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Predicting restored communities based on reference ecosystems using a trait-based approach

Milena Fermina Rosenfield *, Sandra Cristina Müller

Laboratório de Ecologia Vegetal, Programa de Pós-Graduação em Ecologia, Universidade Federal do Rio Grande do Sul, Brazil

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ABSTRACT

Ecological restoration should focus, not only on species composition, but also on the ecological functions provided by the ecosystem, mirroring the characteristics found in the reference site. In this context, plant functional traits could help to achieve this goal, as they directly affect ecosystem processes. Thus, modeling species composition based on species functional traits could provide ways to make predictions about future communities and to assess the functioning of the ecosystem. In order to evaluate how different restored communities are from their reference ecosystem, we used a trait-based modeling approach that predicts relative abundances of a community based on the functional composition of the reference ecosystem. We surveyed adult trees in the canopy and seedlings in the understory in both reference and 10 year-old restoration sites in two different locations in South of Brazil to gather information of species composition and their relative abundances. Functional composition was based on information of leaf traits for all species included in the survey. We applied the model on two different components: canopy and understory species. We found differences in functional composition between the restored communities and the reference sites, indicating that the ten-year old restored forests are still not similar to the reference ecosystem. Both the observed and the predicted understory communities were more similar to the reference ecosystem than the observed canopy communities. It indicates that species that established after restoration interventions have functional composition closer to the reference ecosystem than the set of species initially selected for planting. Modeling the community based on functional trait composition coupled with long-term monitoring of sites undergoing restoration would enable a better evaluation of restoration trajectories and management needs to modify ecosystem functions towards values found in reference sites. Restoration should focus on the recovery of functional composition, which would provide a better set of resources for organisms and promote changes in ecosystem processes.

1. Introduction

Restoration ecology aims to recover ecosystems with the goal of creating a natural ecosystem that is both functional and that provides habitat for many different organisms (SER, 2004; Aronson et al., 2006). In this context, it is usually targeted to reach reference conditions, which is a preserved ecosystem that resembles the one that occurred prior to degradation (SER, 2004). For forest restoration, this usually means planting the same native species found in the reference sites (Lamb, 2005; Rodrigues et al., 2009), with the objective of creating a more similar community in regards to species composition. Although planting a large number of species increases values of biodiversity (Sampaio et al., 2007), it is not ensured that all features observed in the restored site will resemble the mature forest.

The recovery of species composition and vegetation structure towards mature forests does not necessarily follow a predictable trajectory (Norden et al., 2015) and long term monitoring is required to evaluate how different parameters change in time (Suganuma and Durigan, 2015). Many studies show a slow recovery of floristic and structural vegetation parameters along the succession process (Liebsch et al., 2008; Dent et al., 2013), which leads to uncertainties in determining the success of restoration projects. Good indicators of restoration success are a central focus in ecological restoration. More recently, many authors have suggested a set of parameters that would be good predictors of vegetation recovery (Reid, 2015; Suganuma and Durigan, 2015; Brancalion and

* Corresponding author at: Avenida Bento Gonçalves, 9500, 91501-970 Porto Alegre, Brazil.

E-mail addresses: milenarosenfield@gmail.com (M.F. Rosenfield), sandra.muller@ufrgs.br (S.C. Müller).

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Holl, 2016). Among them, basal area and seedling abundance were suggested (Suganuma and Durigan, 2015), but they disregard the contribution of species composition to the increased similarity towards reference sites, which is an important goal in ecological restoration (Reid, 2015). Finally, Brancalion and Holl (2016) suggested that a combination of basal area and abundance with compositional and/or functional parameters would be a more reliable measure to evaluate restoration success. We agree that using functional measures would help in determining whether the restoration has been successful since they relate more directly with ecological processes in the ecosystem level. Thus focus on ecosystem functioning could provide ways to determine if restored sites are performing well irrespectively of species composition, offering conditions for biotic interactions among different groups of species and maintaining ecosystem processes.

This emphasis on ecosystem functions has driven a growing focus on species characteristics (e.g. functional traits) rather than its identity (Diaz and Cabido, 2001; Garnier et al., 2004). A broad definition considers a functional trait as an organism's trait that affects individual or species fitness via effects on growth, reproduction and survival (Violle et al., 2007), responding to environmental conditions or affecting ecosystem properties (Lavorel, 2013). A number of recent studies indicate that trait composition and different functional diversity measures can affect ecosystem processes in a number of ways (Diaz and Cabido, 2001; Garnier et al., 2004; Kazakou et al., 2006). Decomposition is negatively affected by leaf lignin content and dry matter content (LDMC) and positively affected by nitrogen (Freschet et al., 2012); soil fertility is influenced by LDMC and leaf litter nitrogen (Laughlin et al., 2015); above-ground biomass increments and carbon sequestration can be predicted by specific leaf area – SLA (Finegan et al., 2015) and wood density (Larjavaara and Muller-Landau, 2010); and seedling survival is increased by seed mass (Moles and Westoby, 2004). Therefore, given the goal of restoration ecology, instead of just trying to increase species richness, one should look to the different traits related to photosynthetic performance, growth and dispersal of the species selected for planting. Many databases for plant traits are available and provide data for many species across the globe (e.g. Kattge et al., 2011). An important step when working with ecosystem functioning is trait selection (Petchey and Gaston, 2006), which consists in including parameters that really affect ecosystem ("effect traits", Lavorel and Garnier, 2002) and that are not just a response to environmental conditions. Therefore, measuring and evaluating traits that most affect ecosystem properties could be a tool to understand the community dynamic and to guide restoration in achieving targeted functional reference conditions.

Additionally, as species traits affect how species interact and influence the assembly processes that occur in a community (HilleRisLambers et al., 2012), they are believed to drive the way biodiversity affect ecosystem properties (Millennium Ecosystem Assessment, 2005). The possibility of using species traits that most affect ecosystem processes (Suding et al., 2008) could allow the prediction of a community that would promote fast development of a given ecosystem process, based on values from desired targets or reference sites. Recently, several models have been proposed to predict communities based on target ecosystems or functional values (Laughlin et al., 2012). In the field of ecological restoration, this approach could be used by practitioners when selecting the most suitable set of species to be planted in order to increase or slow a specific ecosystem process in a degraded site (e.g. decomposition or nutrient cycling; Laughlin, 2014). It could also be used for theory driven studies in restoration ecology aiming to understand community assembly processes based, for example, on niche complementarity or resistance to species invasion (Funk et al., 2008; Laughlin, 2014). The functional trait-based approach can bring important information to restoration ecology (Laughlin, 2014), especially when the goal is to assess functionality (Diaz and Cabido, 2001).

In this study, we applied a recently proposed trait-based model to predict a community based on the functional composition from the reference ecosystem (Laughlin, 2014). We based our analysis on the expectation that restoration sites should achieve ecosystem characteristics similar to the reference site (SER, 2004) and that monitoring of functional values could show how distant restored communities are from their reference. We aimed to evaluate if the functional composition from forest sites undergoing restoration resembles the characteristics found in the reference ecosystem (remnant forests). More specifically, we aimed to analyze how similar with regards to functional composition are the canopy and the understory communities of restored sites from reference ecosystems by applying a trait-based modeling approach. We then compared the results from both models (the predicted communities based on canopy and the understory) with the observed communities in order to evaluate possible trajectories towards mature forests. Applying the model on both canopy and understory species could provide an interesting perspective on present and future conditions from the restored sites, pointing out to successional trajectories. We focused on the composition of the restoration site from both canopy and understory trees, using as reference the canopy of the remnant forest. Prior to the modeling, we first compared restoration and reference sites in terms of their community-level trait means to highlight the existing differences between these communities and then applied the model to generate predicted communities that meet the range found in the reference ecosystem. The use of trait-based ecology could be an interesting tool for practitioners, due to its capacity to predict communities that are functionally more similar to the targeted ecosystem (Laughlin, 2014). Such modeling approaches could be applied both in the start of the restoration project (predicting abundances for each species available for planting) and after a few years of recovery (as in the present study), with the goal of monitoring the successional trajectory of recovery and using adaptive management to assist restoration (e.g., species removal and/or management of natural regeneration).

2. Material and methods

2.1. Study site and sampling

We performed the study in two forest restoration sites in the South of Brazil (Site 1 – Cachoeirinha: 29°52′S 51°05′W; and Site 2 – Canela: 24°22′S 50°43′W). In each site we performed the survey in both treatments: restoration and reference forest. The type of ecosystem in Site 1 is a semi-deciduous riparian forest. The site had a history of cattle grazing and is inserted in an anthropogenic, urban and disturbed matrix. Restoration practices focused on planting native tree species (ca. 23 species) in order to increase the width of the riparian forest. Site 2 is a semi-deciduous forest that used to be a eucalyptus plantation that was clear-cut. Restoration was also based in planting native species (ca. 34 species) to accelerate ecosystem recovery, and the matrix that surrounds the site is a mix of early to advanced successional-stage forests. After the actions of restoration, both sites were left to recover for approximately 10 years. Reference sites are located adjacent to restoration sites and we assumed that they represent the composition and structure of previous forests of each restoration system. In order to examine the functional composition of restoration and reference sites we sampled 15 plots (100 m^2 in size) per treatment and identified each species inside the plot. The main sample unit (100 m^2) was used to survey adult trees (diameter at breast height