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Can transplantation of forest seedlings be a strategy to enrich seedling production in plant nurseries?

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ABSTRACT

Transplanting individual seedlings is a tool used in restoration studies, which helps to select species that are adapted to particular bioclimatic regions. We aimed to identify forest and physiological patterns in seedlings from extant areas of the Atlantic forest biome in southern Brazil. Individual tree and shrub seedlings from 5 to 55 cm in height were selected from an extant area of approximately 20 ha, transplanted to a nursery and separated into groups by size. Survival and growth rates were assessed periodically over ten months and physiological variables (chlorophyll *a* and *b* content, carotenoid content and chlorophyll *a* fluorescence) were measured at the end of the experiment. In total, 1018 seedlings were transplanted, belonging to 23 families and 50 species. The survival rate, which was on average 74.5%, varied among the height groups, with the highest mortality rate occurring shortly after transplantation. Some physiological characteristics of *Eugenia rostrifolia*, *Cupania vernalis*, *Nectandra megapotamica*, *Trichilia claussenii*, *Sorocea bonplandii*, *Actinostemon concolor*, *Trichilia elegans* and *Cordia trichotoma* change when they are transplanted to a plant nursery. However, an assessment of their growth rates confirmed that these species can develop metabolic strategies that increase their carbon uptake. The main adaptations to increase survival rates were an accumulation of carotenoids and the loss of excess energy in the form of chlorophyll *a* fluorescence. We conclude that species displayed physiological adaptations that support metabolic activities and survival after transplantation. In light of the higher survival rates and favorable plant development, we consider transplantation to be a potential complementary strategy for native species seedling production. Transplantation could increase the growth potential of species that are difficult to produce in plant nurseries and consequently support greater diversity in restoration efforts. However, further studies are needed to assess the survival rate of these transplanted seedlings in restoration plantations in comparison with non-transplanted seedlings.

1. Introduction

Restoration ecology aims to assist natural ecosystems that are degraded by human activities to achieve ecological integrity by restoring their structure and functionality to a minimum level of biodiversity and variability of ecological processes (Hobbs and Harris, 2001; Kageyama et al., 2008).

Among the methods used to reverse the degradation of an area, forest plantations are commonly employed (Rodrigues et al., 2009; Campoe et al., 2014; Ferez et al., 2015). Tree planting contributes to a quick recovery of forest structure, thus providing a suitable habitat for the re-establishment of ecological succession (Aide et al., 2000; Chazdon, 2008; Holl and Aide, 2011).

However, the limited knowledge of different species and interspecific variability are barriers to the production of native species seedlings. Other obstacles include limited knowledge of forest species' phenology and physiology, as well as the existence of several dormancy mechanisms (Fenner and Thompson, 2005), and high predation rates (Zamith and Scarano, 2004).

In this sense, studies have shown the benefits of seedling production in nurseries through transplantation of individuals of natural regeneration (Viani and Rodrigues, 2007; Rodrigues et al., 2009). One of the main advantages associated with this technique is that the seedlings produced are adapted to their own specific bioclimatic regions, especially for species that are currently not available in nurseries. Another advantage is that some steps are

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eliminated, such as tree selection, seed collection, extraction, processing, storage and pre-germinative treatments to overcome dormancy. These steps can be costly and are often difficult due to a lack of supporting technical information.

However, many adjustments need to be made to maximize survival in order to obtain a large number of species, mainly, in relation to the behavior of shade-tolerant species (typical of the understory) when transplanted to the nursery, where there are alterations in the microclimate, such as increased luminosity and temperature and low air humidity. Such alterations tend to reduce the photosynthetic capacity of the plant by degradation of photosynthetic pigments and photoinhibition (Kitao et al., 2000), causing reduction in the quantum efficiency of PSII and a decrease in the efficiency of carboxylation (Gilmore and Govindjee, 1999).

According to Denslow et al. (1990), shade-tolerant species are capable of developing and reproducing in environments with greater luminous intensity, often presenting growth rates equal to or even greater than those of light-demanding species. When plants adjust to the photoinhibitory damage caused by transfer to environments with high luminosity, there is an adaptation of the photosynthetic apparatus to different luminous flux densities (Walters, 2005), which is related to the adequacy of relative proportions of components involved in absorption, transmission and use of luminous energy (Gonçalves et al., 2010).

In this context, we aimed to select forest tree species that are rarely found in nurseries because they are difficult to produce. We identified morphological and physiological patterns in these species after transplanting them to the nursery, considering the following questions: (a) how do responses, in terms of survival and growth of seedlings in a nursery, differ between size classes? (b) which metabolic changes associated with the photosynthetic apparatus are indicative of the development of seedlings from different ecological groups when transplanted from an understory to a nursery?

2. Material and methods

Seedlings were collected from a remnant of the Subtropical Seasonal Forest, located in the Southern Atlantic Forest biome in the state of Rio Grande do Sul, Brazil (29°27′14.71″S and 53°18′14.79″W). The soil of the study area is classified as Entisol, characterized by low levels of available aluminum, sandy texture with small variation throughout the profile. These soils present A and C horizons and are underdeveloped, deep or of average depth, with primary mineral values over 4% and of easy weathering in the sand and or gravel fractions (Embrapa, 2013). The climate, according to the Köppen classification, is of the "Cfa" type, with average annual rainfall between 1400 and 1760 mm (Alvares et al., 2013). In addition, the understory of the study area showed an average luminosity of 43%, measured with the aid of a light meter on a sunny day, between 11:00 am and 2:00 pm.

This experiment is part of a study that analyzed different exclusion rates of natural regeneration and its effect on the developmental dynamics of remnant forest areas (Turchetto, 2015). The young seedlings from this study were randomly selected and subsequently analyzed per species for their transplantation potential in different height groups (group 1 from 5 to 15 cm; group 2 from 15.01 to 25 cm; group 3 from 25.01 to 35 cm; group 4 from 35.01 to 45 cm; group 5 from 45.01 to 55 cm).

During the transplantation in November 2013 (which took place on a rainy day to avoid dehydration of the seedlings), seedlings were carefully removed from the soil, avoiding damage to their root system as much as possible. They were subsequently placed in containers with a water-retaining polymer, where they remained until the moment they were planted (2 h after removal from the soil).

In the nursery, the seedlings were placed in polyethylene bags containing 1.0 L of substrate with subsoil base and cow manure (2:1) and a controlled-release base fertilizer (fertilizer dosage of 6 g L^{-1}) with the following chemical composition of macronutrients: 15% of nitrogen (N); 9.0% of superphosphate (P_2O_5), 12.0% of potassium chloride (KCl); 1.0% of magnesium (Mg) and 2.3% of sulfur (S); and micronutrients: 0.05% of copper (Cu); 0.06% of manganese (Mn), 0.45% of iron (Fe) and 0.2% of molybdenum (Mo).

During transplantation, any large roots exceeding the container size were trimmed. The seedlings were subsequently placed in containers filled with substrate and irrigation was started in order to help the substrate enclose the root system. Furthermore, 50% of the leaves of each individual plant were cut in order to reduce water loss. The containers were kept under a structure with a layer of cloth providing 50% shade.

The methods used were the same as those used in the production of native seedlings. During the first two months, sprinkler irrigation consisted of 12 mm d^{-1}, spread over six daily irrigations and in the rest of the period, it was reduced to 6 mm d^{-1}. Manual weed control was continuous. Cover fertilizer was added 150 days after transplantation, with the same type and amount of fertilizer that was used in the initial fertilization.

The transplanted species were classified into ecological groups according to Budowski (1965), who proposed four ecological succession groups: pioneer, early secondary, late secondary and climax. The classification of species into these succession groups was based on field observations, a literature review (Vaccaro et al., 1999; Scipioni et al., 2013) and the consultation of experts.

The seedlings were assessed for survival rates and growth (in height) immediately after transplantation and, thereafter, every 60 days for a period of 10 months. For the height measurements, a millimeter ruler was used. The survival data were converted to percentages, whereas growth was analyzed through changes in height during the study period.

Additionally, we analyzed the availability of species transplanted from the understory in the forest nurseries in the region, through consultation with 21 nurseries in the state of Rio Grande do Sul, Brazil, in the Southern Atlantic Forest biome.

Among the transplanted species, we selected eight species, with heights between 5 and 55 cm, at random, not considering the separation into height classes, which were: *Trichilia elegans* A. Juss. (late secondary), *Actinostemon concolor* (Spreng.) Müll. Arg. (late secondary), *Cordia trichotoma* (Vell.) Arrab. Ex Steud. (early secondary), *Nectandra megapotamica* (Spreng.) Mez. (early secondary), *Cupania vernalis* Cambess. (early secondary), *Trichilia claussenii* C. DC. (late secondary), *Sorocea bonplandii* (Baill.) W.C. Burger et al. (late secondary), and *Eugenia rostrifolia* D. Legrand (climax). The eight species were selected considering different characteristics, such as the ecological group (early secondary, late secondary and climax), the potential of young seedlings with different ecological characteristics for adapting to environments with contrasting light intensities. We also considered abundance and the importance of each species in the understory, because abundant species tend to develop under different environmental conditions in the forest evaluated and have the ability to develop different physiological adaptations depending on environmental conditions.

When the seedlings were removed from the forest, we marked four individuals per species in the forest understory and in the nursery, to measure the increase in height and physiological parameters (chlorophyll *a* and *b* content, total chlorophyll content, carotenoids, and chlorophyll *a* fluorescence), for later comparisons between the two environments.

The determination of chlorophyll and carotenoid content was performed ten months after transplantation at the Laboratory of