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Diversifying growth forms in tropical forest restoration: Enrichment with vascular epiphytes

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ABSTRACT

Ecological restoration of forests is largely favored by tree planting, often leaving out other important growth forms. Despite their relevant ecological roles, in restoration plantations, epiphytic richness rarely reaches values found in reference ecosystems. At the same time, epiphytes are wasted when forests are cleared for infrastructure projects, instead of being properly relocated. The goal of this study is to improve the knowledge for epiphytic relocation and enrichment, in restoration forests. We seek to answer the following questions: (i) Over a one year period, can six species of epiphytes survive, attach to phorophytes and reproduce, after being transplanted to host trees? (ii) Is epiphyte development after transplantation affected by species of phorophytes, bark roughness, canopy cover and position of transplantation? (iii) Is performance of relocated epiphytes species specific? For this purpose, 360 adult individuals of vascular epiphytes (Bromeliaceae, Cactaceae and Orchidaceae) were transplanted onto host trees located in two semi-deciduous seasonal forests in the Atlantic Forest of Sao Paulo, Brazil. Epiphytes achieved high survival rates after one year (55.2–100% of individuals) and all species presented structures for either sexual or asexual reproduction. Their overall development was enhanced when we carried out transplantations at the beginning of wet season and using sisal string to attach epiphytes and palm fiber to cover phorophyte's bark, which were relevant factors attributing to the success of transplantations. Species of phorophyte was not an attributing factor to the successful development of transplanted individuals, which only showed slight responses to conditions they provided. However, responses among epiphytes were species-specific, demonstrating the importance of studying their biology in order to successfully enrich restoration forests.

1. Introduction

In the process of restoring degraded lands for forest restoration projects, planting tree seedlings is a highly favored method (Ruiz-Jaen and Aide, 2005). Meanwhile, the introduction of non-arboreal growth forms has commonly been disregarded. We expect trees to provide vegetative structures which allow other species to establish, assuring the long-term sustainability of forest systems (Rodrigues et al., 2009). Nevertheless, it is common in forests undergoing restoration, specifically in fragmented landscapes, that the diversity of growth forms comparable to reference ecosystems is not achieved after a few decades, including epiphytes (Kanowski et al., 2003; Garcia et al., 2016; Shoo et al., 2016).

Epiphytes are plants that grow on host trees (hereafter phorophytes), using them only for support. Their relationship with phorophytes may vary from incidental to very intimate (Benzing, 1987). In this study we considered only vascular holo-epiphytes (hereafter epiphytes), which are primarily arboreal with no soil contact (Font Quer, 1953). These plants and the organic matter they accumulate can considerably contribute to the biomass of an ecosystem (Nadkarni et al., 2004). Epiphytes develop relying on water and nutrients from atmosphere (Nadkarni and Solano, 2002), depositions and leachates, without taking them from forest floor, thus having an underlying role in biomass input and mineral cycling (Benzing, 1995). They can also retain water and make it available for fauna to drink, to bath, to forage for small insects (Cestari, 2009) and for anurans to dwell (McCracken and Forstner, 2014) and reproduce (Haddad and Prado, 2005). They can provide distinct microhabitats, microclimates and resources for both invertebrates and vertebrates (Cestari, 2009; DaRocha

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et al., 2016; Fernandez Barrancos et al., 2016). In summary, epiphytes maintain a large array of interactions with other organisms and with inorganic components of an ecosystem (Benzing, 1995).

For their relevance shown above, we expect epiphytes to naturally reach forests undergoing restoration and to contribute to their ecosystem processes. These plants, however, rarely reach desirable diversity in restoration forests in short time, which highlights their need for enrichment into these areas (Garcia et al., 2016; Shoo et al., 2016). Most studies regarding seeding or transplantation of epiphytes aim to understand their distribution in natural ecosystems (Callaway et al., 2002; Winkler et al., 2005; Cascante-Marín et al., 2008; Wagner et al., 2013) or to favor conservation of their biodiversity (Nadkarni and Solano, 2002; Mondragon and Calvo-Irabien, 2006; Toledo-Aceves and Wolf, 2008). Nevertheless, research focusing on outcomes of enriching forests undergoing restoration is still very scarce (Jakovac et al., 2007; Fernandez Barrancos et al., 2016).

The need for knowledge regarding enrichment of forests is even more pressing, since there is epiphytic material available for it, which otherwise would be wasted. Infrastructure projects over the world count on legal clear cutting of tropical forests (Correa et al., 2008; Fearnside, 2015; Li et al., 2015), from where epiphytes could be rescued (McCracken and Forstner, 2014). In addition to that, it is common that, in tropical forests, epiphytes naturally fall from host trees, most part of them in healthy conditions. They would eventually die, if left on the forest floor (Toledo-Aceves et al., 2014) and could be collected instead, as shown in Fernandez Barrancos et al. (2016). Using this material to enrich forests undergoing restoration would be an interesting destination for it, solving two problems at once.

Knowledge on how to best carry out enrichment of epiphytes into restoration forests is still lacking (Shoo et al., 2016). However, studies regarding the biology of epiphytes and their relationship with host trees in natural communities may provide clues. Past observations demonstrate that their distribution is not random (Reyes-García et al., 2008; Einzmann et al., 2015). Studies detected host specificities for epiphytes (Callaway et al., 2002; Otero et al., 2007; Benavides et al., 2011). Others found epiphytes distribution to be related to phorophytes' features such as bark roughness (Callaway et al., 2002; Addo-Fordjour et al., 2009), deciduousness (Andrade and Nobel, 1997; Einzmann et al., 2015), size (Wolf, 2005; Reyes-García et al., 2008) and different tree micro-sites (Andrade and Nobel, 1997; Nadkarni et al., 2004; Sillett and Van Pelt, 2007; Einzmann et al., 2015). Wagner et al. (2015) proposed that the association between epiphytes and their hosts can be even more complex, led by a combination of various factors such as epiphyte's and phorophyte's traits and local conditions. Epiphytes' ability to live may vary depending on the availability of favorable microclimates. In general, species abundance decreases in dryer climates (Gentry and Dodson, 1987), though some epiphytes may be tolerant in times of water scarcity (Reyes-García et al., 2008; Larrea and Werner, 2010).

Based on existing information about epiphytes and their symbiotic relationship with phorophytes, this study aims to answer the following questions: (i) Can six species of epiphytes survive, attach to phorophytes and reproduce one year after being transplanted to host trees, in two different forests undergoing restoration? (ii) Is epiphytic development after transplantation influenced by species of phorophyte, bark roughness, canopy cover and position of transplantation? (iii) Is performance of relocated epiphytes species-specific? By answering these questions, we expect to not only contribute to the knowledge on epiphyte enrichment in restoration forests, but also to propose a form to adequately relocate the epiphytes from forests about to be harvested or cleared.

2. Methods

2.1. Study sites

This study took place in two semi-deciduous seasonal forests undergoing restoration (23 years old and 13 years old respectively). Both forests are surrounded by sugarcane plantations, set amongst highly fragmented landscapes. These forests are located within the Atlantic Forest biome, where very little (approximately 11.4–16%) of the original forest cover remains (Ribeiro et al., 2009). In a reference ecosystem within the same vegetation type as these two forests under restoration, Garcia et al. (2016) found 15 epiphyte species.

The first study site (hereafter IRA) is located in Iracemápolis, São Paulo, Brazil (22°34′37″S, 47°30′31″W). Iracemápolis is a city that underwent a severe water shortage in 1986 and, in an effort to improve the watershed quality, a 50 m wide buffer around the main reservoir of the city was established (Rodrigues et al., 1992). Between 1988 and 1990, seedlings of 140 tree species (120 native and 20 exotic) were planted to restore approximately 80 ha of forest within the zoned buffer (Brancalion et al., 2014). After 23 years, no epiphyte was found in this forest (Garcia et al., 2016).

The city of Iracemápolis is located 599 m a.s.l. and has a Cwa climate (humid subtropical, with a dry winter and hot summer), according to Köppen classification. Annual precipitation is around 1333 mm, ranging from 24 mm in July to 248 mm in January. Mean annual temperature is 20.2 °C, varying from 16.5 °C to 23.0 °C in different months (Alvares et al., 2013).

The second study site (hereafter SBO), located in Santa Bárbara D' Oeste, Sao Paulo, Brazil (22°49′12″S, 47°25′00″W), has a restoration forest planted around a water reservoir. In 1998 and 1999, 34,000 seedlings from 72 different tree species were planted (Mônico, 2012) in 30 ha. Two species of epiphytes were present in the forest after 12 years (Garcia et al., 2016).

Santa Bárbara D'Oeste is located 585 m a.s.l.. The climate is classified as Cfa (humid subtropical, without dry season and with hot summer) according to Köppen classification. SBO receives an annual rainfall of approximately 1278 mm, ranging between 28 mm in July and 239 mm in January. Mean annual temperature is 20.1 °C, varying from 16.4 °C to 23.0 °C throughout different months of the year (Alvares et al., 2013).

2.2. Collection of epiphytes

Six regional species of epiphytes from three different families were collected to enrich restoration forests: *Aechmea bromeliifolia* (Rudge) Baker, *Tillandsia pohliana* Mez (Bromeliaceae), *Lepismium cruciforme* (Vell.) Miq., *Rhipsalis floccosa* Salm-Dyck ex Pfeiff. (Cactaceae), *Catasetum fimbriatum* (C.Morren) Lindl. and *Rodriguezia decora* (Lem.) Rchb.f. (Orchidaceae), all of which are classified as holo-epiphytes (Breier, 2005; Neto et al., 2009). For each experiment, 30 individuals from each species were used. We chose the healthiest specimens we could find.

In February 2011, we collected individuals of *A. bromeliifolia* and *R. decora* from phorophytes at a forest that was about to be cleared, in Santa Bárbara D'Oeste, Sao Paulo, Brazil. In March and April 2011, we collected ramets of *L. cruciforme*, *R. floccosa* and *T. pohliana* and pseudobulbs of *C. fimbriatum* from trees at the University of Sao Paulo campus in Piracicaba, Sao Paulo, Brazil. These ramets were transplanted into IRA. From June to November 2011, individuals transplanted to SBO were collected from the same places mentioned above.

We kept all individuals shaded and irrigated until the moment of transplantation. We weighted and measured all specimens