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Influence of fire regime on forest structure and restoration of a native forest type in the southern Andean Range

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ABSTRACT

There is convincing scientific evidence that fire regime has been affected by climate change, both in their frequency and severity, consequently causing more ecological and socio-economic impacts. Although fire has played an important role in the shaping of the Chilean ecosystems, some forest types could experience changes in their structure, composition and dynamics in relation to the increased incidence of fire. This research has analyzed the changes that have occurred in the structure, composition and dynamics of the "Coigüe-Raulí-Tepa" forest type in a medium-term (13 years since the occurrence of fire) in the "Malleco National Reserve", at its northernmost distribution area. This forest type is dominated by *Nothofagus dombeyi*, *N. alpina* and *Laureliopsis philippiana*. Forest structure has been modified from a "log-normal distribution" to a "potential diameter function". Canopy composition and regeneration establishment have shown different post-fire responses among *Nothofagus* species and *L. philippiana*. After 13 years, the burned area has been massively colonized by *Nothofagus* sprouting. However, there is no successful post-fire response of *L. philippiana* (only 1.19% of seedlings). According to species distribution limit, *L. philippiana* can be highly vulnerable to the effects of climate change and fire regime. Forest managers should take into account the conservation of this forest type when supported high severity fires because they could become secondary forests of other forest types or altered forests which are difficult to classify within any type.

1. Introduction

Since time immemorial, fire has played an important role in the configuration and shaping of the heterogeneous Andean landscape (González and Veblen, 2007), causing the adaptation of native species to fire disturbances and playing an important role in forest dynamics (Veblen et al., 1995, 1996; Donoso, 1998). Fire regime in these ecosystems is characterized by relatively frequent low-intensity surface fires, and less frequent catastrophic or high-intensity fires, with a high tree mortality rate (González et al., 2005, 2010a,b). However, the fire regime of the late twentieth century and early twenty-first century has been modified globally due to socioeconomic changes, the abandonment of rural areas and the impact of change climate (Kitzberger and Veblen, 2003; Flannigan et al., 2006; Khabarov et al., 2014; Oddi and Ghermandi, 2016). The change of fire regime has increased fire severity and their ecological and socioeconomic impacts, and has contributed to larger fires and longer fire seasons (González et al., 2005; Quezada, 2008; Iglesias, 2011; Molina et al., 2011; Rocca et al., 2014; Castillo et al., 2017). As an Andean example, it is the occurrence of two catastrophic forest fires in the Tolhuaca National Park and the Malleco National Reserve (years 2002 and 2015), separated by only 13 years.

In the south-central Chile (between latitude 32 and latitude 55° S), native forests are dominated by *Nothofagus* species. Spatial distribution of these species are greatly affected by massive disturbances which periodically create conditions favorable for their regeneration. These forests in the mid-altitude zone (between 500 and 1000 m above sea level) prevent replacement of the shade-intolerant *Nothofagus* by other shade-tolerant species, such as *Laureliopsis philippiana* (Looser) R.Schodde and *Dasyhyllum diacanthoides* Less. In this sense, the structure and dynamics of *Nothofagus* forests are conditioned by the fire regime (Burns, 1993; González et al., 2010a). They are capable to establish themselves massively

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after a fire forming seedling patches according to their altitudinal and topographic preferences (Burns, 1993; Donoso, 2008; González et al., 2010a; Rogeau and Armstrong, 2017). The vegetation recovery is also directly related to forest site quality (Donoso, 2008), mainly associated with its resources, such as lithologic, climatologic and light conditions (Bertacchi et al., 2014; Bhadouria et al., 2016). The shade-intolerant species of the *Nothofagus* genus, such as *N. dombeyi* seedlings colonize immediately in gaps and open areas (González et al., 2005), producing a massive seed recruitment (Veblen et al., 1996; González et al., 2010b) and seedling establishment (Donoso, 1998). On the other hand, the semi-shade-tolerant species of the *Nothofagus* genus, such as *N. alpina*, have developed post-fire mechanisms, in order to regenerate from sprouts (Veblen et al., 1996; Donoso, 2008).

Even though natural fire regime is considered as a cornerstone of the ecosystem dynamics (Pausas, 2012), vegetation response depends on the adaptation of species to changing fire regime, both fire frequency and fire intensity (Flatley et al., 2015; Chavardes and Daniels, 2016). Post-fire resprouting and mortality of *Nothofagus* species have shown significant differences based on the fire severity (González et al., 2010b). *Nothofagus* species regenerate in a much more efficient way under moderate severity conditions. On the other hand, under severe burning conditions, some species could have difficulty to regenerate (González et al., 2010a). Therefore, there is a growing interest in post-fire studies based on fire severity and seedling and sapling responses in order to make decisions about restoration activities (Vega et al., 2013; Bhadouria et al., 2017).

In spite of fire is an active element in the configuration and shaping of Andean ecosystems and the fire adaptations of native species, the new fire regime could transform fire into a threat to the biodiversity and conservation of certain forest types (Iglesias, 2011). Large fires are expected to be more frequent in the twenty-first century. There are different studies according to the short term vegetation recovery (González and Veblen, 2007; González et al., 2010a,b), but there is a lack of information about the medium-term dynamics. The aim of this study was to describe changes in the structure of a “Coígue-Raulí-Tepa” forest type (*Nothofagus* forests) after 13 years of fire occurrence, when it was affected by a high fire severity. The structure was analyzed based on canopy composition and forest changes in terms of both diameter and height distributions. Our study would not be limited to the canopy layer, but it shall also analyze the current condition of regeneration according to its composition and its diameter and height structure. The outcome of this research could be used as support material for the decision-making process integrating biodiversity conservation and forest fire restoration goals. Therefore, the potential impacts associated to fire severity should provide a tool to improve budget allocation and landscape management in the process of sustainable territorial planning of “Coígue-Raulí-Tepa” forests.

2. Materials and methods

2.1. Study area

The Malleco National Reserve is located in the northeast of the IX Region of Chile (Fig. 1), within the “Araucarias Biosphere Reserve”. The Reserve occupies 16,625 ha, constituting the first protected area established by the Chilean State (1907). However, after its legal protection, the Reserve has been affected by severe forest fires in 1912, 1928, 1956 (Iglesias, 2011), 2002 and 2015. The first of them were directly related to the forest clearing to create agricultural lands and livestock feed resources (Otero, 2006). While the 2002 fire was caused by lightning, the 2015 fire has pointed out that its origin is caused by an anthropogenic cause. It is noteworthy that these former fires affected low-altitude areas of the Reserve (Iglesias, 2011).

We selected “Coigüe-Raulí-Tepa” forest type that covers 1350 ha in the Malleco National Reserve. In the study area, this forest type is characterized by dominant canopy stratum of *Nothofagus dombeyi* Mirst.Oerst. and *N.alpina* (Poepp & Endl.) Oerst. of 20–30 m of height, with co-dominant and intermediate strata of *Laureliopsis philippiana* (Looser) (R. Schodde). and other accompanying species, such as *Gevuina avellana* Molina. and *Aextoxicon punctatum* Ruiz et Pav. The undergrowth is dominated by *Chusquea* spp. and *Lycopodium* spp., although a wide variety of other species can be found, most notably *Drimys winteri* J.R.Forst & G. Forst and *Gaultheria mucronata* (L.f.) Hook & Arn.

The sampling area was located in the “Niblinto” sector, with an altitude between 870 and 1010 m above sea level and north-facing slopes. The annual precipitation varies between 2500 and 3500 mm, with below-freezing temperatures and frequent snowfalls in the winter. The average slope was highly variable based on the sampling unit, ranging between 18% and 41%. The soil is Andosol type, or derived from recent volcanic ash deposited on basaltic and andesitic bedrock. Although this soil presents a suitable infiltration capacity, it could have limitations due to the erosion encouraged by the absence of vegetation cover caused by the occurrence of forest fires (CONAF, 2014).

2.2. Design of field inventory

The pre-fire inventory (the last months of 2000 and early 2001) was conducted using four strata based on the differences in stand density. For a stratified random sampling, considering an infinite population, a maximum of 10% sampling error would be allowed with a fiducial probability of 95%. According to these statistical conditions, the sample amounted fifteen plots in four strata that cover more than 130 ha. All these sampling units were affected by the 2002 fire, so vegetation recovery had a period of 13 years. However, five original plots were affected by a second large fire in March 2015, so they didnít have vegetation cover at the time of this second inventory. Out of the ten plots that were not affected by the 2015 fire, eight of them were affected by a “high severity” (burned understory and a mortality of 65–85% of the trees, existing live trees in small remnant patches), and two of them were affected by a “very high severity” (total consumption of understory and canopy layers, with changes in the color and texture of the soil). According to the small size of “very high severity” sample (not enough for a statistical analyst), we only considered the “high severity” sampling units to this study.

The forest inventory was carried out in square plots with 1225 m^2 including dominant trees, co-dominant, intermediate trees (diameter at breast height up to 15 cm) and suppressed trees (diameter at breast height up to 2 cm). The data sampling collected both stand and tree mensuration variables such as canopy composition (*N. dombeyi*, *N. alpina*, *L. philippiana* and other species), diameter at breast height (cm), stand height (m), commercial height (m), phytosanitary condition based on visual examination according to FAO standards and potential forest exploitation depending on the stem characteristics (sawn-wood, industrial roundwood and paperboard or biomass production).

On the other hand, regeneration inventory was carried out in square subplots with 12.56 m^2 according to the high plant density. Four subplots were collected in each sampling unit, and as a consequence, the regeneration inventory amounted thirty-two plots. The data collection included the following variables: species, basal diameter (cm), plant height (m), phytosanitary condition (good, moderate and bad categories based on visual examination