, 2008). Therefore, the literature information suggests the soil seed bank plays a limited role in the passive restoration studied here. Based on the same rationale presented to justify the assumption of a negligible sprouting establishment following the *Cupressus lusitanica* plantation clearcutting, we also admitted a limited role for the seedling bank in the recovery of the passive restoration area.

The hypotheses considered above which rely on the influence of animal seed dispersers find support in the analysis of frequency distributions of dispersal syndromes. For instance, the zoochory dispersal syndrome was equally prevailing among the species in the two areas (Figure 2A), but this predominance considering the individuals of zoochoric species was more conspicuous in the SFA (Figure 2B), suggesting a remarkable contribution of animal seed dispersers for the recovery of the restoration site.

The comparability between the SFA and the SPC concerning the representation of the non-pioneer functional group was not affected by the fact that the vegetation in the latter area occurs in gaps. Small forest gaps are colonized predominantly by the same late successional species that occur in the surrounding understory (MARTINS; RODRIGUES, 2002), but we suggest that the SPC gaps were not small enough for this to occur. For instance, the mean size for the SPC gaps, 180 m^2, was greater than the mean size of the gaps studied by Martins and Rodrigues (2002), 126 m^2, and surpassed the threshold limit for the predominance of pioneer species, 150 m^2, suggested by Brokaw (1982).

The greater proportion of non-pioneer species in the SFA suggests a more favorable trajectory towards the recovery at the restoration site. This same consideration can be deduced based on the analysis of the slopes of the rank/log-abundance plot curves. For the 10 most abundant pioneer species the rate of reduction in the logarithm of the abundance did not differ significantly between the SFA and SPC ($F = 0.128$, DF = 1, 16, $p = 0.726$) (Figure 4A), but, for the non-pioneer species, the reduction in abundance was significantly less pronounced in the SFA ($F = 11.440$, DF = 1, 16, $p = 0.0046$) (Figure 4B). The low slope of the non-pioneer species curve for the SFA in relation to the slope of the SPC curve suggests less stringent competitive relationships, and consequently, a lower risk of stagnation of the succession processes in the first area. Martínez-Garza and Howe (2003) warn of the risk of a time-consuming period of domination by pioneer species during the recovery of tropical forests in restoration sites in relation to the recovery in gaps. However, the absence of significant differences between the slopes of the rank/log-abundance plot curves for the pioneer species in the SFA and the SPC points to equally stringent competitive relationships among pioneer species in the two areas and so, to a low risk of a time-consuming period of domination by pioneer species in the SFA.

The evaluation of the passive restoration in the SFA, using the recovery of man-made gaps in the SPC as a reference, revealed that the species richness, diversity, proportion of non-pioneer

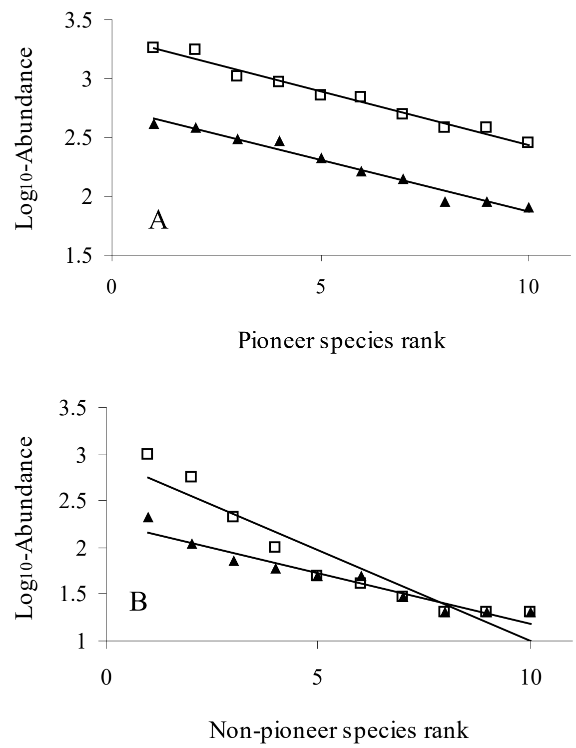


FIGURE 4: Rank/log-abundance plots along with linear regression lines for the ten most abundant pioneer (A) and non-pioneer (B) species in the State Forest of Avaré (triangles) and State Park of Cantareira (squares).

FIGURA 4: Gráficos de rol do logaritmo da abundância junto com linhas de regressão linear para as dez espécies mais abundantes, pioneiras (A) e não pioneiras (B), na Floresta Estadual de Avaré (triângulos) e no Parque Estadual da Cantareira (quadrados).

species and frequency distribution of dispersal syndromes are comparable to or even more favorable for the recovery of the Atlantic forest in the SFA. Our results showed that forest recovery in the SFA matches the definition of passive restoration relating to the vegetation status and suggest that this is also true concerning its trajectory (ARONSON; DURIGAN; BRANCALION, 2011). It is not to say that the complete recovery of the Atlantic forest in the study area should not be aided. Evidence from the observation of secondary Atlantic forests shows that it may take 100 years or more for composition and structure attributes to recover (LIEBSCH; MARQUES; GOLDENBERG, 2008), which suggests that some action by management may be useful even when passive restoration is successful. For this reason, the planting of zoochoric non-pioneer species with large seeds has been encouraged, due to the difficulties of natural seed dispersal for those species in fragmented landscapes (WUNDERLE, 1997; MARTÍNEZ-GARZA; HOWE, 2003). We suggest monitoring the seed rain in the study area in order to detect which of the species that characterize mature forests in the region are not present, in order to identify which species could be used in enrichment plantings.

CONCLUSIONS

Contrary to the hypothesis of this study, our results showed a relatively high effectiveness of passive restoration in recovering species richness, diversity, dispersal syndromes and functional groups composition in the restoration site. This indicates that the recovery of native vegetation after forest plantation clearcutting may occur even when the plantation species inhibit the establishment of native species beneath the forest canopy during the management cycle. It is worth stressing the potential of passive restoration even in a landscape in which original forest cover was highly fragmented, as was the case in the State Forest of Avaré region.

We suggest that the effectiveness of passive restoration may be dependent of factors such as: the effect that the planting species has on the soil; details of the logging operation; and the action of faunal seed dispersers. In the specific case studied here, we highlight three conditions related to the above mentioned factors which could have been decisive in the success of the passive restoration on the study area: (1) the possible positive influence of *Cupressus lusitanica* upon soil attributes like fertility; (2) the permanence of branchy piles, which promotes nuclei of native vegetation, in the study area after the forest plantation clearcutting; and (3) the existence of conditions favorable to the presence of bats and other animal seed dispersers in the study area.

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