Restoration Success: Secondary Forests at the Margin of the Hydroelectric Reservoir (Minas Gerais State, Brazil)

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ABSTRACT

Background: Disturbance with removal of the original vegetation and intense erosion during construction of hydroelectric reservoir can destroy the vegetation and the natural environmental. the present study aimed to characterize the correlations between the inventoried tree communities and soil attributes in order to demonstrate the influence of physical and chemical characteristics of the soil on the tree (DE = Degraded; DI = Disturbed and CON = Preserved). A survey was performed with the allocation of 36 plots of 20 x 20 m, in which trees with DBH ≥ 5 cm were sampled. For the soil analysis, two samples were collected within each plot in order to form a composite sample. Correlations between biotic and edaphic attributes had their significance tested using the Monte Carlo permutation test. Edaphic and biotic variables were compared by unifactorial variance analysis (ANOVA), connected to a posteriori Tukey Test. The ordering showed the separation of the plots into three groups (DE, DI and CON) according to the proportion of disturbance levels. The areas in restoration process presented edaphic and tree community composition heterogeneity. The soils of all studied categories were characterized by its low nutrient availability and acidity ranging from medium (DE) to high (DI and PRE) and varying content of organic matter, which is more highly stored in the forest area. The fertility degree and other soil characteristics partially explain the floristic compositions and changes in the abundance of populations in the tree communities.

INTRODUCTION

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER, 2004). The goal of restoration is to create a self-supporting ecosystem that is resilient to perturbation without further assistance (Urbanska et al., 1997; SER, 2004). But how do we know when we have reached that goal? The suggestion is that restoration success could be based on vegetation characteristics, species diversity or ecosystem processes. Besides, it can be possible to promote a more integrated approach that includes many variables to provide a better measure of restoration success. So, there is a lack of research involving evaluations of forest communities originated from the restoration of degraded areas implemented through reforestation projects, impeding the establishment of indicators to assess the quality of these reforestations (Kageyama and Castro, 1989; Reis et al., 2003; Melo and Durigan, 2007; Oliveira and Engel, 2011; Peña-Claros, 2003).

As The Society of Ecological Restoration International (SER) (2004) there is a list of nine ecosystem attributes as a guideline for measuring restoration success. A restored ecosystem should have the following attributes: (1) similar diversity and community structure in comparison with reference sites; (2) presence of indigenous species; (3) presence of functional groups necessary for long-term stability; (4) capacity of the physical environment to sustain reproducing populations; (5) normal functioning; (6) integration with the landscape; (7) elimination of potential threats; (8) resilience to natural disturbances; and (9) self-sustainability. Although, few studies have the financial resources to monitor all these attributes and the monitoring phase of most restoration projects rarely lasts for more than 5 years.

The evaluation of environmental restoration activities evolves the selection and analysis of a set of indicators, such as physical, chemical and biological soil attributes (Duarte and Casagrande, 2006). However,
the discrepancy of scientific information is accentuated when the restoration of forest ecosystems in dramatically affected areas, such as loaned areas, are pondered (Barbosa, 2006). These areas are degraded ecosystems that were eliminated along with vegetation, biotic attributes of their regeneration, such as the seed bank, seedling bank and seed rain, and the fertile soil layer (horizon A) (Brown and Lugo, 1994; Ferreira et al., 2007). Because of this, issues such as soil compaction, low infiltration rates and water storage capacity, oxygen deficiency, high resistance to root penetration, increased density and lack of soil organic matter, occur (Brown & Lugo, 1994; Reis & Kageyama, 2003). In order to recover, it is necessary to select and identify species suited to the new soil conditions and to hasten the formation of soil horizons (Gonçalves, 2008).

In general, all studies evaluated the recovery of vegetation structure or diversity after restoration process. When the characterization of relations between the soil variables and with the vegetation composition can it enables the improvement of forest restoration models, and the identification of species to be used in forest planting arrangements (Rodrigues & Gandolfi, 1998). In degraded areas, these studies also assist in verifying the efficiency of ecosystem rehabilitation interventions, in addition to elucidating the degree of stability of the studied areas (Tilman, 1996).

The studied areas in restoration process suffered different levels of degradation due to the construction of the Hydroelectric Reservoir of Camargos and Itutinga (MG) in the 1950s. Due to current needs, the present study aimed to characterize the correlations between the inventoried tree communities and soil attributes in order to demonstrate the influence of physical and chemical characteristics of the soil on the tree. To guide the search, the following questions were put: i) what are the floristic dissimilarities between the tree communities in recovery process with different levels of disturbance? ii) the chemical and physical properties of soils in these environments influence the distribution of tree species?

**Methodology:**

**Characterization of the study areas:**

The research was conducted in six areas located upstream and downstream of the Hydroelectric Reservoir of Camargos and Itutinga of the Companhia Energética de Minas Gerais – CEMIG (Figure 1), on the right bank of the Rio Grande, Itutinga (Minas Gerais). Among the areas surveyed, five are recovery areas which have been in environmental restoration process for 20 years. One area was used as the loan, with horizon C exposed, lasting for about 30 years without any recovery process. The recovery of the areas occurred between 1992 and 1995, using mechanical restoration and vegetative practices by planting woody species. The natural vegetation of the region has semideciduous forest formations interspersed with grassland and savanna physiognomies. Regional climate incorporates the transition between Cwb and Cwa, according to Köppen’s classification (Antunes, 1986). The average temperature of the coldest month is below 18° C and of the hottest month, exceeding 22° C.

![Fig. 1](image-url): Geographical location and arrangement of the sampling plots in the areas at the margin of the Hydroelectric Reservoir of Camargos and Itutinga, MG.

**Vegetation sampling:**

The method to evaluate the distribution of the vegetation in recovering process used in this study was the plot method (Mueller-Dombois; Ellenberg, 1974). This procedure consisted in the allocation of 36 plots,
measuring 20 x 20 m (400 m²), corresponding to a total sampling area of 1.44 ha, distributed over the areas (Figure 1). All trees with the height of 1.30 m above ground level (DBH ≥ 5 cm) were considered. The botanical material was identified based on literature and by comparison in the Herbarium at the Universidade Federal de Lavras (UFLA). The species index was updated with the specific binoms from the Royal Botanic Gardens, Kew (1993), and Missouri Botanical Garden Web site (available at: http://http://www.missouribotanicalgarden.org/). The classification system used was APG II (Souza; Lorenzi, 2005).

**Soil analysis:**

A soil survey was conducted in the studied areas. For the characterization of the chemical and physical properties of the soils, two samples were collected at a depth of 0-20 cm within each plot to form a composite sample. Analyses were performed in the laboratory of the Soil Department of the UFLA. The following soil characteristics were determined: pH in water, total organic carbon, phosphorus (P), potassium (K), calcium (Ca²⁺), magnesium (Mg), aluminum (Al³⁺), potential acidity (H+Al), sum of bases (SB), cation exchange capacity [CEC (t)] effective cation exchange capacity at pH 7.0 (T), base saturation index (V), Al saturation index (m) and soil particles size (sand, silt and clay) to define the texture class (Embrapa, 1997).

**Ordination of soil and vegetation data:**

To test the hypothesis that the areas in recovery process present floristic differentiation connected to pressures and also soil attributes, the vegetation data were analyzed together with data from the soil analysis, based on the canonical correlation analysis (CCA) (Ter Braak, 1987). The Monte Carlo permutation test was used to evaluate the significance level of the main axis of canonical ordination, in order to assess the probability of matches found in the relationships among biotic and edaphic attributes (Ter Braak, 1986). Two matrices were prepared for this analysis: the first, containing the abundances of tree species in the plots and, a second, with data containing data of the soil attributes. The analyzes were performed using the program PC-ORD (McCune; Mefford, 1999).

After a preliminary analysis, the soil variables H+Al, Mg, Ca, V, MO and silt, which showed weak correlations between plots (r <0.3), were eliminated. The normality of the normality was verified by the D’Agostino-Pearson test. Data expressing reason relation were previously processed by the function

\[ X' = \arcsen \left( \frac{X}{100} \right) \]

in order to adjust the statistical assumptions, while discrete or continuous quantitative data were transformed by square root or logarithmic functions, respectively. The biotic and soil attributes of the areas with different levels of disturbance were compared by unifactorial variance analysis (ANOVA), connected to a posteriori test of Tukey.

**RESULTS AND DISCUSSION**

**Species composition and physiognomic structure at land restoration areas with different levels of disturbance:**

Taking into account all the sites 58, 46 and 64 were recorded according the different levels of disturbance. More than half of the species were represented by 5 individuals or less. Among the areas with different levels of disturbance being restored, it was found that the categories DE and DI showed little variation in the number of species (Table 1). It was observed that the species of early succession (pioneer + early secondary) were more numerous, showing characteristics of a forest in early succession stage. Some abundant species (≥ 30 individuals in total) were present in high number at the both sites (DE and DI). According to Figure 2, 13 species were common to the three categories studied: Clitoria fairchildiana, Copaifera langsdorffii, Croton floribundus, Eriobotrya japonica, Hymenaea courbaril, Lithraea molleoides, Machaerium villosum, Myrcia venulosa, Myrsine coriacea, Nectandra oppositifolia, Peltophorum dubium, Tapirira guianensis e Tapirira obtusa. Between the DE and PE were found in common 23 species in common. As the unique species, nine (22%) were found at the DE, 11 (16.4%) at PE and 39 (61%) at the CON.

<table>
<thead>
<tr>
<th>Table 1: Summary of the variables of the areas’ tree species’ physiognomic structure found for tree species in the restoration process areas with different levels of disturbance at the margin of the Hydroelectric Reservoir of Camargos and Itutinga, MG.</th>
<th>PHYSONOMIC STRUCTURE</th>
<th>AREAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DE</td>
<td>DI</td>
</tr>
<tr>
<td>N° of individuals</td>
<td>898</td>
<td>499</td>
</tr>
<tr>
<td>N° of species</td>
<td>58</td>
<td>46</td>
</tr>
<tr>
<td>N° of families</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Density (ind. ha⁻¹)</td>
<td>1.417 a</td>
<td>1.156 a</td>
</tr>
<tr>
<td>Basal Area (m² ha⁻¹)</td>
<td>16.11 a</td>
<td>8.54 b</td>
</tr>
<tr>
<td>DBH mean (cm)</td>
<td>12.71 a</td>
<td>12.08 b</td>
</tr>
<tr>
<td>H_mean (m)</td>
<td>7.58 a</td>
<td>8.76 b</td>
</tr>
</tbody>
</table>

The families with larger numbers of individuals at the DE site (Figura 3), stand out: Fabaceae (337), Myrtaceae (96), Anacardiaceae (87), Primulaceae (46), Meliaceae (23), Lythraceae (12), Urticaceae (12),
Lauraceae (12), Asteraceae (8) and Moraceae (8). In PE areas class families among the most representative of the number of individuals 80 stand out: Fabaceae (422 individuals), Anacardiaceae (117), Myrtaceae (60), Asteraceae (39), Euphorbiaceae (18), Primulaceae (15), Bignoniaceae (9), Lauraceae (6), Lythraceae (6) e Meliaceae (5). No fragmento de vegetação nativa, as principais famílias com maior número de indivíduos foram: Anacardiaceae (118 indivíduos), Fabaceae (152), Lauraceae (89), Burseraceae (50), Meliaceae (25), Myrtaceae (24), Salicaceae (17), Hypericaceae (10) and Euphorbiaceae (8).

Fig. 2: Venn diagram extracted from the floristic composition of the three categories at the margin of the Hydroeletric Reservoir of Camargos and Itutinga, MG. (MG) with the number of shared species. Where, DE = Degraded area; PE = Disturbed area; CON = Reference area; E = exclusive species; C = shared species between the three e N = total number of species iat each categorie.

Fig. 3: Number of individuals in 10 families with the highest representation of the number of species (a) and on the number of individuals (b) per family in the tree layer of the areas being restored and native forest fragment surrounding the reservoirs of Camargo and Itutinga, MG. Where DE = degraded, disturbed DI = CON = conserved and CON = fragment (native vegetation).

Summary of the variables of the areas’ tree species’ physiognomic structure at the Table 2. The height values obtained for the areas of categories DE-PE (t = 0.99, p<0.01) e DE-CON (t = 1.41, p<0.01) were differed significantly. However, there is not significant difference between the areas PE-CON (t = 0.41, p= ns). A higher proportion of individuals occurred in the range between 5 and 10 m (Figura 4). Around 30% of individuals present in the native fragment were recorded in greater height range (10 a 15 m). The largest individuals 19,9 m and were found in the sites of category PE, corresponding to individuals of the *Acacia mangium*, that is tolerant to poor soils and growing fast (CHEN, 2011). In the condition of the sites, the canopy is mainly composed of reforestation *A. mangium*. However, as this speie has a short life (about 20 years) and the trend is that within a short time this species is no longer present in the studied areas having already senescent plants.

A densidade de árvores foi de 1.417, 1.156 e 1.716 indivíduos.ha\(^{-1}\), for DE, PE and COM areas, respectively. The value obtained for the category CON differed significantly from the categories PE-DE (p<0.05). However, there was no significant difference between DE and PE for density values. The values of basal area of categories DE-PE (r = 0.006, p<0.01) and PE-CON (r = 0.005, p<0.01) differed significantly. It should be noted, that the categories PE (15,10 m\(^2\).ha\(^{-1}\)) was significantly different from the other (DE = 9,34...
m².ha⁻¹ e CON = 8.24 m².ha⁻¹), probably the highest density of *A. mangium* (356 ind.ha⁻¹). There was no significant difference between the areas DE-CON (*t* = 0.003, *p* ≈ ns). Comparing these results with surveys in the region (Minas Gerais State, Brazil) using the same inclusion criteria (DBH ≥ 5 cm), the basal area of study areas was lower (Frame 1).

### Frame 1: Summary of the variables of the areas’ tree species’ physiognomic structure and composition found for tree species in the restoration process areas with different levels of disturbance at the margin of the Hydroelectric Reservoir of Camargos and Itutinga (Minas Gerais State) and another research sources. **H**média = average height; **DAP**média = diâmetro à altura do peito; densidade (ind.ha⁻¹) e área basal (m².ha⁻¹).

<table>
<thead>
<tr>
<th>Local</th>
<th><strong>H</strong>média (m)</th>
<th><strong>DBH</strong>média (cm)</th>
<th><strong>DENSIT Y</strong> (ind. ha⁻¹)</th>
<th><strong>AREA BASAL</strong> (m². ha⁻¹)</th>
<th><strong>SOURCE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Camargos (Minas Gerais, State) - DE</td>
<td>7.59</td>
<td>11.60</td>
<td>1.292</td>
<td>9.34</td>
<td>This research</td>
</tr>
<tr>
<td>Camargos (Minas Gerais, State) – DI</td>
<td>8.59</td>
<td>13.34</td>
<td>1.214</td>
<td>15.10</td>
<td>This research</td>
</tr>
<tr>
<td>Camargos (Minas Gerais, State) – CON</td>
<td>9.00</td>
<td>12.08</td>
<td>1.716</td>
<td>8.24</td>
<td>This research</td>
</tr>
<tr>
<td>Forest - Campus Federal University of Lavras (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>1.500</td>
<td>27.24</td>
<td>ESPIRITO-SANTO et al. (2002)</td>
</tr>
<tr>
<td>Forest - Campus Federal University of Lavras (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>19.77</td>
<td>OLIVEIRA-FILHO et al. (1994a)</td>
</tr>
<tr>
<td>Capivari, Lavras (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>27.70</td>
<td>SOUZA (2001)</td>
</tr>
<tr>
<td>Forest, Ingai (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>29.31</td>
<td>BOTREL (2001)</td>
</tr>
<tr>
<td>Galego Forest, Luminárias (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>28.33</td>
<td>RODRIGUES (2001)</td>
</tr>
<tr>
<td>Remaining Forest Rio Capivari, Lavras (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>1.487</td>
<td>31.03</td>
<td>SOUZA et al. (2003)</td>
</tr>
<tr>
<td>Disturbed spring, Lavras (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>1.795</td>
<td>--</td>
<td>PINTO et al. (2005)</td>
</tr>
<tr>
<td>Degraded Spring, Lavras (Minas Gerais, State)</td>
<td>--</td>
<td>--</td>
<td>642</td>
<td>--</td>
<td>PINTO et al. (2005)</td>
</tr>
</tbody>
</table>

### Physiognomic structure and patterns of species distribution and soil attributes:

The height values obtained for areas of categories DE-DI (*t* = 0.99, *p* < 0.01) and DE-PRE (*t* = 1.41, *p* < .01) differed significantly. However, no significant difference occurred between these areas (*t* = 0.41, *p* = ns). The tree densities were of 1.292, 1.214 and 1.716 individuals.ha⁻¹, for categories DE, DI and PRE, respectively. The value obtained for the PRE category differed significantly from the DE-DI category (p < 0.05). However, no significant difference occurred between DE and DI for density values. The values of the basal area to the areas of categories DE-DI (*t* = 0.006, *p* < 0.01) and DI-PRE (*t* = 0.005, *p* < .01) differed significantly. It was noted that the DI category was significantly different from the others, with the highest density of individuals of *Acacia mangium* (356 ind.ha⁻¹). However, no significant difference between the areas of DE-PRE (*t* = 0.003, *p* = ns).

The eigenvalues of the CCA for the first two ordination axes showed the floristic gradient between areas in restoration process (Figure 4). Axis 1 illustrates the existence of a moderate gradient, where a substitution of...
species occurred, while axis 2 indicates a short gradient due to variations mainly concerning the abundance of
species (Ter Braak, 1987). Together, the first three axes of the ordination explained 21.6% of the overall variance, with a great portion of the variance remaining unexplained. However, this situation is characterized as frequent in vegetation studies (Ter Braak, 1987). The CCA produced considerably higher values for the species-environment correlations ($r > 0.8$) on the first axis, and the Monte Carlo permutation tests indicated that the abundance of species and soil attributes were significantly correlated.

The K, Al and P variables were strongly and positively correlated with the first ordination axis (Table 4), while SB and t showed strong and positive correlation with the second axis. pH and Al variables were the only significant difference between the three categories of areas, and contributed to the segregation between the area PRE and the areas DE and DI, the first with higher concentrations of aluminum index and lower pH (Figure 2), in addition to the highest levels of K and P. Moreover, DE area showed a higher total of exchangeable bases and cation exchange capacity, and these attributes provided the main distinctions between the areas with intense level of disturbance. The CCA showed that the soil variables are not distributed homogeneously in the areas. The soil attributes were partially explained the floristic relations and changes in the population abundance in tree communities. The remaining unexplained variance is associated with environmental variables not recorded, such as canopy openness, proximity to sources of propagating material, topographic position, biotic interactions (Nappo et al., 2000), in addition to the history and disturbance levels, which are characterized as a qualitative variable and are difficult to measure.

The ordination along axis 1 showed separation of the plots according to the proportion of sustained disturbance level. The plots were classified into the following groups: (a) represented by the category PRE, plots that occur on the right side of the ordination, with a prevalence of highly acidic and of low fertility soil, high Al index, low SB, very low V, high content of organic matter, low t and high T; (b) represented by plots of category DE, occurring in the upper left with low acidic and low fertility soils, low Al index, high SB, very low V, average organic matter content, low t and medium T; and (c) represented by plots of DI, which occur in the lower left with low fertility soils, average Al content, low SB, average organic matter content, low t and medium T.

**Fig. 4:** Diagram of the plots, species and soil attributes in the first two ordination axes produced by canonical correspondence analysis (CCA) computed from inventoried tree community areas in restoration process (DE and DI) with different levels of disturbance and the Semideciduous Forest (PRE ) at the margin of the Hydroelectric Reservoir of Camargos and Itutinga, MG. The plots are represented by symbols corresponding to the areas with different levels of disturbance: DE = degraded; DI = disturbed and PRE = preserved. Edaphic variables: sulfur (S), phosphorus (P), potassium (K), aluminum (Al$^{3+}$), cation exchange capacity [CTC (t)], effective cation exchange capacity at pH 7.0 (T), base saturation index (V) and pH in water.

Associated with the soil characteristics observed in CON, was the distribution of populations of Actinostemon concolor, Andira fraxinifolia, Cheiloclinium cognatum, Cordia sellowiana, Daphnopsis fasciculata, Gochnatia polymorpha, Guatteria nigrescens, Machaerium hirtum, Myrcia splendens, Protium pilosissimun e Terminalia faigifolia, suggesting that these species have affinity for clay soils, low pH and aluminum. These species have excelled in abundance and were correlated with the levels of P and K. These patterns of distribution indicated by the CCA are consistent with the Spearman correlation coefficients.

At the other end of the gradient, in areas where the acidity was lower, occurred larger representations of silt and sand, and also low cation exchange capacity and base saturation, the grouping of plots related to a larger
abundance of species *Calophyllum brasiliense* (shade tolerant swamp species– Vilela et al., 2000), *Caryocar brasiliense*, *Eremanthus incanus*, *Eugenia florida*, *Luehea grandiflora*, *Mimosa bimucronata* and *Platpodium elegans*. *E. incanus* and *P. elegans* are species common in seasonal forests of Atlantic domain (Oliveira-Filho & Fontes, 2000), while *Caryocar brasiliense* is typical of the Cerrado area (Ratter et al., 2003).

Seen as the region is presented as an ecotone area between the Cerrado and Atlantic areas (Lima et al., 2006), the occurrence is not surprising and shows the process of natural regeneration. Other species which showed progress in forest regeneration were *Calophyllum brasiliense* and *Mimosa bimucronata*, which comprise of species associated to humid environments, usually connected to water bodies (Rodrigues and Nave, 2000), as is the case of the reservoir margins. Finally, *E. florida* and *L. grandiflora* comprise of species of wide distribution in the forests of Minas Gerais (Oliveira-Filho and Fontes, 2000).

**Conclusion:**

The areas in recovery process analyzed, corresponding to different levels of disturbance, had edaphic and tree community composition heterogeneity. The fertility degree and other soil characteristics partially explain the floristic composition and changes in the abundance of population in the tree communities. The research may represent a source of information for the restoration of areas where environmental conditions are similar.

**REFERENCES**


