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Environmental Technology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tent20

Analysis of effectiveness of three forest interventionist techniques and proposal of a new and integrated model of forest restoration

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Accepted author version posted online: 13 May 2015.

To cite this article: Karen Regina Castelli, Mariana Gregorio Barreto, Wendy Francesconi, Leandro Dalla Valle, Giulliana Mondelli, Fernanda Maria Abilio & Alexandre Marco da Silva (2015): Analysis of effectiveness of three forest interventionist techniques and proposal of a new and integrated model of forest restoration, Environmental Technology, DOI: 10.1080/09593330.2015.1043957

To link to this article: http://dx.doi.org/10.1080/09593330.2015.1043957

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Publisher: Taylor & Francis
Journal: *Environmental Technology*
DOI: 10.1080/09593330.2015.1043957

Analysis of effectiveness of three forest interventionist techniques and proposal of a new and integrated model of forest restoration

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Abstract

We assessed the efficacy of three different forest intervention techniques, in terms of phytosociological and edaphic responses, that were implemented in 2007. In a farm where trees are planted and managed for cellulose production as well as set aside for environmental conservation, four stands were analyzed: three of them were considered degraded and were managed using different intervention techniques (transposition, perches, and abandonment), and a fourth stand comprised of pristine vegetation was considered a control(reference). Floristic and phytosociology data was collected in three 10x10m plots established in each stand. Also, a total of 48 soil samples were collected to analyze physical and chemical attributes of the topsoil for the different stands. In terms of biodiversity, all the treatments showed significantly lower values when compared to the reference area. However, the soils in all the treatment and reference stands are similar in terms of physical and chemical attributes. Taking into account the specificities of each restoration technique, we verified that the integrated use of a set of management practices, constituted by the (1) abandonment of the area and (2) following a selective killing of the eucalyptus, is the most suitable and promising model to provide fast and effective restoration in terms of environmental indicators.

Key-words: environmental indicator, environmental assessment, forest ecology, forest restoration technology, interventionist practices

1. Introduction

Ecological restoration is the process of helping the recovery of an ecosystem that has been degraded, damaged, or destroyed [1]. Ecological restoration projects are usually designed aiming to accelerate and/or guide the path of restoration of an ecosystem to a close approximation of its condition prior to disturbance [2]. Several techniques and models have been developed to establish specific or general features and/or routes of ecosystem patterns and/or processes aiming towards restoration [3, 4]. Restoration techniques vary from passive, where the only actions taken are to eliminate the negative impact drivers, to highly interventionist, where several modifications are made to accelerate environmental recovery [5, 6].

Nucleation restoration techniques, for example, embrace activities that result in small units of vegetation established within the degraded area. Compared to plantation techniques, they result in lower cover but more diverse communities [7]. Some activities that fall under this category are the use of trees as perches, construction of artificial shelters for animals, planting of herbaceous shrub areas, seed and soil bank transposition, seed rain, planting of native trees in patches, or establishment of ecological stepping-stones [6, 8].

Although such techniques are used for the restoration of degraded environments, cases of ecological restoration in eucalyptus regions have not been extensively studied [9]. In many regions, including Brazil, eucalyptus forests have long been used for the cultivation of commercial trees [10, 11]. Eucalyptus plantations are important for the production of wood and other forest-based raw materials, which reduces dependence on remaining natural forests.

Nonetheless, the implementation of tree plantations has many negative environmental consequences such as the use of non-native species, reduced biodiversity [12], heavy use of soil amendments, and the use of heavy machinery for harvesting. Tree plantations reduce ecological health compared to natural forests. After tree harvest when the management of such areas changes from production to conservation, ecological restoration techniques may be preferred rather than "doing nothing" to more rapidly return to of the environmental conditions found in adjacent natural forests [13].

Most of the changes in soil properties in response to disturbance and reclamation are dependent on the reestablishment and development of the plant community [14]. According to the level of degradation and distance from healthy forested fragments, degraded areas might respond differently depending on the application of different restoration techniques. In forest plantations, the soils and vegetation usually differs from their natural conditions [13, 15]. Currently, we do not completely understand how these environmental features are modified after the application of ecosystem restoration techniques.

Evaluating ecosystem responses using environmental indicators such as vegetation structure, plant diversity, and soil quality is common in restoration projects [16, 17]. Some of the environmental indicators described ahead were used to compare the effect of different restoration techniques on areas previously planted for eucalyptus cultivation.

Considering the hypotheses that (1) although restoration projects have similar goals (e.g., recovering ecosystem integrity, health, and the potential for long-term sustainability), the use of different restoration techniques will generate differing environmental outcomes, and (2) after six years restoration management the three restored areas present statistically similar environmental indicators compared with an adjacent, pristine forest; in this study we aimed evaluating the effectiveness of each interventionist technique in terms of phytosociological and edaphic attributes.

2. Study site

2.1. Environmental features

The farm that encompasses our study sites lies in the Bofete Municipality, central region of the São Paulo State in southeastern Brazil. The geographical coordinates are: 23°03′05″ South latitude and 48°09′57″ West longitude (Fig. 1). The annual average temperature is 15.1°C (minimum 10.6°C and maximum 18.9°C). The average annual rainfall is 1,491 mm [18]. Relief is mainly composed of smooth rolling hills. The original vegetation is a mosaic formed by fragments of Semidecidual portions of Atlantic rain forest and portions of Brazilian savanna. The Atlantic forest that occurs in the countryside of the São Paulo State is a vegetation formation that encompasses semideciduous species in the genera *Cedrela*, *Parapiptadenia, Cariniana*, *Copaifera, Peltophorum, Astronium*, *Handroanthus*, *Balfourodendron.* The Brazilian savanna is very similar to the semidecidual Atlantic Forest, but the trees usually present a tortuous architecture of the trunk and branches. In the outer parts of the branches the tissue is formed by a thick layer of dead cells that protect the tree against fires, which are a common ecological component of this biome. Some examples of species present in the Brazilian savanna include the genera *Caryocar, Salvertia, Bowdichia, Dimorphandra* [19].

The central region of Sao Paulo is currently dominated by agricultural activities [15]. The bedrock material is essentially sandy medium- or fine-textured, lying over a part of the Guarani aquifer. As consequence, soils are predominantly sandy in texture. The dominant soil order is Alfisols, and the soil organic matter concentration is usually low [15].

2.2. Description of forest restoration techniques

The 650 hectares study farm belongs to an international corporation that produces cellulose from trees. The farm has two main goals: cultivation of commercial tree species for cellulose production, and environmental conservation.

In order to obtain the international certification (FSC® Certification Forest Stewardship Council– www.fsc.org), the farm must maintain a percentage of natural forest land cover. In June 2006, in order to increase the percentage of natural forest, the farm managers decided to restore some degraded areas. However, they did not know what was the most efficient technique to achieve their restoration goals. Hence, a set of new land use management actions were implemented with the aim to inform future restoration initiatives and establish a sustainable restoration trajectory on this farm and on other farms owned by the corporation. One of such actions was an experimental approach to restore three previous eucalyptus plantation areas.

Three stands of approximately one hectare each were set aside for the restoration study (Fig. 2). All of the stands had been used previously for planting *Corymbia citriodora* (Hill & Johnson), which is known as eucalyptus in Brazil. In 2006 all forest management activities (understory control, pesticide use, soil amendments) were stopped, and the restoration interventions, two of them considered nucleation techniques, began.

In the first stand, all eucalyptus trees were removed leaving it completely cleared. Following, approximately 114 kilograms (dry weight) of forest litter from adjacent natural forest patches were uniformly spread on the soil surface. The transpositions were executed in the dry season and no more interventions were made. This treatment was named “transposition”.

In the second stand, eucalyptus trees were kept in the plot. The trees had an approximate height of 18 m and were spaced 3 x 2 m apart. There were no additions of any kind of allochthonous material (e.g. forest litter). However, the trees in this stand were chemically killed by inserting herbicide into the root system. Although the trees were dead, they were kept standing to serve as perches for birds, bats and other seed disperser animals. Here we named this treatment “perch”.

In the third eucalyptus stand, the trees were kept alive in the plot. The eucalyptus trees were planted in 2001, but management activities stopped and restoration started in 2006. The trees (and stand) were five years old. In 2006, all weed control, soil amendment application, pruning, and thinning management activities ended. The understory in the stand was kept alive and human interventions ceased. We named this treatment “abandonment”.

Successful ecosystem restoration following disturbance is usually assessed according to the degree of similarity between the restored site and a relatively undisturbed reference site [14]. Hence, we considered a fourth area as a control or “reference” area for the study. This area is located in the same property and consists of a native forest fragment that has been used for environmental conservation and environmental education [20].

Data collection was carried out in the four areas. The information collected in the “reference” area was used to compare the environmental status and performance of the three restoration treatments.

2.3. *Collection of floristic and phytosociological data*

In 2013 three square-shaped parcels (10 x 10 m) were created in each research stand. In each parcel, the diameter at breast height (DBH) of all trees ≥ 1 cm in diameter was measured at 1.30 m from the ground. The DBH was measured using a caliper. For large trees a tape was used to measure the perimeter and subsequently estimating their diameter. In the parcels of the stand perches, all dead trees of eucalyptus and also all live trees that meet the criteria of DBH were catalogued [21].

Afterward, we identified the trees taxonomically (reaching the species level when possible), using appropriate taxonomic keys and consulting experts to avoid misclassifications. We also checked the phytosanitary status of the trees, i.e., evidence of possible diseases. Dead trees were also measured and identified taxonomically when possible.

Once the database was formed, we calculated the Shannon’s index of diversity, through the formula [22]:

$$\overline{\mathrm{H}} = -\sum \mathrm{P_i} * \log \mathrm{P_i} \qquad (1)$$

Where: $\overline{\mathrm{H}}$ is the Shannon’s index; $\mathrm{P_i}$ is the proportion of the individuals belong to species “i”.

We also calculated the Jaccard’s index of similarity among the stands, using the equation [9, 22, 23]:

$$J(A, B, ...) = \frac{|A \cap B|}{|A \cup B|} \qquad (2)$$

Where: J (A,B,…) is the amount of the intersection divided by the amount of the union of the sample sets.

For each individual tree, dead or alive, the above ground biomass was estimated using the equation proposed by Arevalo et al. [24]:

$$AB = 0.1184 \times DBH^{2.53} \tag{3}$$

Where: AB is the amount of above ground biomass, dead or alive, in kg, DBH is diameter at breast height; 0.1184 and 2.53 are constants.

The database was subdivided into groups according to some criteria. First, the tree species were classified according to three regeneration phases (modified from Rolim & Chiarello [25]): Pioneer (very fast growth rates, light demanding, gap colonizer, seed bank, short life-span); Secondary (medium growth rates, shade-tolerant, seedling bank, medium life-span) and Climax (slow growth rates, shade-tolerant, seedling bank, large seed, long life-span). After, the dispersion guilds were proposed according the main agents of seed dispersal (wind and water) or biotic (animals and the plant itself) [26]. The third criterion was to identify the trees by origin, distinguishing native from non-native species.

2.4. Collection of soil samples and data

In each stand, twelve undisturbed soil samples were collected using a volumetric ring [27]. These were packed and transferred to the laboratory for analysis. Each sample was dried and divided by the volume of soil to determine the dry density.

In addition, five points were randomly selected and a of 500 g soil sample was taken using a steel hoe. In the laboratory, each sample was crushed and passed through a 2.00 mm sieve mesh.

The sieved material was used to determine physical and chemical properties of the soil (Table 1). Samples whose base saturation value was lower than 50% were classified as dystrophic, and samples whose value was equal or higher than 50% were considered eutrophic [28].

2.5. Statistical analyses

Each of the four stands was considered a treatment unit [22]. Hence, the Kruskal Wallis test was applied to determine the phytosociology and soils differences among sites. Spearman's non parametric correlation tests were also carried out among some soil chemical attributes from each stand. Cluster analyses (Euclidean distance and complete linkage) were conducted considering the phytosiciological and soil data separately, as well as togetherto assess the overall similarity among the stands. In all tests an *apriori* significance level of α=5% was set.

3. Results

3.1. Floristic and phytosociology data

A total of 435 individual trees and 52 species were recorded in the twelve studied parcels. The reference area presented the highest number of trees, which was significantly different from the transposition and perch stands (Table 2). For all stands, most of the trees had diameters at breast height smaller than 4.77 cm. The abandonment stand had the highest mean value for tree height, while the trees from "transposition" had the lowest. Above ground biomass was lowest in the transposition stand.

Overall, the mean Shannon index (H') was 0.86 for all sites combined. Separately, we observed that the abandonment stand had the highest H' value (1.17) and was more diverse than the reference area (H'=1.05). On the other hand, the transposition and perch stands had H' values of 0.65 and 0.58, respectively, which were lower than the overall mean (Table 3).

Considering all the stands, 80% from the total trees species use biotic seed dispersal mechanisms. The Myrtaceae was the predominant botanic family and was represented by eight species, while the Fabaceae family followed with four species. All other tree families were represented by three or less species.

The dissimilarity which occurred among the stands is evidenced by the Jaccard's (J) index values (Table 4). The experimental stand that presented the highest J index value in relation to the reference stand was abandonment. The transposition and perch stands had low J values relative to the reference stand.

3.2. Soil data

The soils at the farm have a sandy texture and are dominated by the fine sand fraction. The values of dry density ranged from 0.85 to 1.76 g/cm^3. The pH values indicate that the soils are acid and have low cation exchange capacity. Due the low base saturation, they are predominantly dystrophic (Table 5).

Mean values of dry density were similar and not significantly different across stands (Table 6). Soils from the reference site were the most acid, and along with the soils from transposition site had the highest mean values of soil organic matter concentration. However, none of the studied sites (abandonment, transposition or perch) had SOM concentrations that were significantly different than those in the reference area.

While soils from the reference area had the highest P values (not significantly different however), they also had the lowest K and Ca values. The overall correlation among Ca and Al was inverse and highly significant (r^2=0.83, $P<0.0001$). For the K values no significant differences were noted, and for Ca values a significant difference was found between the reference and abandonment sites. For Mg, the reference area had mean values lower than the other stands (less than a half), and these were significantly different than the transposition and abandonment stands. In the reference stand, we also observed considerably higher Al concentration values, as well as the highest value of cation exchange capacity. Samples taken from both the reference area and perch stands were classified as dystrophic. On the other hand, most of the samples taken in the other two stands were classified as eutrophic.

The correlation between pH and base saturation values was $r^2 = 0.91$ (significant $P < 0.0001$), while the correlation between saturation of Al and base saturation was inverse and also highly significant $r^2 = 0.91$ (significant $P < 0.0001$).

3.3. *Integrated analyzes*

The outcomes of cluster analyses conducted using floristic data, soils data, and both data sets show that stands were significantly different than the reference area (Fig. 3). Abandonment and transposition presented significant similarity for all combinations of datasets. When the floristic and phytosociology data were analyzed separately, perches presented the worse performance. When the soil attribute data were analyzed separately, the perches stand was the most similar with the reference area. When all data were analyzed together, perches also had greater similarity with the reference area than the others stands.

4. Discussion

4.1. *Floristic and phytosociology data*

When data from each restoration stand were analyzed, some strengths and weaknesses were observed in each technique. The transposition stand presented low biodiversity index. It is important to remember that the transpositions of the forest littler were conducted in the dry season, which is when the wind favors seed dispersal and establishment [29]. This technique should have an indirect effect inhibiting herbaceous vegetation growth given that it acts a soil cover. This fact was clearly reported by Rodrigues et al. [30], who verified that in the plots where the forest litter was present, the native herbaceous vegetation was largely reduced.

In the transposition stand of our study, however, the parcels were completely covered by a non-native grass brachiaria (*Brachiaria decumbens*) that has a wide range of adaptation. The establishment of this invasive species was a critical element limiting the growth of new native plants. The grass causes the formation a mulch layer over the ground with allelopathic properties that inhibit the germination of seeds [31].

In order for the transposition treatment to be more effective, two complementary actions could be done: 1) efforts to avoid the brachiaria propagation are necessary. Although the employment of a specific chemical is considered a suitable technique [32] and some products could be effective, alternative techniques should be priority considered. For example, the cultivation of pumpkin, zucchini or other crops of economic importance that cover the ground surface [33], and 2) increasing the amount of forest litter to be delivered to the area to be restored. This is important because the raising and spread of brachiaria clearly harmed a crucial ecological function that was the emergence of new tree species and dramatically influenced in the local patterns of biodiversity.

In the case of the abandonment stand, and taking into account that the area could serve as habitat to other species, planted forests are characterized by some constraints due to their more- or less-intensive management. For example, clear cutting and comparatively short rotations favor the occurrence of ruderal plant species (i.e., species able to survive on inhospitable and/or disturbed habitats), whereas some long-lived climax species may not be present [34]. This fact does not occur in the abandonment area due the ceasing of management actions [13].

For the perch stand, the goal of killing the trees and keep them standing (not removing them) was to use the dead trees to attract frugivorous birds that could disperse seeds through droppings. In parcels of this stand, the eucalyptus trees were disposed on line among them and uniformly distributed along the stand. We hypothesized that if such trees effectively played a role as perch, then around the perching tree a nucleus of advanced succession would be formed [35]. However, our data proves that this fact did not occur.

The perches stand presented the lowest performance in terms of plant biodiversity when compared to the reference area. This is evidence that proving that biodiversity restoration was not very effective through this technique, even considering the fact that this stand is located near natural forested areas. Hence this leads us to suppose that the environment formed with the perches was not suitable for species potentially disperser of seeds. The missing of something that could attract the birds, like fruits, probably influenced the low performance of the perches, because in field was observed most commonly the occurrence of bird species classified as predators instead of dispersals (K. R. Castelli, personal observation).

4.2. Soil data

In terms of physical attributes, dry density was very similar among the stands. Comparing our data with a study conducted by Mosca [15] in other adjacent regions of the studied farm and considering area planted with eucalyptus and pastured areas, soils that were still being cultivated with eucalyptus are denser than the ones evaluated in our study. According to Mosca [15], soils cultivated with eucalyptus had a mean value of 1.50 g/cm^3, and soils covered with grassy vegetation (pasture) had a dry density of 1.70 g/cm^3. Comparing such values with the ones presented in our study, we believe that the restoration techniques need to address soil compaction in order to return dry density to conditions similar to natural areas.

In general, our data indicates that at lower pH values there is higher soil dystrophy and Al concentrations. For all stands, Ca is the dominant exchangeable cation in the sum of bases. On the other hand, in both the reference and perch stands, the contribution of Al to the cationic exchange capacity was critical (67.2 and 61.7% respectively). The soils of all stands are acidic and high acidity is a stressor, limiting the germination of seeds and growth of many plants species [8, 36]. This might be a possible additional fact that explains of the low number of trees in the perches stand.

The fact of none of the managed sites had SOM concentrations that were significantly different when compared with soils from the reference area is an important finding because the SOM is frequently cited as a major indicator soil quality [37]. The two stands with highest SOM values were reference and transposition, but the accumulation of SOM probably occurred through differing mechanisms. In the dissertation by Castelli [21] the values of accumulated litter over the forest floor reported for these same stands were 14.1 t/ha for transposition and 22.9 t/ha for reference. In the transposition stand the litter is formed mainly by brachiaria grass (*Brachiaria* sp.) [21]. Although the deposition (litterfall) is not so intense, its the decomposition results in humus that persist in the soil and that can lead to high SOM values. In the reference area the forest litter is formed mainly by decomposing leaves and branches.

In contrast, the abandonment stand had the lowest SOM amount. Castelli [21] reported annual average amounts of accumulated forest litter of 20.3 t/ha. The litter in the abandonment stand is formed primarily by leaves, whose decomposition generates organic products (humus) of weak persistence in the soil. Consequently, although the accumulated amount of forest litter is high (probably due the high rate of litterfall), the SOM may be not large enough as reported here because the humus is highly decomposable (i.e., is highly capable of being mineralized). In perches we reported relatively low amount of litter accumulated over the soil (14.4 t/ha) and low amount of SOM as well.

4.3. Integrated assessment and proposal of a new model

No single stand presented indicators satisfactorily comparable to the reference area. For the perch stand, the dystrophic and highly acidic soils could have deter the germination of seeds that could possibly been delivered by wildlife. In addition, killing the trees was a not an effective strategy because the timber was not used commercially, and the bare branches were not attractive to birds and/or bats as habitat. Hence, keeping some live trees rather killing them would be a better restoration alternative [8].

From the transposition stand experience two conditions favored the establishment of brachiaria grass: (1) the open canopy and (2) the acid soils. The rapid colonization of the grass formed a dense mulch layer over the ground, which probably prevented the germination of seeds occasionally transferred from other places by wind or animals.

Overall, the abandonment stand presented the best outcomes. We confirm that this practice was the best form of management towards biodiversity restoration. This is regardless of the soil attributes [8, 13] and of the distance from a natural forest patch [38]. These findings are supported by the Jaccard's index results.

According to the meta-analysis conducted by Benayas et al. [39], the successful restoration projects tend to increase the provision of biodiversity and ecosystem services by 44 and 25%, respectively. Conversely, values of both remained lower in restored versus intact reference ecosystems [12]. This characterizes an environment with new processes and patterns with non proven capacity of self-perpetuation. Hence, new forms of interventions are demanded [3].

Although none of the techniques was satisfactory in terms of returning to the environmental conditions found in the reference area, we identified benefits from the application of each technique. Aiming to more effectively reestablish the main ecological functions considered critical for the sustainability of a forest ecosystem, a novel and integrated model is here proposed.

- Stop forest management actions that clear the forest's or plantation understory is recommended to let shrub vegetation grown during the initial restoration phase. It is expected that the close canopy by the live trees in the abandoned stand will prevent the colonization of invasive photophilic species, and instead promote ecosystem succession processes to take place.
- The periodic and selective killing of some eucalyptus trees is recommended. For instance, 10% of the trees should be killed yearly (the trees to be cut should be randomly chosen along the stand, rather than linearly or in groups or regions in the stands).
- The trees killed should be kept standing rather than removed. As the dead trees fall naturally, forest gap dynamics take place allowing the creation of micro-environments required for the establishment of different plant species, hence promoting ecosystem plant diversity. Further, removing trees is a work that usually causes a series of environmental impacts in the forest. If the trees are to be removed for commercial purposes, then we suggest follow basic principles of best management practices in forestry [32]. This activity should be developed in order to minimize the disturbances to the forest floor and mineral soil. Under dry ground conditions, directional felling should be carefully planned and removal of trees with mechanical equipment may be utilized [32].

This guidance is especially important for our study area because the corporation aims to remove the trees as well as restore the areas to the ecological standards and values of the original forest.

5. Conclusions

After six years of the implementation of different intervention activities we conclude that, none of the techniques reached satisfactory results. However, considering the positive aspects observed in each stand and also some of the problems associated with them (for example, invasive plant species, unsuccessful use of perches by birds), we conclude that the integration of different aspects by each technique could reach the desirable ecological results.

Considering the specificities of each technique of restoration, we state that the integrated use of a set of management practices, constituted by the (a) abandonment of the area and (b) following a selective killing and posterior removal of the eucalyptus trees, is the most suitable model to provide fast and effective restoration in terms of environmental indicators. This model can be used in several other areas in the Brazilian territory or elsewhere. We emphasize that this proposal is economically feasible and perfectly acceptable by tree corporations that provide certifications of quality.

Acknowledgements

To International Eucatex Corporation, by allowing the development of the project. The Instituto de Pesquisas Tecnológicas do Estado de São Paulo (IPT) and Coordenação de Aperfeiçoamento de Pessoal de Ensino Superior (CAPES) for scholarships provided for students. The IPT also provided laboratorial structure for some analyses of soil physical attributes.

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Table 1. Description of the methods employed to quantify each soil property

Property	Brief description
Amounts of sand, silt and clay	Through sieving method for sands and pipette or sedimentation for silt and clay, using sodium hydroxide as dispersant agent.
pH	After pass trough a 2.00 mm sieve, we took 20 g of the fraction with grains smaller than 2.00mm and gently mixed with 50 ml of distilled or deionized water in a glass beaker. Hence, the solution was homogenized using a glass rod and it was remained untouched by 30 minutes. We used a multi-parameter probe, Oakton model PCS Test 35, previously calibrated for pH quantification.
Soil organic matter	Using the potassium dichromate (wet digestion), with titration with ferrous ammonium sulfate 0.05 M. After, the result was multiplied by 1.78, meaning the coefficient of transformation from grams of carbon into grams of soil organic matter
Phosphorus (P) mg/dm^3 Exchangeable potassium (K) - mmolc/dm^3 Exchangeable sodium (Na) (mmolc/dm^3)	Using the Mehlich extractant solution. After the mixing with reagents and filtration, the solution was submitted for reading in a spectrophotometer, calibrated in wavelength of 600 nm and after applying the result in an equation. For K and Na the solution was submitted to a flame photometer.
Exchangeable magnesium (Mg) (mmolc/dm^3) Exchangeable calcium (Ca) mmolc/dm^3 Aluminum (Al^{3+}) (mmolc/dm^3)	The Ca and Mg are extracted together with the Al by 1M KCl. First, a fraction for the extract Al is titrated with NaOH in presence of bromothymol blue as indicator. In another fraction of the extract, the titration reveals the Ca and Mg concentrations using ethylenediaminetetraacetic acid (EDTA) complexometry, using as indicator eriochrome black-T. A third aliquot is taken for the determination of Ca EDTA complexometry and calcon carbonic acid as indicator.

H mmolc/dm^3	Using a solution of calcium acetate, and the titrating with an alkalimetric solution
Total Exchangeable Bases (T.E.B.) mmolc/dm^3	Using the equation: T.E.B. = Ca + Mg + K + Na
Cationic exchange capacity (C.E.C.) mmolc/dm^3	Using the equation: C.E.C. = T.E.B. + H + Al^{3+}
Saturation of bases –BS (%)	Using the equation: BS = (T.E.B. / C.E.C.) * 100

Table 2. Phytosociological attributes for each management site

Variables	Reference	Abandonment	Perch	Transposition
Total number of trees considering all plots (total area = 300m^2)	184b	156a,b	45a	50a
Number of trees with diameter at breast high > 4.77 cm considering all plots (total area = 300m^2)	45b	68b	17a,b	2a
Predicted number of individuals diameter at breast high > 4.77 cm per hectare (*)	1500 Not classified	2267 Suitable	567 Minimum	67 Critical
Mean diameter (cm)	5.7c	5.4b	6.1b	2.7a
Height (m)	4.7c	5.7d	3.6a,b	2.4a
Biomass (kg)	189.7c	26.1b	63.0b	5.1a

(*) According to SMA (2014): five years after the restoring actions, if in the restored area the number of trees with diameter at breast high < 4.77 cm per hectare is < 200 it is considered critical, meaning that the expected minimal values were not reached and new interventions are necessary to be made in the area. When the number ranges from 200 to 500, it is considered minimum, meaning that the values accomplish the minimal exigencies, however further actions are necessary to be done in order to does not hazard the future results. When the number is larger than 500 trees per hectare, it is considered suitable, meaning that the expected results were successfully obtained accordingly the time of restoration.

Table 3. Ecological descriptors of plant biodiversity. For the variable of the amount of species in each 100 m², identical letters means non significant difference according to Kruskal Wallis test (*P* = *5%*)

Variables		Reference	Abandonment	Perch	Transposition
Total number of identified species considering all parcels of each stand		30	29	7	8
Mean (left) and coefficient of variation (right, in %) of the number of species per 100 m²		15b,c 29.1	16c 25.8	5a 10.8	6a,b 27.0
Shannon Index		1.05	1.17	0.58	0.65
Percentage of species according to seed dispersion	Biotic	90	80	57	87
	Abiotic	10	20	43	13
Percentage of tree species according to ecological group	Pioneer	31	33	86	38
	Secondary	62	67	14	62
	Climax	7	0	0	0
Percentage of indigenous tree species		100	95	86	100

Table 4. Jaccard's similarity index (J) for all studied stands

Combination	T x P	T x R	T x A	P x R	P x A	R x A	RxTxA	TxPxR	TxPxA	PxRxA	PxRxTxA
Value of J	0.25	0.06	0.09	0.06	0.17	0.63	0.02	0.02	0.06	0.04	0.02

Stands: A – abandonment; P – perch; R – reference; T – transposition

Table 5. Descriptive statistic for data of soil attributes analyzed in the stands

Soil attribute		Min	Max	Total range	Median	1st Quartile	3rd Quartile	Average	CV (%)
Dry density (g/dm^3)		0.85	1.76	0.91	1.26	1.12	1.32	1.23	15.2
Sand	Coarse (g/kg)	10.0	40.0	30.0	30.0	17.5	40.0	28.0	54.5
	Medium (g/kg)	240.0	270.0	30.0	250.0	240.0	262.5	253.0	5.9
	Fine (g/kg)	600.0	680.0	80.0	650.0	637.5	657.5	645.0	5.1
	Total (g/kg)	880.0	960.0	80.0	930.0	917.5	937.5	925.0	3.6
Silt (g/kg)		20.0	40.0	60.0	30.0	27.5	32.5	30.0	27.2
Clay (g/kg)		20.0	90.0	79.0	35.0	27.5	52.5	45.0	69.1
Soil Organic Matter (g/dm^3)		11.0	33.0	22.0	18.0	15.0	21.5	18.8	29.9
pH		3.8	5.3	1.5	4.4	4.1	5.0	4.5	11.9
P (mg/dm^3)		4.0	8.0	4.0	5.5	4.0	7.0	5.8	26.4
Exchangeable K (mmolc/dm^3)		0.7	2.5	1.8	1.5	0.9	1.8	1.4	40.0
Exchangeable Ca (mmolc/dm^3)		3.0	16.0	13.0	7.0	5.0	10.0	7.9	47.0
Mg (mmolc/dm^3)		1.0	6.0	5.0	4.0	2.0	5.0	3.6	43.3
Na (mmolc/dm^3)		0.0	0.3	0.3	0.1	0.0	0.1	0.1	87.0
Al^3 (mmolc/dm^3)		0.0	23.0	23.0	7.5	1.0	17.3	8.9	89.1
Saturation of aluminum (%)		0.0	75.0	75.0	37.7	5.5	68.0	37.2	77.9

Total Exchangeable Bases (mmolc/dm³)	4.8	22.9	18.1	12.0	8.7	17.3	12.9	41.2
CEC (mmolc/dm³)	26.5	69.1	42.6	38.9	34.7	55.2	44.0	28.6
Base Saturation (%)	10.9	60.7	49.8	31.9	15.1	51.0	33.3	55.4

Table 6. Mean and coefficient of variation (CV, in %) for the soil attributes according to the different sites. For dry density, N=12, for granulometry N=1, for all other attributes, N=5 in each site. For each variable, same letter among the treatments means no significant relation according to Kruskal Wallis test (P=5%)

Soil attributes		Reference		Abandonment		Perch		Transposition	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
Sand	Coarse (g/kg)	40.0	--	10.0	--	40.0	--	20.0	--
	Medium (g/kg)	240.0	--	270.0	--	240.0	--	260.0	--
	Fine (g/kg)	650.0	--	680.0	--	600.0	--	650.0	--
	Total (g/kg)	930.0	--	960.0	--	880.0	--	930.0	--
Silt (g/kg)		40.0	--	20.0	--	30.0	--	30.0	--
Clay (g/kg)		30.0	--	20.0	--	90.0	--	40.0	--
Dry density (g/cm³)		1.23a	11.3	1.24a	9.4	1.23a	19.7	1.20a	20.3
Soil Organic Matter (g/dm³)		22.0a,b	27.6	14.0a	14.3	16.4a,b	9.2	22.8b	26.9
pH		3.9a	3.8	4.9b	5.5	4.1a,b	3.0	5.0b	4.6
P (mg/dm³)		6.4a	28.4	5.6a	32.4	4.8a	17.4	6.2a	21.0
Exchangeable K (mmolc/dm³)		1.0a	28.5	1.5a	27.0	1.1a	51.4	1.8a	34.0
Exchangeable Ca (mmolc/dm³)		4.8a	30.9	11.2b	32.4	5.4a,b	24.8	10.2a,b	28.1
Mg (mmolc/dm³)		1.6a	34.2	4.6b	24.8	3.6a,b	31.7	4.4b	25.9

Na (mmolc/dm³)	0.1a	63.9	0.1a	91.3	0.1a	0.0	0.0a	223.6
Al³ (mmolc/dm³)	15.4b	23.7	1.4a	81.4	16.4b	32.4	2.2a,b	81.3
Saturation of aluminum (%)	67.0b	12.7	8.5a	93.3	60.5b	20.9	12.8a	91.8
Total Exch. Bases (mmolc/dm³)	7.6a	30.4	17.4b	27.8	10.2a,b	23.8	16.4b	23.6
C.E.C. (mmolc/dm³)	57.0b	19.6	32.4a	15.3	51.8a,b	11.3	34.8a	7.3
Saturation of Bases (%)	13.3a	24.6	53.0b	14.0	20.1a,b	30.6	46.8b	19.1
Percentage of samples classified as dystrophic (Sat of Bas < 50%)	100	--	20	--	100	--	40	--
Percentage of samples classified as eutrophic (Sat of Bas ≥ 50%)	0	--	80	--	0	--	60	--

Figures' Captions.

Figure. 1 Location of the studied stands.

Figure. 1 Farm map, with location of the stands. Transposition (red), Perch (blue), Abandonment (black) and reference (orange). Below the images coordinates of the stands (UTM, 22K zone, SAD69 System).

Figure 3. Dendrograms depicting the combination of the stands. In all figures, the values in the vertical axis mean the percentage of dissimilarity. Upper: Floristic and phytosociology. Middle: data of soils attributes. Bottom: Floristic and phytosociology and soil attributes. In all figures, dashed lines is the limiting value to be considered significant or not (higher values are significant).

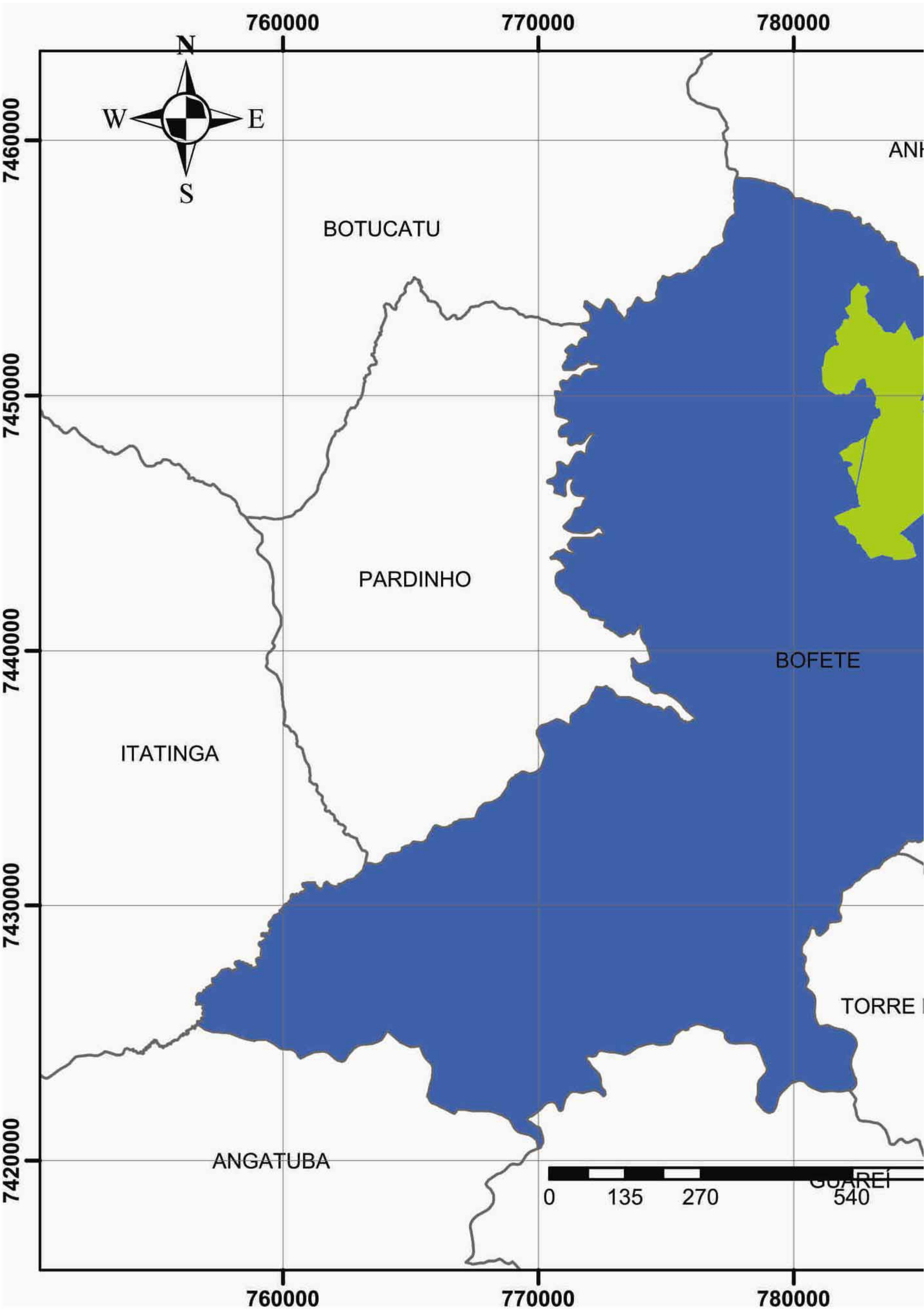
Appendix I. List of species found in the studied area, their respective ecological group and group of syndrome of seed dispersion. Acronyms: stand where it was found: *A* – abandonment, *R* – reference, *T* – transposition, *P* – perches. Ecological groups: *P* – pioneer, *NC* – not classified, *ES* – early secondary, *LS* – late secondary, *C* – climax. Agents of dispersal: *A* – abiotic, *B* – biotic. Or. (origin): *N* – native, *E* – exotic.

Family	Scientific denomination	Stand were it was found				Ecological group	Agents of dispersal	Or.
		A	R	T	P			
Anacardiaceae	*Tapirira guianensis Aubl.*	•	•		•	P	B	N
Annonaceae	*Guatteria australis A.St.-Hil.*	•	•			ES	B	N
Apocynaceae	*Tabernaemontana catharinensis A.DC.*	•		•	•	P	B	N
Arecaceae	*Euterpe edulis Mart.*		•			C	B	N
Arecaceae	*Syagrus romanzuffiana (Cham.) Glassman*			•		ES	B	N
Asteraceae	*Gochnatia polymorpha Less*			•	•	P	A	N
Asteraceae	*Vernonia diffusa less*				•	P	A	N
Burseraceae	*Protium heptaphyllum (Aubl.) Marchand*	•	•			ES	B	N
Cannabaceae	*Celtis fluminensis Caurata*			•		LS	B	N
Celastraceae	*Maytenus evonymoides Reissek*		•			LS	B	N
Ebenaceae	*Diospyros inconstans Jacq.*	•				ES	B	N
Euphorbiaceae	*Alchornea glandulosa Poepp. & Endl.*		•			ES	B	N
Euphorbiaceae	*Alchornea triplinervia (Spreng.) Müll.Arg.*		•			ES	B	N
Euphorbiaceae	*Croton floribundus Spreng.*		•			P	A	N
Fabaceae	*Machaerium hirtum (Vell.) Stellfeld*	•				P	B	N
Fabaceae	*Andira fraxinifolia Benth.*		•			P	B	N
Fabaceae	*Dalbergia sp.*		•			ES	A	N
Lacistemataceae	*Lacistema hasslerianum Chodat*		•			C	B	N
Lauraceae	*Ocotea velutina (Nees) Rohwer*	•				LS	B	N
Lauraceae	*Endlicheria paniculata (Spreng.) J.F.Macbr.*		•			LS	B	N
Lauraceae	*Nectandra oppositifolia Nees*		•			LS	B	N
Lecythidaceae	*Cariniana estrellensis (Raddi) Kuntze*		•			P	B	N
Meliaceae	*Trichilia pallida Sw.*	•	•			ES	B	N

Myrtaceae	*Eucalyptus* sp.	•			•	P	A	E
Myrtaceae	*Eugenia florida DC.*	•		•		LS	B	N
Myrtaceae	*Eugenia francavilleana O.Berg*	•				NC	B	N
Myrtaceae	*Myrcia guianensis (Aubl.) DC.*	•				NC	B	N
Myrtaceae	*Campomanesia guazumifolia (Cambess.) O.Berg*	•			•	P	B	N
Myrtaceae	*Myrceugenia sp.*		•			SC	B	N
Myrtaceae	*Myrcia hebepetala DC.*		•			SC	B	N
Myrtaceae	*Myrcia splendens (Sw.) DC.*		•			SC	B	N
Myrtaceae	*Psidium guajava*			•		P	B	N
Nyctaginaceae	*Guapira hirsuta (Choisy) Lundell*		•			LS	B	N
Peraceae	*Pera glabrata (Schott) Poepp. ex Baill.*	•				ES	A	N
Piperaceae	*Piper arboreum Aubl.*	•	•	•		NC	B	N
Polygonaceae	*Triplaris americana L.*	•				P	A	N
Primulaceae	*Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.*		•			P	B	N
Rubiaceae	*Randia calycina Cham.*	•				LS	B	N

Appendix I. Continuation

Family	Scientific denomination	Stand were it was found				Ecological group	Agents of dispersal	Or.
		A	R	T	P			
Rubiaceae	*Palicourea marcgravii A.St.-Hil.*		•			LS	B	N
Salicaceae	*Casearia sylvestris Sw.*	•	•			P	B	N
Sapindaceae	*Matayba elaeagnoides Radlk.*	•	•			P	B	N
Sapindaceae	*Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl.*	•	•			LS	B	N
Sapindaceae	*Cupania vernalis Cambess.*	•	•			P	B	N
Siparunaceae	*Siparuna guianensis Aubl.*	•	•	•	•	ES	B	N
Solanaceae	*Solanum sp.*		•			P	B	N
Thymelaeaceae	*Daphnopsis fasciculata (Meisn.) Nevling*		•			NC	B	N
	Non identified (dead)	•	•					
Myrtaceae	*Myrcia guianensis (Aubl.) DC.*	•				NC	B	N
Rutaceae	*Citrus* X limon (L.) Osbeck	•				P	A	E
Sapindaceae	*Matayba elaeagnoides* Radlk.	•				P	B	N
Sapotaceae	*Chrysophyllum gonocarpum* (Mart. & Eichler ex Miq.) Engl.	•				LS	B	N
Siparunaceae	*Siparuna guianensis* Aubl.	•				ES	B	N
Meliaceae	*Trichilia pallida* Sw.	•				ES	B	N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Localization Map from Santa Terezinha Farm
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Botucatu
Conchas
Pardinho
Bofete
Itatinga
Porangaba
Torre de Pedra
Angatuba
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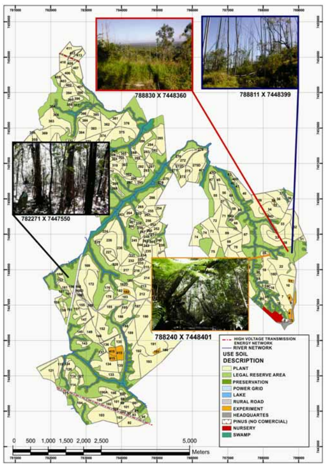
São Paulo
Bofete - 64,500.00ha
Sta. Terezinha - 3,920.00ha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HIGH VOLTAGE TRANSMISSION ENERGY NETWORK
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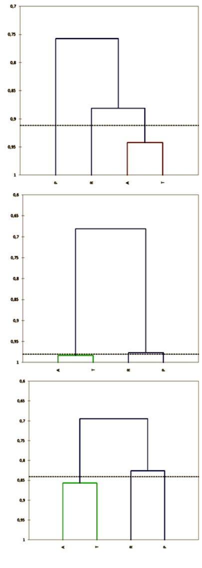
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