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Plant size dependent response of native tree regeneration to landscape and stand variables in loblolly pine plantations in the Atlantic Forest, Argentina

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ABSTRACT

The interest in the conservation of biodiversity in productive ecosystems has increased considerably in recent years due to the continuing loss of natural vegetation. The effect of forest plantations on biodiversity is currently a relevant research topic since they are expanding worldwide. Native understory vegetation may maintain ecosystem processes and increase the availability of habitats, food and other resources for different animal groups. Native tree regeneration in plantations is affected by the planted species, stand age and density, and silvicultural practices, among others. Despite that some general trends have been identified, results from different studies are not always comparable, partially because not all sources of variation were considered simultaneously, the size of plants is different between studies, no different classes of plant sizes are compared, or the local flora determines specific responses to landscape and stand variables. In this work, we analyzed the relationship between native tree density, species richness and species composition in the understory of forest plantations and stand characteristics including stand age and density, canopy openness, proximity to native forests remnants and pre-planting land use history. The study was conducted in monoculture plantations of *Pinus taeda* in Misiones Province, Northeastern Argentina. In 35 stands, we estimated plant density and species richness for three plant size classes: seedlings (> 50 cm height and < 1 cm in diameter at breast height (DBH)), saplings (1–5 cm DBH) and small trees (5–10 cm DBH). Our results are in agreement with general trends previously reported in the study area and worldwide. We found that native trees in the plantations showed a strongly size-dependent response to stand and landscape variables. The composition and richness of the seedlings were primarily dependent on the native forest cover at a landscape scale while the species composition, richness, and density of saplings and small trees were mainly affected by stand age and density. Our results showed that the management of pine plantations should maintain the rotation for more than 20 years, a basal area below 30 $m^2 \cdot ha^{-1}$ and a 25–30% of native forest cover at the landscape scale to increase the richness and density of the native trees in loblolly pine plantations of the Atlantic Forest.

1. Introduction

The interest in the conservation of biodiversity in productive ecosystems has increased considerably in recent years due to the continuing loss of natural vegetation and habitat reduction for animal and plant species (Estades et al., 2012; Simonetti et al., 2013). The effect of forest plantations on biodiversity is currently a relevant research topic since they are expanding worldwide. Biodiversity tends to increase when forest plantations are set in degraded environments (Hartmann et al., 2010; Lugo, 1997; Stephens and Wagner, 2007), but a clear loss of biodiversity is observed when plantations replace native forests (Zurita, 2008). However, many native plant species can regenerate in tree plantations, leading to the formation of a diverse understory (Geldenhuys, 1997; Keenan et al., 1997; Lugo, 1997).

Native understory vegetation may maintain ecosystem processes and increase the availability of habitats, food and other resources for different animal groups. Therefore, plantations can act as corridors, rather than barriers, improving landscape connectivity, animal movement, and plant dispersion (Lindenmayer et al., 2003). Moreover, plant species contribute to the maintenance of a diverse soil biota enhancing

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the productivity in the long-term (De Deyn et al., 2008). In landscapes dominated by forest plantations, stands of different ages form a dynamic mosaic in which young stands increase their structural complexity until harvested. Improving understory density and diversity promotes an increase in the provision of ecological services throughout the growing cycle (Lindenmayer et al., 2003; Stephens and Wagner, 2007).

Previous studies worldwide showed that native tree regeneration in plantations is affected by the planted species, stand age and density, and silvicultural practices, among others. It has been observed an increase in regenerating native trees density and species richness with stand age (Geldenhuys, 1997; Keenan et al., 1997) as a consequence of increased chance for arrival, establishment and growth as well as due to changes in plantation structure. Habitat permeability for seed dispersers is higher in older than in younger stands (Vespa et al., 2014) which increase seed arrival. In addition, as a consequence of tree growth and silvicultural practices, there are changes in stand structure that strongly influence the understory structure throughout the growing cycle (Aubin et al., 2008; Dummel and Pinazo, 2013; Otto et al., 2012; Seiwa et al., 2012; Senbeta et al., 2002). Old stands show a higher species richness of native trees in the understory (Dummel and Pinazo, 2013; Onaindia and Mitxelena, 2009; Wang et al., 2004), and tend to be more similar to the surrounding native vegetation (Norton, 1998) than younger plantations. A reduction in the stand density planting density usually favors the understory development (Dummel and Pinazo, 2013; Onaindia and Mitxelena, 2009; Wang et al., 2004). At a similar age, stands with lower tree density exhibit a higher species richness than plantations stands with higher tree densities (Loumeto and Huttel, 1997; Seiwa et al., 2012).

Thinning affects the development of the understory by increasing the availability of resources as well as acting as a mechanical disturbance. Thinning can increase light availability and promote other environmental changes associated with the reduction in basal area (Arevalo and Fernandez-Palacios, 2008; Trentini et al., 2017; Utsugi et al., 2006). The mechanical damage associated with thinning can also have a counteracting effect by increasing the mortality of native seedlings and saplings. The responses of tree species to the environmental changes promoted by thinning or tree growth throughout the growing cycle depend on plant size. Recruitment, growth and mortality rates are size-specific due to ontogenetic changes between life stages as well as different conditions of light availability associated with a vertical gradient (Brokaw and Busing, 2000; Lusk, 2004; Metcalf et al., 2009).

Land use history and landscape structure also affect the density and diversity of the native trees established in plantations. An intensive land-use history may result in plantations with a low seed bank expression and a low regrowth (Gachet et al., 2007). In these cases, the regeneration of understory plants is highly dependent on dispersion processes (Senbeta and Demel, 2001), so the presence of seed sources in the environment becomes essential (Ito et al., 2004). Management at the landscape scale should maintain or create a suitable configuration of native forest remnants to ensure the arrival of seeds to the understory of the plantations (Koh et al., 2015; Onaindia and Mitxelena, 2009). Also, maintaining the connectivity of forest remnants is extremely important to reduce degradation. Reduced seed dispersal has been recognized as an important mechanism for degradation of forest remnants, in the Atlantic Forest in Brazil (Cramer et al., 2007; Tabarelli et al., 2004).

Despite these general trends are recognized, results from different studies are not always comparable. This might be because not all sources of variation are simultaneously considered, for example, different plant sizes between studies, the different plant size classes were not compared, or because the local flora determined specific responses to landscape and stand variables. Thus, further local studies are needed to obtain specific information on silvicultural management and increase our general knowledge about plantations and biodiversity.

The subtropical forests in northeastern (NE) Argentina correspond to the southern portion of the Atlantic Forest extending along the Atlantic coast of Brazil and southeastern Paraguay. Approximately 93% of the original cover of the Atlantic Forest has been lost due to human activities. During the last three decades, the area of forest plantations in Argentina, mostly of *Pinus taeda*, had a five-fold increase (Izquierdo and Clark, 2012). Specific information is undoubtedly needed to optimize a cost-benefit relationship for adopting management decisions. In this work, we analyzed the relationship between the species composition, richness, and abundance of native trees in the understory and stand characteristics including stand age and density, canopy openness, proximity to native forests remnants and pre-planting land use history. We expect that (1) aging will have a positive effect at lower stand densities and close proximity to native forests, (2) the intense land use history and the proximity to the native forest will affect the composition of tree species by influencing the species establishment differentially from the soil propagule bank or through seed dispersal, and (3) factors related to the soil propagule bank and to seed dispersal (i.e., land use history and proximity to the native forest) will more strongly affect small plants while those related to growth conditions (i.e., stand density and canopy openness) will affect especially larger plants.

2. Materials and methods

2.1. Study area

The study was conducted in monoculture plantations of *Pinus taeda* belonging to small and medium forest companies with distinctive management conditions, land use history and site quality, located in Misiones Province, Northeastern Argentina (Fig. 1). Thirty-five stands of different age and plantation density were selected for sampling. The pine plantations were located mainly on red soils (Ultisols, Kandiudults) (Soil Survey Staff, 1992) and corresponded to the first, second or third production cycle on lands from both agricultural crops and native forest clearcuts. The annual rainfall in the study area is about 2000 mm, evenly distributed throughout the year, and an average annual temperature of 21.8 °C with a monthly mean amplitude of approximately 10.8 °C (Cabrera, 1976).

2.2. Sampling design

In each stand, we established one sampling unit which consisted of four circular plots located in the corners of a 30 m side square. Circular plots of different areas were used for trees (300 m^2), saplings (100 m^2) and seedlings (25 m^2). Sampling units were established at least 20 m far from the stand edge. The center of each plot was georeferenced using a global positioning system (GPS). The geographical coordinates were projected into plane coordinates for spatial analysis.

2.3. Tree regeneration

We estimated the species richness and density of three size classes: seedlings (> 50 cm height and < 1 cm in diameter at breast height (DBH)), saplings (1–5 cm DBH) and small trees (5–10 cm DBH). We considered trees those greater than 10 cm DBH at adult stage.

2.4. Canopy cover and stand structure

In the center of each circular plot, we took a hemispheric photo at 1.3 m height using a Nikon Coolpix 950 camera with a Nikkor 8 mm lens on a self-level platform (Delta-T Devices, Cambridge, UK). Photos were analyzed with the software Gap Light Analyzer to estimate: a) the fraction of total solar radiation transmitted (FRT, %), b) the canopy openness (CO, %), and c) the leaf area index (LAI). The diameter at breast height (DBH) of the *Pinus taeda* trees was measured in each of the 300 m^2 plot and the stand basal area (BA), density (individuals per hectare) and mean quadratic diameter of pines (pmqd) was calculated.