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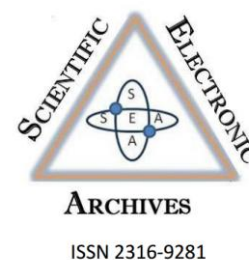
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Reference areas and edaphoclimatic variables: support for the choice of tree species in the restoration of riparian forests in Southern Brazil

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Abstract. Identifying factors involved in the choice of species for forest restoration is a great challenge, given the wide range of biotic and abiotic factors that may influence ecosystem trajectories. This review aims to highlight the information from reference areas and edaphoclimatic factors as aids in the choice of forest species to be used in the restoration of riparian forests, especially for the southern of Brazil. Native forest species of natural occurrence in riparian areas offer the potential for recovering these environments, depending on the ecological group and stage of ecological succession where they are naturally present. However, floristic and phytosociological surveys in well-preserved remnant riparian forests with no anthropogenic interference and in areas at different stages of natural succession are needed. This will enable the identification of the most representative species which are adapted to the conditions of local sites. Additionally, information must be correlated with chemical, physical and biological aspects of the soil as well as ecological processes and climatic characteristics, enabling the proper choice of species. Thus, the components of soil-plant-atmosphere system must be incorporated into the degraded environments in order to achieve an integrated recovery of ecological processes.

Keywords: Atlantic Forest Biome, Native species, Floristics, Phytosociology, Soils.

Introduction

The existing forest remnants suffer constant degradation from human action. One of the most expressive examples of this is the Atlantic Rainforest Biome, which has only 11.6% of the original cover (Rodrigues et al., 2011; Melo et al., 2013) and currently presents an increase of 9% in the rate of deforestation (SOS MATA ATLÂNTICA; INPE, 2014). The causes of degradation are associated with the growing demand for raw materials from industries and with the expansion of agricultural regions, causing more pressure on natural resources (Suding, 2011; Maron et al., 2012).

The intense exploitation of these remnants establishes the beginning of the environmental degradation process, which causes loss of biodiversity and soil structure degradation (Rocha-Junior et al., 2014; Bertachi et al., 2016) and affects the provision of ecosystem services (Hansen et al., 2013; Pütz et al., 2014). Moreover, the

fragmentation of natural ecosystems also leads to the isolation of these remaining habitats, hindering the seed dispersal, vegetation regeneration and the entire balance of the ecosystem.

Thus, actions that seek biological stability of natural ecosystems are essential to their balance. Forest restoration methods, such as nucleation, enrichment, densification, and planting of native tree species can be used in order to restore the local ecological functions (Brancalion et al., 2009; Miranda Neto et al., 2010; Reis et al., 2010; Compoe et al., 2014; Turchetto et al., 2016). Currently, studies have shown that seedling planting accelerates the process of natural succession in relation to the abandonment of areas (Kageyama et al., 2008; Rodrigues et al., 2011). This is mainly due to the process of area degradation, which in several situations is characterized by the loss of ecological processes and absence of natural resilience potential, commonly identified in the agricultural

matrix (Melo et al., 2013). In these places, the introduction of native species attracts wildlife, in particular pollinators and seed dispersers, contributing food, places for nesting and refuge from predators (Catterall et al., 2012), and consequently fostering the regeneration in the understory.

However, there is a lack of studies on selection of species to be used for environmental recovery since the ecological behavior of native trees in the field is still unknown for most species and there is variation among physiographic regions. Therefore, it is essential to determine which factors should be initially evaluated in the area, aiming at the choice of species adapted to such conditions. This is considered a great challenge due to the large number of biotic and abiotic variables as well as the interactions that may influence the ecosystem trajectories.

Thus, the present study aims to present a literature review to highlight the importance of information from reference areas and from the edaphoclimatic variables for proper choice of forest species to be used in the restoration of riparian forests in the southern region of Brazil.

Contextualization and Analysis

Riparian forests and the need for preservation

The Riparian forests are characterized by vegetation that permeates the rivers, springs and reservoirs (Brazil, 2012). These environments are environmentally and ecologically important as they act as ecological corridors and provide stability to the soil, which reduces surface erosion and nutrient runoff (Alvarenga et al., 2006).

The requirements for the conservation and restoration of riparian forests are based on knowledge of the role of this vegetation in the protection of water resources and to increase landscape connectivity, by operating as biological corridors. Landscape ecology studies have shown that riparian forests act as excellent ecological corridors, connecting isolated fragments (Brancalion et al., 2010). Thus, considering the ecological importance and the need to maintain water quality, riparian forests have been gaining attention from researchers in relation to the adoption of methodologies for their recovery.

Different methods of forest restoration can be used to restore ecosystem functionality, such as plantations, which are widely used (Rodrigues et al., 2009; Campoe et al., 2014; Ferez et al., 2015). Planting native tree seedlings can enhance forest succession, benefiting the continuity of species-specific functions in the ecosystem.

Reference ecosystem as a tool for species selection

In order to assist in the recovery process of an ecosystem, the composition of the species to be used deserves attention, as there is a need to prioritize combinations of species with different characteristics regarding the ecological groups

(filling and diversity), functional groups (legumes and non-legumes), crown coverage, phenology, among others (Rodrigues et al., 2009).

In addition, one must consider the ecological region where the species are distributed, which can facilitate the recovery due to suitable development of the species in the field. The floristic composition of a region can be influenced by phytogeographical and ecological aspects (Guariguata & Ostertag 2001). When the analysis of the environment reveals planting of trees to be a promising technique for recovery, it is initially assumed that all the native species found in the region offer potential for its recovery.

Nevertheless, previous floristic surveys in riparian areas without anthropogenic interference and in remnants at different successional stages are important in order to list effective species for recovery of riparian forests. In these locations, it is important to identify species with functionality to restore riparian environment and species for specific regions of riparian forest (dams, embankment, flood zone). Given the availability of propagative material near the area to be recovered, these species will constitute the planting arrangement.

Use of regional species increases the probability of reproductive success and natural regeneration due to their higher tolerance for predators. Moreover, it fosters the maintenance of pollinators and existing seed dispersers, which use them as shelter or food (Kageyama & Gandara 2000). Additionally, for Fonseca et al. (2001), recovery also requires the knowledge of phytosociological aspects, population structure, and species autecology as well as silvicultural aspects involved in collecting seeds, seedling production, and behavior of the species in plantations.

Thus, identifying a reference ecosystem is essential to the success of restoration projects. According to the International Society for Ecological Restoration, reference areas are important to aid in restoration planning in order to acquire knowledge about the ecosystem managed (SER, 2004). An example is reported in Marcuzzo et al. (2014) who evaluated the restoration process in two degraded areas using as a comparison a reference area located in a remnant of a preserved secondary subtropical seasonal forest, located in a Full Protection Conservation Unit in southern Brazil. In this study, the authors concluded that the areas studied are in the process of restoring the natural succession, since they presented increased wealth, structure, and ecological processes in relation to the reference area.

However, Suganuma et al. (2013) found that not all attributes of a mature forest can be used as reference for areas in restoration, for example, the density of pteridophytes and lianas, since these characteristics are perceptible as the ecosystem evolves. On the other hand, according to these authors, structural, functional, and wealth attributes

such as the total richness, density (tree and regenerative component), basal area, canopy cover and proportion in relation to shade tolerance, do not vary and provide good indications.

Floristic and phytosociological surveys in preserved riparian forests in the region and in different stages of succession enable the identification of species that are better adapted to the local environmental conditions, favoring the success of plantations. The species that occur in a given environment come from intra and interspecific biotic interactions which are evolutionary and also adapted to the local edaphoclimatic conditions. For this reason, they must be prioritized in plantations with environmental purposes. These surveys in nearby locations and under similar conditions to the location of future deployment allow the restoration of the landscape, as close as possible to the original.

To complement the phytosociological survey, species diversity, interaction between plants, and secondary ecological succession are also parameters that should be considered. A large number of species have been used in forest restoration projects aiming at high diversity. Nevertheless, the choice of an appropriate species, highly adapted, and capable to survive and begin the succession is more important than just high level of wealth.

According to The Nature Conservancy (TNC), ecology group, degree of commercialization, and classification of planting are relevant information for selecting species in forest restoration projects (TNC, 2013). In accordance with these authors, ecological group influences the selection of restoration method. Knowledge of the degree of commercialization of wood occurs is necessary to assure sustainable management of the areas characterized as legal reserves by federal legislation (Brazil, 2012), while the classification of species regarding planting enables the establishment of two categories based on silvicultural characteristics of filling and diversity (Rodrigues et al., 2009).

Edaphoclimatic factors which influence the choice of species for reforestation of riparian forests

In addition to the introduction of vegetation, recovery of degraded environments must entails consideration of components of the soil-plant-atmosphere system aiming at the integrated re-establishment of biological processes. For this purpose, edaphic, vegetable and atmospheric aspects should be evaluated (Reis-Duarte & Casagrande, 2006). However, studies involving ecosystem trajectories rarely identify factors needed for restored areas to reach their goals (Suganuma et al., 2013).

Soil is the substrate for the development of the plant root system, responsible for providing water and nutrients in adequate quantities. Thus, it is important to consider its chemical, physical and biological aspect. Previous knowledge of chemical

characteristics enables the determination of the degree of fertility and possible nutritional deficiencies due to crop exportation, erosion or leaching.

The replacement of essential nutrients is crucial, since both macro and micro-nutrients are important for plant development. Their presence is essential mainly during the early years of intervention, when the soil presents a low content of organic matter and nutrient cycling is not established yet (Reis-Duarte & Casagrande, 2006). When Melo & Durigan (2006) compared biomass accumulation in mature forests and during reforestation of riparian forests, they showed the importance of nutrition due to greater biomass accumulation in highly fertile clay soils in relation to less fertile sandy soils.

However, according to Ferez et al. (2015), it is common to use low intervention silviculture techniques in restoration plantings, with little or no soil preparation and fertilization below what is necessary to meet the demand of plants. Given the lack of studies involving fertilization of native forest species, the decision-making about fertilization in most cases considers cultivated species like *Pinus* spp., *Eucalyptus* spp. and *Ilex paraguariensis* as reference.

With regard to physical attributes, previous analysis of soil compaction is also important. This compaction is caused mainly by anthropic action related to the practice of mechanized agriculture and livestock, which compress both the topsoil and subsoil. The different levels of soil compaction influence the development of plant roots, storage and movement of water, air and heat, which may cause a reduction in root growth and erosion. Thus, introducing species adapted to this condition is required in areas of compacted soil, giving preference to those whose root system is widely distributed. For this purpose, it is essential to have prior access to information regarding chemical and physical soil characteristics in order to choose from the list of local floristic species those which are the most appropriate.

In addition, microbiological indicators of soil should be considered in order to assess the capacity to cycle and store nutrients, thus quantifying the presence and the activity of edaphic microorganisms for restoration of soil processes (Chaer & Tótola, 2007).

Another important feature is the regional climatic characteristics, such as rainfall, temperatures, frost occurrence, intensity and duration of the soil water deficit. The southern region of Brazil is characterized by well-defined climatic seasons, with intense waves of low temperatures, which can reach negative values, leading to the incidence of frosts.

Different responses regarding susceptibility to low temperatures are attributed to the characteristics of each species. Rorato et al. (2011) reported that the initial tolerance of different forest

essences to frost allows us to make inferences about plant adaptation and its interference in species growth and development. Previous knowledge about tolerance and resilience to meteorological phenomena, such as the incidence of frosts, is fundamental in the choice of species, especially in the southern region of Brazil, in order to minimize mortality and damage to plantations (Caron et al. 2011).

Thus, a number of edaphoclimatic factors should be considered in advance, in order to correlate them with the species from the local floristic lists, cataloguing those that present potential for recovery of certain environments. For that purpose, information from studies and research that have been previously carried out or are in progress must be sought, and a careful analysis must be conducted to define potential species, with a higher chance of success in recovery.

Potential species for southern Brazil

An indication of native forest species is presented in Table 1. These species are representative of the Seasonal Subtropical Forest and have potential to be used in the recovery of degraded riparian forests due to the growth characteristics, canopy cover, phenology, ability to produce undergrowth, nutrient cycling, and carbon sequestration.

Species belonging to the filling group (initial stage of succession) show rapid growth, large canopies to quickly shade the area, and potential nutrient cycling, whereas the species of the diversity group (secondary and climax) show distinct performances (Brançalion et al., 2009).

Table 1. Native tree species with potential to be used in degraded areas in the South of Brazil.

Species	Family	Group	Reference
<i>Actinostemon concolor</i> (Spreng.) Müll.Arg.	Euphorbiaceae	Diversity ¹	1; 2; 4
<i>Allophylus edulis</i> (A.St.-Hil., Cambess. & A. Juss.) Radlk.	Sapindaceae	Filling ²	1; 2
<i>Apuleia leiocarpa</i> Vogel	Fabaceae	Diversity ²	2
<i>Casearia sylvestris</i> Sw	Salicaceae	Filling ²	1; 2
<i>Chrysophyllum marginatum</i> (Hook. & Arn.) Radlk.	Sapotaceae	Diversity ⁴	4
<i>Cordia americana</i> (L.) Gottschling & J.S.Mill.	Boraginaceae	Diversity ¹	1; 2; 4
<i>Cupania vernalis</i> Cambess	Sapindaceae	Diversity ¹	1; 2; 4
<i>Enterolobium contortisiliquum</i> (Vell.) Morong.	Fabaceae	Filling ³	3
<i>Eugenia rostrifolia</i> D. Legrand	Myrtaceae	Diversity ²	2
<i>Ficus luschnathiana</i> (Miq.) Miq.	Moraceae	Diversity ²	2
<i>Gymnanthes klotzschiana</i> Müll.Arg.	Euphorbiaceae	Filling ⁴	4
<i>Inga vera</i> Willd	Fabaceae	Filling ³	3
<i>Luehea divaricata</i> Mart. & Zucc.	Malvaceae	Filling ⁴	4
<i>Machaerium paraguariense</i> Hassl.	Fabaceae	Filling ²	2
<i>Nectandra megapotamica</i> (Spreng.) Mez	Lauraceae	Diversity ¹	1; 2
<i>Nectandra lanceolata</i> Nees	Lauraceae	Diversity ¹	1
<i>Ocotea puberula</i> (Rich.) Nees	Lauraceae	Filling ²	2
<i>Parapiptadenia rigida</i> (Benth) Brenan.	Fabaceae	Diversity ²	2
<i>Phytolacca dioica</i> L.	Phytolaccaceae	Filling ²	2
<i>Sebastiania brasiliensis</i> Spreng.	Euphorbiaceae	Diversity ²	2
<i>Schinus terebinthifolius</i> Raddi	Anacardiaceae	Filling ³	3
<i>Sorocea bonplandii</i> (Baill.) W.C. Burger, Lanjouw & Boer	Moraceae	Diversity ²	2
<i>Trichilia clausenii</i> C. DC.	Meliaceae	Diversity ¹	1; 2; 4
<i>Trichilia elegans</i> A. Juss	Meliaceae	Diversity ¹	1; 2; 4

D= Diversity, F= Filling. 1 Marcuzzo; Araujo; Longhi (2013); 2 Callegaro et al. (2014); 3 Marcuzzo; Araujo; Gasparin (2015); 4 Almeida et al. (2015).

Ceiba speciosa (A.St.-Hil.) Ravenna, *Citharexylum montevidense* (Spreng.) Moldenke, *Cordia trichotoma* (Vell.) Arrab. ex Steud. and *Solanum mauritianum* Scop are featured as species with potential to be part of the filling group. For the diversity group, the previously cited ones are featured, in addition to *Dalbergia frutescens* (Vell.) Britton, *Diospyros inconstans* Jacq., *Eugenia*

involucrata DC., *Handroanthus heptaphyllus* (Vell.) Mattos and *Psidium cattleianum* Sabine. Studies characterizing the behavior of these species under field conditions, especially degraded vegetation areas, will allow the confirmation of their potential in these environmental conditions.

Final considerations

Strategies of ecosystem ecological restoration through the introduction of tree species with a focus on riparian forests should consider the information from the reference areas gained from ecological, floristic, and phytosociological surveys. These surveys should be performed on preserved remnants that represent various stages of succession, located in areas with similar soil and climate conditions.

Correlating the species with chemical, physical and biological aspects of soil and climatic aspects will provide a basis to make the proper choice of species to be used in forest restoration programs.

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