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Mimosa scabrella BENTH. (FABACEAE) ENHANCES THE RESTORATION IN COAL MINING AREAS IN THE ATLANTIC RAINFOREST

Keywords:
Biodiversity
Atlantic Rainforest
Floristic
Restoration ecology

ABSTRACT: A Pilot Reclamation Project (PRP) was developed in 1982 by the Environmental Protection Agency of the State of Santa Catarina-Brazil, with the objective to evaluating the adaptation of woody species to a land degraded by coal mining. After a full topographic reconstitution of the landscape, addition of nutrient load and sowing of herbaceous species, the area was split into 12 plots in which seedlings of 12 tree species were planted: three native trees [*Bastardiopsis densiflora* (Hook. & Arn.) Hassl., *Mimosa scabrella* Benth., *Schizolobium parahyba* (Vell.) Blake] and nine exotic species [*Eucalyptus saligna* Sm., *E. viminalis* Labill., *E. citriodora* Hook., *Grevillea hilliana* F.Muell., *Hovenia dulcis* Thunb, *Melia azedarach* L., *Pinus elliottii* Engelm., *P. taeda* L., *Syzygium cumini* (L.) Skeels]. After 22 years, from the beginning of the PRP, the exotic species presented higher percentage of survival than native species; the plots which received either *B. densiflora* and *S. parahyba* or were covered only with herbaceous vegetation associated with solely a few shrubs. Conversely, the plots which received seedlings of *M. scabrella* displayed clear evidence of restoration in progress. The study conducted in plots that have received *M. scabrella* indicate an improvement of nutrient load (N, K, organic matter) in the substrate, a diversified composition of tree coverage (very similar to the nearby remnants of the Atlantic Rainforest) and other life forms, with prominent establishment of native trees with predominance of zoophilous and zoochorous species. Some characteristics of *M. scabrella* that could explain its outstanding capacity to enhance the restoration of the Atlantic Rainforest are also discussed along this paper.

Histórico:
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Mimosa scabrella BENTH. (FABACEAE) MELHORA A RESTAURAÇÃO EM ÁREAS DE MINERAÇÃO DE CARVÃO NA FLORESTA ATLÂNTICA

Palavras chave:
Biodiversidade
Floresta Atlântica
Florística
Restauração ecológica

RESUMO: Um Projeto Piloto de Recuperação (PPR) foi desenvolvido em 1982 pela Fundação do Meio Ambiente do Estado de Santa Catarina – Brasil, objetivando avaliar a adaptação de espécies arbóreas em áreas degradadas pela mineração de carvão. Após uma completa reconstituição topográfica da paisagem, além da carga de nutrientes e sementes de espécies herbáceas, a área foi dividida em 12 pontos onde foram plantadas mudas de 12 espécies de árvores: três espécies nativas [*Bastardiopsis densiflora* (Hook. & Arn.) Hassl., *Mimosa scabrella* Benth., *Schizolobium parahyba* (Vell.) Blake)] e nove espécies exóticas [*Eucalyptus saligna* Sm., *E. viminalis* Labill., *C. citriodora* Hook., *Grevillea hilliana* F.Muell., *Hovenia dulcis* Thunb., *Melia azedarach* L., *Pinus elliottii* Engelm., *P. taeda* L., *Syzygium cumini* (L.) Skeels]. Após 22 anos, as espécies exóticas apresentaram elevada taxa de sobrevivência em comparação com as espécies nativas; os pontos que receberem *B. densiflora* e *S. parahyba* foram cobertos apenas com espécies herbáceas associadas com alguns arbustos. Reciprocamente, os pontos que receberam mudas de *M. scabrella* demonstraram claras evidências no processo de restauração. O estudo conduzido em pontos que receberam *M. scabrella* indicaram uma melhoria na carga de nutrientes (N, K, matéria orgânica) no substrato, uma composição diversificada da cobertura arbórea (muito similar com os remanescentes próximos de Floresta Atlântica) e outras formas de vida, com proeminente estabelecimento de árvores nativas com predominância de espécies zoofílicas e zoocóricas. Algumas características de *M. scabrella* que podem explicar esta excepcional capacidade de melhorar a restauração da Floresta Atlântica também são discutidas ao longo desse artigo.

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INTRODUCTION

Expansion of industrialization needs massive energy generation for which huge quantities of coal are extracted through mining, causing extensive landscape destruction (SINGH; SINGH, 2006). However, coal is an important source of energy that plays a vital role in powering the economies of many countries worldwide. Coal fulfills 30% of the energy demand for human activities throughout the world, and the demand for coal could grow more than 9 billion tons per year by 2019 (INTERNATIONAL ENERGY AGENCY, 2014; AHIRWAL et al., 2016).

Coal mining activities cause devastation of small areas, but the local environmental impact is much greater as the ecosystem suffers drastic alterations. Methodologies for the restoration of these areas have been subject to wide-ranging debate, namely the challenge between technical restoration and spontaneous succession. Such a debate paves the way to the assessment of the biological diversity, taking into account the idiosyncrasies of the different biotypes in affected areas (SALEK, 2012; PULSFORD et al., 2016).

Prach and Hobbs (2008), referring to restoration in disturbed areas and addressing the question about spontaneous succession versus technical restoration, related that technical restoration is required where both environmental stress and productivity are high and where clear abiotic thresholds are apparent; otherwise spontaneous succession is preferred. However, according to the authors, a priori requires an assessment of the level of environmental stress and productivity in a site to be restored.

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER, 2004; BRANCALION et al., 2015) and an effective way to use land resources economically and achieve harmony between people and land in mining area (ZHENQI et al., 2012). A successful restoration program attempts to accelerate the natural recovery processes to restore the soil fertility and to enhance the biological diversity (DOBSON et al., 1997; SINGH; SINGH, 2001).

Therefore, this paper aimed to describes the evolution of natural tree and other life forms establishment and soil conditions within Pilot Restoration Project (PRP) plots after 22 years of implementation, emphasizing the contributions from *Mimosa scabrella* Benth. to the process of restoration, as a facilitative species for area restoration. This sort of information provides technical contribution towards the selection of native species to be used in restoration projects aiming at the reconstitution of pristine Atlantic Rainforest for the sake of conservation or leisure.

MATERIAL AND METHODS

The study was conducted at the Municipality of Siderópolis (28° 34' 51" S and 49° 24' 23" W). The climate according to Köppen climate classification is Cfa (Alvares et al. 2013) and the vegetation formation characterized as Dense Ombrophilous Forest, according to IBGE (2012).

In 1982, the Foundation for Environmental Protection of the State of Santa Catarina (FATMA) developed a pioneer PRP aiming to assess the adaptation of native and exotic woody species in a land of 2.16ha that had received coal mining wastes for approximately 40 years. After the full topographic reconstitution of the landscape, the whole area was covered by a layer of 0.2m of constructed soil, and afterwards it received nutrient load and seeds by hydroseeding process using five herbaceous species: *Festuca arundinacea* Schreb, *Lolium multiflorum* L., *Melinis minutiflora* P.Beauv., *Paspalum notatum* Flüggé and *Trifolium repens* L. (SANTA CATARINA, 1982).

The land under study was split into three stands of 0.72ha (Block I, Block II and Block III), as depicted in Figure 1. Each stand was divided into 12 plots of 600m^2 (30m x 20m) in which seedlings of twelve tree species were randomly planted. Each plot received 25 seedlings of one single tree species and was tagged as A, B, C, …, M. This way, plots A, B and F received native tree species [*Bastardiopsis densiflora* (Hook. & Arn.) Hassl., *M. scabrella* and *Schizolobium parahyba* (Vell.) Blake] whereas the other plots received exotic species: *Eucalyptus saligna* Sm., *E. viminalis* Labill., *E. citriodora* Hook., *Grevillea hilliana* F.Muell., *Hovenia dulcis* Thunb., *Melia azedarach* L., *Pinus elliottii* Engelm., *P. taeda* L. and *Syzygium cumini* (L.) Skeels (SANTA CATARINA, 1982).

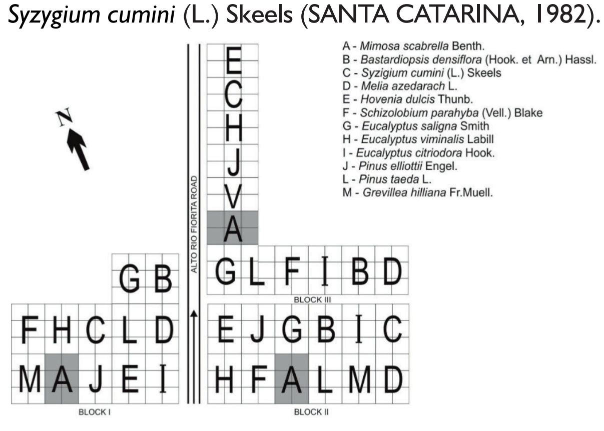

FIGURE 1 Distribution of planted tree species on the "Pilot Restoration Project" at Siderópolis County, Santa Catarina state, Brazil.

In that site, after opencast mining, there was loss of biodiversity, soil erosion, contamination of rivers, and other marked impacts caused by coal mining activities.

Soil analysis

In 2003, after 22 years of implementation, three samples of soil were taken from a depth of 0.2m and homogenized in a pile, producing a single sample that was considered as representative of the cluster. Chemical analysis of the substrate was carried out by the Company for Integrated Development of Agriculture of the State of Santa Catarina (CIDASC), following standard methods (TEDESCO et al., 1995) adopted by an official network of soil laboratories of the South of Brazil (ROLAS). According to those methods, analytical results are expressed in terms of soil volume, such as $mg{\cdot}dm^{-3}$ or $cm_c{\cdot}dm^{-3}$ (centimol-charge per dm^3), instead of soil mass ($mg{\cdot}kg^{-1}$ or $cmc{\cdot}kg^{-1}$). Standard methods used by ROLAS to carry out chemical analysis of soils are described elsewhere (SANTOS et al., 2008). Chemical composition of the substrate carried out in 2003 was compared to another one performed in 1982 by PRP, just after site restoration, at the same depth (0.2m). The results were also compared with others yielded by similar analysis carried out in a nearby forest remnant (SANTOS, 2003) and in overburden piles (SANTOS et al., 2008).

Vegetation analysis

To study floristic diversity and spontaneous succession, in 2003, a detailed floristic inventory was undertaken including different life forms (trees, shrubs, herbs and vines). Pollination and seed dispersal modes (VAN DER PIJL, 1982; FAEGRI; VAN DER PIJL, 1979) and successional category were assigned based on species ecology and morphology of their diasporas and complemented by literature data (Reitz 1965-1989; Reis 1989-2011). Species were identified by using the existing reference collection of the Herbarium Padre Dr. Raulino Reitz (CRI) and literature (REITZ 1965-1989; REIS 1989-2011).

To determine the structure of tree species, measurement of height (h) and diameter (d) of all individuals with Diameter at Breast Height (DBH) higher than 5cm (DBH ≥ 5cm) was accomplished and the following parameters were calculated from the results: density, frequency, dominance and importance value (IV), according to methodology proposed by Mueller-Dombois and Ellenberg (2002) and diversity index (Shannon index - H´) (MAGURRAN, 2003). After identification, the species were grouped in families according to Angiosperm Phylogeny Group (APG IV, 2016) or ferns (SMITH et al., 2006). All collected reproductive material was stored in the herbarium CRI. Similarity analysis with regional vegetation was performed using the Jaccard index as maintained by Legendre and Legendre (2012).

To approach natural tree establishment, all individuals with DBH < 5cm from any tree species were considered "regeneration compartment" which was divided into Class 1 – 0.2m > h ≤1.0m, Class 2 – 1.0m > h ≤3.0m and Class 3 – h > 3.0m. The spontaneous succession estimate (DR_{it} [1], FR_{it} [2] and RNC_{it} [3]) of each species of any regeneration compartment was obtained by the following expressions (FINOL, 1971; VOLPATO, 1994; KLEIN et al., 2009). Where: RNC_{it} = Estimate of natural regeneration of species i which belongs to a specific class t (%); DA_{it} = Absolute density of species i which belongs to a specific class t; DR_{it} = Relative density of species i which belongs to a specific height class t (%); FA_{it} = Absolute frequency of species i that belong to a specific height class t; FR_{it} = Relative frequency of species i that belong to a specific height class t (%); i = Subscript related to species; t = Subscript related to classes.

$$DR_{it} = \frac{DA_{it}}{\sum_{t=1}^{3} DA_{it}} \quad [1]$$

$$FR_{it} = \frac{FA_{it}}{\sum_{t=1}^{3} FA_{it}} \quad [2]$$

$$RNC_{it} = \frac{DR_{it} + FR_{it}}{2} \quad [3]$$

Following the approach of natural tree establishment, a single species, which belongs to a particular height class, was compared to all other existing species within the whole tree community. In agreement with this procedure, it was obtained for each species i, a parameter called Index of Natural Regeneration of the populations (RNT_i) that is the sum of RNC_{it} determined for each height class, as follows [4]. The higher the magnitude of RNT_i, the higher the regeneration success of species i within the whole community.

$$RNT_i = \sum_{t=1}^{3} RNC_{it} \quad [4]$$

RESULTS

During the general visual observation of the plots of the former "Pioneer Restoration Project" (PRP), it was registered that most plots, after 22 years of implementation, were still covered only with herbaceous vegetation associated with few shrub individuals. In those plots, the herb species were almost the same as those that had been planted at the beginning of the project: *L. multiflorum*, *M. minutiflora*, *P. notatum*, *F. arundinacea* and *T. repens*. Tree species, however, were found only in the three plots where *M. scabrella* had been planted. This way, those *M. scabrella* plots were the subject of detailed soil and floristic analysis. The results are presented as follows.

Soil

The analysis of the chemical composition of the substrate of *M. scabrella* plots carried out in 2003 depicts no difference among the three *M. scabrella* plots (Tukey`s test at 5% probability). On the other hand, as displayed in Table 1, in comparison with the chemical composition of the substrate registered in 1982, there was a remarkable improvement in nutrient load (K, P and organic matter) after 22 years. In a general way, it was also detected better nutritional conditions for the *M. scabrella* plots than the soil from a nearby forest remnant.

TABLE 1 Soil chemical characterization of the Mimosa scabrella plots at the Pilot Restoration Project (PRP) versus nearby areas.

Soil characteristics	PRP		Forest remnant	
	1982	2003	2003	2003
pH	4.3	4.4± 0.4	4.3	3.9±0,4
Phosphorous ($mg \cdot dm^{-3}$)	2.3	6.5±1.3	2.5	3.0±1.1
Potassium ($mg \cdot dm^{-3}$)	94.1	200.7±54.0	85	98.0±16.0
Organic matter (%)	0.9	9.3±0.6	3.8	3.0±0.8
Aluminium ($cmolc \cdot dm^{-3}$)	6.2	1.9±0.1	5.5	5.4±0.3
Calcium + Magnesium ($cmolc \cdot dm^{-3}$)	4.7	9.8±4.5	2.2	2.0±0.3
Sodium ($mg \cdot dm^{-3}$)	-	19.3±4.5	13.0	11.6±2.7
H + Al ($cmolc \cdot dm^{-3}$)	-	10.5±3.6	13.2	17.5±2.1
pH - $CaCl_2$	-	4.1±0.5	3.8	3.6±0.6
Sum of bases ($cmolc \cdot dm^{-3}$)	-	10.4±4.6	2.5	1.5±0.3
ECC ($cmolc \cdot dm^{-3}$)	-	20.9±3.3	15.7	19.0±3.0
Saturation of bases (%)	-	49.3±20.2	15.3	7.9±3.9

Vegetation analysis

Results from floristic inventory carried out on the *M. scabrella* plots display 48 tree species (29 families), 33 shrub species (11 families), 21 herb species (seven families) and six vines (three families). No epiphytes were evidenced at those plots. Asteraceae is the most diverse family, including a great variety of life forms (Table 2). Regarding spontaneous succession, representatives of all successional categories were detected, with a predominance of pioneer and early secondary species among all life forms (Figure 2). With respect to pollination and seed dispersal strategies, as depicted in Figure 3, there is a major incidence of zoophilous and zoochorous species.

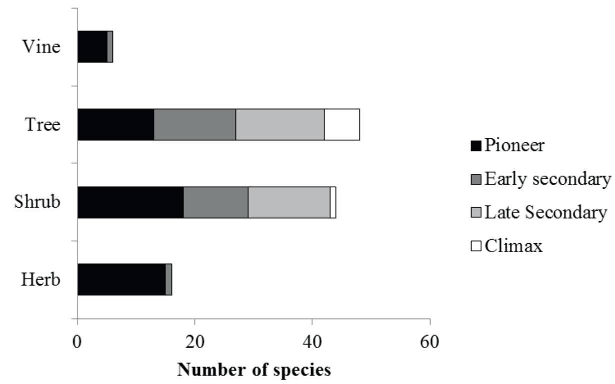

FIGURE 2 Successional categories among life forms observed at Mimosa scabrella plots of the "Pilot Restoration Project" at Siderópolis County, Santa Catarina State, Brazil.

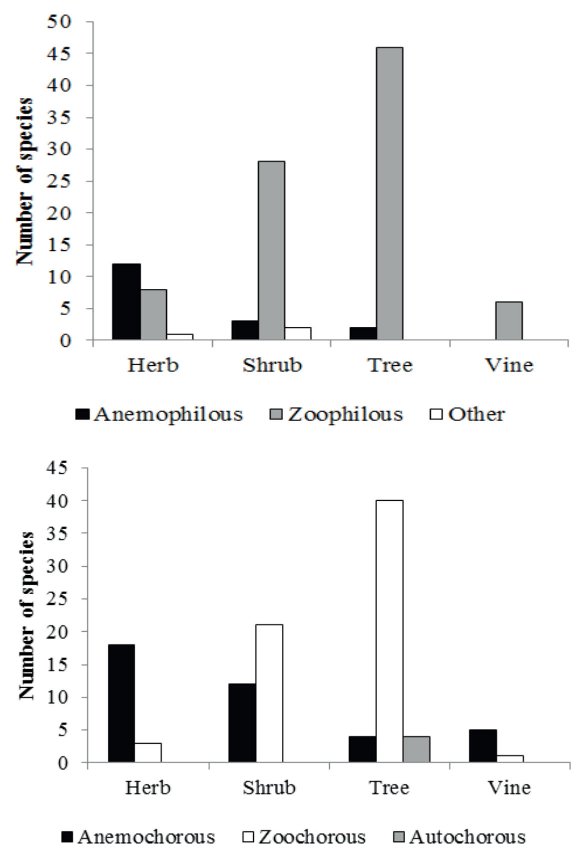

FIGURE 3 Pollination and dispersal strategies of all life forms observed at the "Pilot Restoration Project" at Siderópolis County, Santa Catarina State, Brazil.

TABLE 2 Plant species sampled at Mimosa scabrella plots of the "Pilot Restoration Project" followed by their respective successional groups (SG), pollination (PS), A = anemophilous; Z = zoophilous, and dispersal strategies (DS), An = anemochorous; Au = autochorous; Z = zoochorous.

Life form/Species	Botanical family	SG	PS	DS
Herbaceous terricolous				
Andropogon bicornis L.	Poaceae	Pioneer	A	An
A. leucostachyus Kunth	Poaceae	Pioneer	A	An
Axonopus cf. paranaensis Parodi	Poaceae	Pioneer	A	An
A. fissifolius (Raddi) Kuhlm.	Poaceae	Pioneer	A	An
Centella asiatica (L.) Urb.	Apiaceae	Pioneer	Z	An
Chaptalia nutans (L.) Pol.	Asteraceae	Pioneer	Z	An
Desmodium adscendens (Sw.) DC.	Fabaceae	Pioneer	Z	Z
Elionurus sp.	Poaceae	Pioneer	A	An
Erechtites valerianifolius (Wolf) DC.	Asteraceae	Pioneer	Z	An
Melinis minutiflora P.Beauv.	Poaceae	Pioneer	A	An
Paspalum conjugatum P.J.Bergius	Poaceae	Pioneer	A	An
P. urvillei Steud.	Poaceae	Pioneer	A	An
Rumohra adiantiformis (G.Forst.) Ching.	Dryopteridaceae	Pioneer	-	An
Schizachyrium gracilipes (Hack.) A.Camus	Poaceae	Pioneer	A	An
Steinchisma laxa (Sw.) Zuloaga	Poaceae	Pioneer	A	An
Coccocypselum cordifolium Nees & Mart.	Rubiaceae	Early secondary	Z	Z
C. lanceolatum (Ruiz & Pav.) Pers.	Rubiaceae	Early secondary	Z	Z
Ichnanthus pallens (Sw.) Munro ex Benth.	Poaceae	Early secondary	A	An
Liparis nervosa (Thumb.) Lindl.	Orchidaceae	Early secondary	Z	An
Pseudechinolaena polystachya (Kunth) Stapf	Poaceae	Early secondary	A	An
Sacoila lanceolata (Aubl.) Garay	Orchidaceae	Early secondary	Z	An
Shrubs				
Austroeupatorium inulaefolium (Kunth) R.M.King & H.Rob.	Asteraceae	Pioneer	Z	An
Baccharis spicata (Lam.) Baill.	Asteraceae	Pioneer	Z	An
Chromolaena laevigata (Lam.) R.M.King & H.Rob.	Asteraceae	Pioneer	Z	An
Eupatorium polystachyum DC.	Asteraceae	Pioneer	Z	An
E. serratum Spreng.	Asteraceae	Pioneer	Z	An
Heterocondylus alatus (Vell.) R.M.King & H.Rob.	Asteraceae	Pioneer	Z	An
Kaunia rufescens (Lund ex DC.) R.M.King & H.Rob.	Asteraceae	Pioneer	Z	An
Lantana camara L.	Verbenaceae	Pioneer	Z	Z
Rubus brasiliensis Mart.	Rosaceae	Pioneer	Z	Z
R. *imperialis* Cham. & Schltdl.	Rosaceae	Pioneer	Z	Z
R. *rosifolius* Sm.	Rosaceae	Pioneer	Z	Z
Senecio brasiliensis (Spreng.) Less.	Asteraceae	Pioneer	Z	An
Solanum cf. *johannae* Bitter	Solanaceae	Pioneer	Z	Z
S. lucidum Moric.	Solanaceae	Pioneer	Z	Z
S. pseudocapsicum L.	Solanaceae	Pioneer	Z	Z
S. variabile Mart.	Solanaceae	Pioneer	Z	Z
Tibouchina urvilleana (DC.) Cogn.	Melastomataceae	Pioneer	Z	An
Vernonanthura tweediana (Baker) H.Rob.	Asteraceae	Pioneer	Z	An
Blechnum brasiliense Desv.	Blechnaceae	Early secondary	-	An
Leandra australis (Cham.) Cogn.	Melastomataceae	Early secondary	Z	Z
L. regnellii (Triana) Cogn.	Melastomataceae	Early secondary	Z	Z
Maranta arundinacea L.	Marantaceae	Early secondary	Z	Z
Miconia sp.	Melastomataceae	Early secondary	Z	Z
M. petropolitana Cogn.	Melastomataceae	Early secondary	Z	Z
M. sellowiana Naudin	Melastomataceae	Early secondary	Z	Z
M. tristis Spring	Melastomataceae	Early secondary	Z	Z
Piper arboreum Aubl.	Piperaceae	Early secondary	A	Z
P. cernuum Vell.	Piperaceae	Early secondary	A	Z
P. gaudichaudianum Kunth.	Piperaceae	Early secondary	A	Z
Psychotria leiocarpa Cham. & Schltdl.	Rubiaceae	Late secondary	Z	Z
Thelypteris sp.	Thelypteridaceae	Late secondary	-	An
Mollinedia schottiana (Spreng.) Perkins	Monimiaceae	Climax	Z	Z
Psychotria suterella Müll.Arg.	Rubiaceae	Climax	Z	Z
Trees				
Cecropia glaziovii Snethl.	Urticaceae	Pioneer	Z	Z
Clethra scabra Pers.	Clethraceae	Pioneer	Z	Z
Miconia cabucu Hoehne	Melastomataceae	Pioneer	Z	Z
Mimosa scabrella Benth.	Fabaceae	Pioneer	Z	Au
Piptadenia gonoacantha (Mart.) J.F.Macbr.	Fabaceae	Pioneer	Z	Au
Piptocarpha axillaris (Less.) Baker	Asteraceae	Pioneer	Z	An
Sapium glandulosum (L.) Morong	Euphorbiaceae	Pioneer	Z	Z
Solanum mauritianum Scop.	Solanaceae	Pioneer	Z	Z
S. pseudoquina A.St.Hil.	Solanaceae	Pioneer	Z	Z
Tabernaemontana catharinensis A.DC.	Apocynaceae	Pioneer	Z	An
Tetrorchidium rubrivenium Poepp.	Euphorbiaceae	Pioneer	A	Au
Trema micrantha (L.) Blume	Cannabaceae	Pioneer	Z	Z
Vernonanthura discolor (Spreng.) H.Rob.	Asteraceae	Pioneer	Z	An

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Life form/Species	Botanical family	SG	PS	DS
Trees				
Aegiphila integrifólia (Jacq.) Moldenke	Lamiaceae	Early secondary	Z	Z
Aiouea saligna Meisn.	Lauraceae	Early secondary	Z	Z
Alchornea triplinervia (Spreng.) Müll.Arg.	Euphorbiaceae	Early secondary	Z	Z
Banara parviflora (A.Gray) Benth.	Salicaceae	Early secondary	Z	Z
Casearia sylvestris Sw.	Salicaceae	Early secondary	Z	Z
Citharexylum myrianthum Cham.	Verbenaceae	Early secondary	Z	Z
Cupania vernalis Cambess.	Sapindaceae	Early secondary	Z	Z
Guapira opposita (Vell.) Reitz	Nyctaginaceae	Early secondary	Z	Z
Hieronyma alchorneoides Allemão	Phyllanthaceae	Early secondary	Z	Z
Jacaranda puberula Cham.	Bignoniaceae	Early secondary	Z	An
Myrcia splendens (Sw.) DC.	Myrtaceae	Early secondary	Z	Z
Myrsine coriacea (Sw.) R.Br.	Primulaceae	Early secondary	A	Z
Ocotea puberula (Rich.) Nees	Lauraceae	Early secondary	Z	Z
Zanthoxylum rhoifolium Lam.	Rutaceae	Early secondary	Z	Au
Allophylus edulis (A.St.Hil., Cambess., A.Juss.) Radlk.	Sapindaceae	Late secondary	Z	Z
Annona neosericea H.Rainer	Annonaceae	Late secondary	Z	Z
A. rugulosa (Schltdl.) H.Rainer	Annonaceae	Late secondary	Z	Z
Cabralea canjerana (Vell.) Mart.	Meliaceae	Late secondary	Z	Z
Calyptranthes lucida Mart. ex DC.	Myrtaceae	Late secondary	Z	Z
Cedrela fissilis Vell.	Meliaceae	Late secondary	Z	Z
Endlicheria paniculata (Spreng.) Macbr.	Lauraceae	Late secondary	Z	Z
Ficus luschnathiana (Miq.) Miq.	Moraceae	Late secondary	Z	Z
Ficus cestrifolia Schott	Moraceae	Late secondary	Z	Z
Magnolia ovata (A.St.Hil.) Spreng.	Magnoliaceae	Late secondary	Z	Z
Matayba guianensis Aubl.	Sapindaceae	Late secondary	Z	Z
Nectandra oppositifolia Nees et Mart.	Lauraceae	Late secondary	Z	Z
Prunus subcoriacea (Chod. & Hassl.) Koehne	Rosaceae	Late secondary	Z	Z
Virola bicuhyba (Schott ex Spreng.) Warb.	Myristicaceae	Late secondary	Z	Z
Xylopia brasiliensis Spreng.	Annonaceae	Late secondary	Z	Z
Brosimum lactescens (S.Moore) C.C.Berg	Moraceae	Climax	Z	Z
Ocotea mandioccana A.Quinet	Lauraceae	Climax	Z	Z
Euterpe edulis Mart.	Arecaceae	Climax	Z	Z
Protium kleinii Cuatrec.	Burseraceae	Climax	Z	Z
Sloanea guianensis (Aubl.) Benth.	Elaeocarpaceae	Climax	Z	Z
Trichilia lepidota Mart.	Meliaceae	Climax	Z	Z
Vines				
Mikania glomerata Spreng.	Asteraceae	Pioneer	Z	An
M. hirsutissima DC.	Asteraceae	Pioneer	Z	An
M. micrantha Kunth	Asteraceae	Pioneer	Z	An
Orthosia urceolata E.Fourn.	Apocynaceae	Pioneer	Z	An
Oxypetalum wightianum Hook. & Arn.	Apocynaceae	Pioneer	Z	An
Wilbrandia ebracteata Cogn.	Cucurbitaceae	Early secondary	Z	Z

Regarding tree structure, the tree adult component (DBH $\geq$ 5cm) of the studied area (1,600m^2) was composed of 222 individuals representing 23 species (H´ = 2.460 nats and equability E = 0.7769) with a basal area equal to 12.72m^2 (Table 3). Although *M. scabrella* was still the tree species with the greatest importance values (IV) at the studied site (IV = 55.98), another native species also displayed similar high IV such as *M. coriacea* (IV = 39.68), *M. cabucu* (IV = 39.12) and *Casearia sylvestris* (IV = 30.33). These four species totalized 55% of the total IV of the area (Table 3).

No exotic tree species was found in the studied area. Through analysis of the vertical structure of the adult component (Figure 4), it was possible to identify a basic stratification, where the lower stratum (up to 6m) was occupied by *E. edulis*, *B. parviflora* and *T. micrantha* and the higher stratum (up to 15m) was occupied by *M. coriacea*, *O. puberula*, *V. discolor* and *M. scabrella*. The medium stratum (6-15m) was occupied by other species and young representatives of the higher strata (Figure 4).

The vast majority of tree individuals were in the lower diameter classes (5cm ≥ DBH < 10cm), as depicted in Figure 5. The species with greatest density in the higher diameter class (DBH > 20cm) were *M. scabrella* (4 individuals), *S. pseudoquina* (3 individuals) and *O. puberula* (3 individuals). It was detected low similarity with nearby forest remnants with decreasing values towards both extreme situations: forest remnant versus highly degraded areas. The greatest similarity was obtained with areas that represent the intermediate level of succession (ISj) as displayed in Table 4.

With respect to natural tree establishment (Table 5), 45 tree species were recorded in the regeneration compartment. Among these, 25 species are exclusively observed in the regeneration compartment and 20 species were also registered in the adult compartment. As depicted in Table 5, *M. coriacea* (RNT = 18.55%), *M. guianensis* (RNT = 7.69%) and *M. cabucu* (6.59%) displayed the highest natural regeneration indexes (RNT). Only three species of the adult compartment were not observed in the regeneration compartment: *P. gonoacantha*, *P. axillaris* and *F. cestrifolia*. No exotic tree species was detected in the regeneration compartment.

TABLE 3 Structure parameters for DBH >5cm tree species at *M. scabrella* plot of the "Pilot Restoration Project". Species presented in a decreasing order of importance value (IV), being: AF=absolute frequency (%); RF=relative frequency (%); AD=absolute density (individuals.ha-1); RD=relative density (%); ADo=absolute dominance (m²) and RDo=relative dominance (%).

Species	AF	RF	AD	RD	ADo	RDo	IV
Mimosa scabrella	66.67	11.76	233.33	18.92	3.22	25.30	55.98
Myrsine coriacea	72.22	12.75	172.22	13.96	1.65	12.98	39.68
Miconia cabucu	66.67	11.76	216.67	17.57	1.25	9.79	39.12
Casearia sylvestris	61.11	10.78	155.56	12.61	0.88	6.93	30.33
Ocotea puberula	33.33	5.88	100.00	8.11	1.44	11.33	25.32
Aegiphila integrifolia	38.89	6.86	66.67	5.41	1.02	8.05	20.32
Alchornea triplinervia	33.33	5.88	50.00	4.05	0.73	5.71	15.64
Solanum pseudoquina	33.33	5.88	38.89	3.15	0.79	6.21	15.24
Endlicheria paniculata	33.33	5.88	55.56	4.50	0.41	3.26	13.64
Hieronyma alchorneoides	22.22	3.92	27.78	2.25	0.22	1.74	7.92
Vernonanthura discolor	11.11	1.96	16.67	1.35	0.40	3.12	3.43
Cecropia glaziovii	16.67	2.94	16.67	1.35	0.10	0.78	5.08
Nectandra oppositifolia	16.67	2.94	16.67	1.35	0.09	0.72	5.01
Cabralea canjerana	11.11	1.96	11.11	0.90	0.06	0.44	3.30
Piptadenia gonoacantha	5.56	0.98	5.56	0.45	0.20	1.58	3.01
Clethra scabra	5.56	0.98	11.11	0.90	0.07	0.55	2.43
Piptocarpha axililaris	5.56	0.98	5.56	0.45	0.05	0.41	1.84
Ficus cestrifolia	5.56	0.98	5.56	0.45	0.04	0.32	1.75
Trema micrantha	5.56	0.98	5.56	0.45	0.03	0.24	1.67
Zanthoxylum rhoifolium	5.56	0.98	5.56	0.45	0.03	0.23	1.66
Banara parviflora	5.56	0.98	5.56	0.45	0.01	0.11	1.54
Euterpe edulis	5.56	0.98	5.56	0.45	0.01	0.10	1.53
Annona rugulosa	5.56	0.98	5.56	0.45	0.01	0.10	1.53
Total	566.67	100	1,233.33	100	12.72	100	300

DISCUSSION

Considering that the main goal of ecosystem restoration is to recover species composition, structure and the function of the original ecosystem prior to disturbance (BRADSHAW, 1990; MACMAHON, 1997; ALDAY et al., 2011a), the results from the "Pilot Restoration Project" (PRP) evidenced two major aspects: i) the inadequacy of taking into account solely the survival of former planted tree species as an indicator of success in restoration programs, once natural regeneration is the most important factor; ii) the preponderant importance of an appropriate species selection in restoration programs. The PRP evaluation, after 22 years from its implementation, showed that *M. scabrella* was the only native species that was still alive. However, the plots that received *M. scabrella* (A-plots in Figure 1) were the only ones that displayed restoration in progress. The other plots with exotic species, as depicted in Figure 1, still with the former planted species, were growing relatively well, but with nothing else than the species that had been planted at the early beginning of the project.

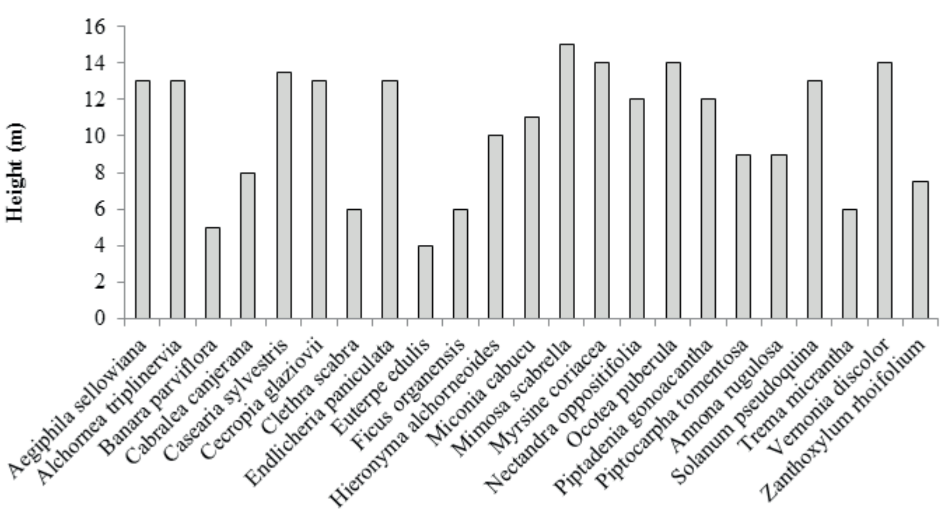

FIGURE 4 Trees species (DBH > 5cm) and their respective height (m) at *Mimosa scabrella* plots, "Pilot Restoration Project" at Siderópolis County, Santa Catarina state, Brazil.

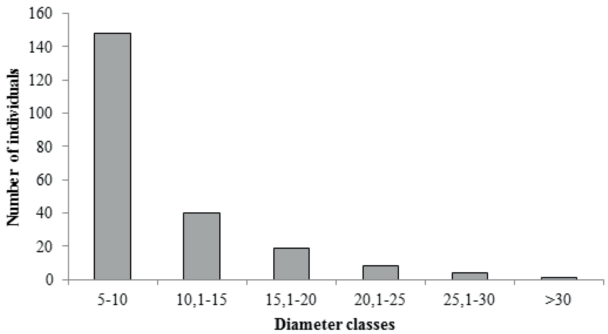

FIGURE 5 Number of individuals according to diameter classes in the *Mimosa scabrella* plots, "Pilot Restoration Project" at Siderópolis County, Santa Catarina State, Brazil.

Through the exotic species (*C. citriodora*, *E. saligna*, *E. viminalis*, *G. hilliana*, *P. taeda*, *P. elliottii* and *S. cumini*) the PRP was able to promote no better than restoration (or rehabilitation), a process of converting degraded land to an alternative land use deemed acceptable to stakeholders (BRADSHAW, 1990; MEFFE; CARROLL, 1994; POWTER, 2002). It is necessary to point out, however, that the main objective of restoration is not to recreate the original ecosystem, but to reestablish land productivity and its function (KAISER-BUNBURRY et al., 2017) to a point where the environment will be sustainable in the long-term, with dominant species able to establish and persist on the site (LUGO, 1992; BROWN; LUGO, 1994; ENGEL; PARROTA, 2003; HOBBS et al., 2007; ALDAY et al., 2010). In view of that, restoration also could not be totally confirmed by PRP due to the almost absence of spontaneous succession within the plots that received exotic species, since these species are recognized as one of the main causes of biodiversity loss on the planet (MORO et al. 2012) and are present in current legislation in Santa Catarina (SANTA CATARINA, 2012).

On the other hand, at the *M. scabrella* plots, it was evidenced several characteristics related to the improvement of the ecosystem structure (species composition and complexity) and function, as follows: explicit improvement of soil conditions, vegetation coverage composed of distinct life forms distributed in a vertical stratification with species composition very similar to the nearby natural forest remnants; predominance of pioneer species but also with late secondary and climax species; native tree and other life forms species spontaneous succession on the site and predominance of zoophilous and zoochorous species that attract and maintain native fauna.

What characteristics of *M. scabrella* favour the ecosystem improvement or the recovering development? Firstly, its capacity of being symbiotic associated to Nitrogen-fixing bacteria (root nodules), as described by Franco et al. (2000) and Coelho et al. (2007). This association can incorporate more than $500 kg \cdot N \cdot ha^{-1}.year^{-1}$ to the ground-plant system (FRANCO et al., 2000). Furthermore, it expands the rhizosphere, improving plant capacity of absorbing other important nutrients, mainly Phosphorus, which has limited availability and low mobility in tropical soils (JANSA et al., 2011). Nitrogen and Phosphorus are the most limiting nutrients related to plant establishment and growth (PEOPLES; CRASWELL, 1992). Considering that, the Nitrogen-fixing bacteria root nodules are an important and efficient strategy for the environmental restoration (FRANCO et al., 2000; CHAER et al., 2011). Moreover, it is important to emphasize the outstanding capacity of *M. scabrella* to produce litter, achieving the amount of $8,490 kg \cdot ha^{-1}.year^{-1}$ of dry organic matter plus $253 kg \cdot ha^{-1}.year^{-1}$ of nitrogen and $15 kg \cdot ha^{-1}.year^{-1}$ of potash (BAGGIO; CARPANEZZI 1997). The accumulation of litter by legume trees also promotes enrichment of the soil fauna and the activation of processes of nutrient cycling and soil organic matter formations (CHADA et al., 2004; BANNING et al., 2008).

In regards to Nitrogen-fixing by plants for restored areas in mining areas, Chada et al. (2004) describe that where planting was performed in embankments with a mixture of two herbaceous leguminous, not inoculated with rhizobium, the system proved to be

TABLE 4 Floristic similarity (Jaccard's coefficient = ISJ) related to tree species, Santa Catarina state, Brazil, considering the studied site and nearby areas representing different sucessional stages.

Source	Successional stage	Municipality	Latitude	Longitude	Number of species	Area (ha)	ISJ
This study	Medium	Siderópolis	28°36'	49°33'	23	0.018	–
Santos et al. (2008) (Overburden piles)	Initial Siderópolis	28°35'	49°25'	21	0.28	0.13	
Santos et al. (2006)	Initial	Criciúma	28°41'	49°21'	16	0.5	0.26
Santos et al. (2003)	Medium	Siderópolis	28°34'	49°24'	78	0.5	0.22
	Advanced	Siderópolis	28°34'	49°23'	85	0.5	0.18
Citadini-Zanette (1995)	Pristine	Orleans	28°21'	49°17'	119	1.0	0.10

unsustainable, while others using Nitrogen–fixing plants showed successful outcomes (CHAER et al., 2011), being *M. scabrella* among the promising species, and recommended for the humid and sub-humid tropics (FARIA et al., 2010).

The values yielded for organic matter reflect the importance of the onsite herbaceous coverage. Herbaceous vegetation plays a paramount role at the initial condition of new soils, due to vegetal biomass accumulation (BENDFELDT, 1999). Higher values compared to those in remnant forests are explained by the fact that forest soils, given their structure, present higher decomposition of litter when compared to prepared soils, as in the present study.

It must be stressed that herbaceous vegetation in forest soils yields lower biomass production when compared to post-mining areas, where herbaceous vegetation, especially grass, populates these environments with high initial biomass productivity (GILEWSKA; DRZYMALA, 2001).

Another *M. scabrella* favorable characteristic is its high capacity of attracting pollinating insects and dispersing birds due to different mechanisms. On one hand, it is due to its massive blooming: a tree of approximately 15m in height produces around 40,000 globose inflorescences with an average 55 flowers each one. The great offer of nectar and pollen attracts mainly bees, besides several sorts of flies, wasps and beetles (HARTER-MARQUES; ENGELS, 2003). On the other hand, *M. scabrella* presents a very complex interaction with cochineal insects that are transported by ants up to the trunks and branches. These insects, after sucking the sap, excrete a transparent and sweet liquid that attracts a great diversity of insects (flies, bees, butterflies) and birds (hummingbirds and insectivores), as reported by Costa et al. (1993). Some perisporiaceous fungi grow saprophytically on leaves, branches and trunk, depending also on that sugary substance (FIDALGO; FIDALGO, 1967). These fungi form a characteristic dark coverage onto the trunk and branches of *M. scabrella* individuals and it is considered as an indicative of fodder availability for local insect and avifauna (BASSO et al., 2007).

This study has shown that other life forms also belong to the community and must be used in restoration projects (ALDAY et al., 2011b) and that despite homogenous planting currently no longer accepted when ecological restoration is aimed at (PARROTA; KNOWLES, 2003; RODRIGUES et al., 2009). This study once again corroborates the importance of the use of legume trees in degraded areas restoration (CHAER et al., 2011), as well as the importance of fauna at the natural spontaneous succession or regeneration, beneath the plantations in harshly degraded lands (see SANSEVERO et al., 2011) or open degraded lands (VICENTE et al., 2010).

Integration of other life forms in the restoration process is important for forest trees species colonization, mainly under the conditions of planned soils, as in the present study. When carrying out experiments in post-mined areas in the United States, Fields-Johnson (2012) revealed that the use of annual species is a promising practice when the goal is native forest restoration, as long as colonization conditions for native vegetation is favourable, what is directly associated with the dispersal capacity of the forest species that make up the surrounding areas.

Zoochorous predominance as a dispersal strategy verified in the studied area reveals the interdependence between vegetation and fauna in the restoration of coal mining degraded areas as well as its later successional advancement (SALEK, 2012).

All the above-mentioned characteristics highlight the importance of interaction capacity during the species selection for restoration programs (PARROTTA et al., 1997; RODRIGUES et al., 2009). Native species with multi-way interactions seem to favor the improvement of the ecosystem structure (species composition and complexity) and function (SANSEVERO et al., 2011). As pointed out by Falk et al. (2006), the understanding and application of positive species interaction would either facilitate or accelerate the rates of change. Selection of non-native species or even native ones that are not able to establish natural processes or ecosystem services will be less cost-effective and require more human input to achieve recovering.

CONCLUSION

After 22 years from the early beginning of the "Pilot Restoration Project" (PRP), the results from the studies conducted in plots that had received *M. scabrella* indicate an improvement of nutrient load (N, K, organic matter) in the substrate, a diversified composition of tree coverage and prominent establishment of indigenous trees with predominance of zoophilous and zoochorous species, i.e. those species that are able to attract and maintain native fauna. The good results observed within *M. scabrella* plots of the PRP make contrast with the very poor restoration observed within the other plots which received either exotic or even indigenous species.

When dealing with the selection of native tree species in order to reconstitute the Atlantic Rain Forest, the use of *M. scabrella* in harshly degraded areas as in opencast coal mining may improve the nutrient load of the substrate and also accelerate or facilitate the spontaneous succession due to its marked capacity of producing multi-way interactions that seem to favour the ecosystem's structure and function improvement.

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