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Economic susceptibility of fire-prone landscapes in natural protected areas of the southern Andean Range

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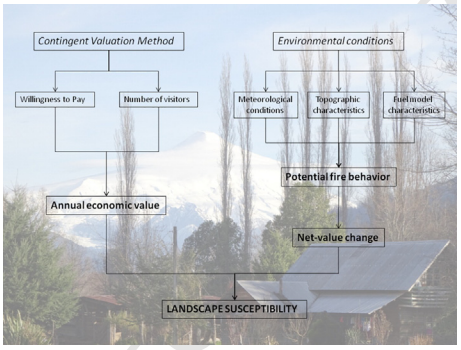
HIGHLIGHTS

- Landscape goods could constitute a large proportion of the ecosystem value, mainly in protected areas.
- The economy relevance of landscape goods would justify greater investments in fire prevention programs.
- Fire intensity level can directly support the estimation of the net-value change.
- There was an outstanding difference in landscape susceptibility based on the natural protected area.

GRAPHICAL ABSTRACT



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ABSTRACT

Large fires are the most important disturbances at landscape-level due to their ecological and socioeconomic impacts. This study aimed to develop an approach for the assessment of the socio-economic landscape susceptibility to fire. Our methodology focuses on the integration of economic components of landscape management based on contingent valuation method (CVM) and net-value change (NVC). This former component has been estimated using depreciation rates or changes on the number of arrivals to different natural protected areas after a large fire occurrence. Landscape susceptibility concept has been motivated by the need to assist fire prevention programs and environmental management.

There was a remarkable variation in annual economic value attributed to each protected area based on the CVM scenario, ranging from 40,189–46,887 $/year ("Tolhuaca National Park") to 241,000–341,953 $/year ("Conguillio National Park"). We added landscape susceptibility using depreciation rates or tourist arrival decrease which varied from 2.04% (low fire intensity in "Tolhuaca National Park") to 76.67% (high fire intensity in "Conguillio National Park"). The integration of this approach and future studies about vegetation resilience should seek management strategies to increase economic efficiency in the fire prevention activities.

1. Introduction

Forest fires are an active element in the configuration and shaping of wide variety of ecosystems (FAO, 2007). In this sense, fire has played a keystone role in the shaping of the heterogeneous Andean landscape (González et al., 2010) and its forest dynamics (Veblen et al., 1995;

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Donoso, 1998). Although humans have used fire since the Neolithic Era (Abrams, 1992), climate change and anthropic factors are transforming fire into a threat to the biodiversity and conservation (Chavardes and Daniels, 2016).

Catastrophic forest fires have ravaged parts of Chile, Portugal, Spain and United Sated this year. As an example, Chile was affected by severe forest fires between January and February 2017 with >470,000 ha under different fire intensity levels (Rivera-Careaga, 2017). Lead Emergency Management Authority (LEMA) catalogued this fire as a "firestorm", an unprecedented phenomenon in the history of humankind (European Civil Protection Agency, 2017). They highlighted the fact in a single night the fire consumed 8000 ha/h. Comparatively, France requested support for a fire that burned a total of 8000 ha and Spain's firefighting capacity collapsed with a fire that involved just 25,000 ha. The experts hypothesize that the type of fire that is being seen for the first time with Chile's "firestorm" will occur in the future in several countries because it is partly due to phenomena such as climate change.

Forest fires constitute a worldwide problem, given their serious tangible assets, environmental service and landscape goods impacts (Rodríguez-Silva and González-Cabán, 2010). Therefore, an increase in economic losses from wildfires has been corroborated from different studies (Román et al., 2013; Chuvieco et al., 2014). In this sense, large wildfires could become a threat to social valuable landscapes because of climate change and fire regime change (Molina et al., 2017a). Landscape resource don't usually take the form of monetary values in wildfire impacts valuation. Although indirect methods are challenging, forest management should involve intangible assets, mainly in natural protected areas. The high socio-economic value of protected areas should lead to preventive actions, in order to preserve its tourism activity, and as a consequence, its economic value. It is essential that landscape resource can be fully taken into account in planning and decision-making.

Although tangible assets and ecological losses have immediate short and medium-term importance, the disappearance or changes in landscape give rise to additional long-term impacts. However, in spite of some research approaches (Rodríguez y Silva et al., 2010; Castillo et al., 2013), there is lack of knowledge of the long-term economic impacts, mainly in natural protected areas. The conclusions of these former studies focus on the need of a detailed study of the economic susceptibility of forest landscapes against wildfires. It is essential that the socio-economic values of the environmental services and landscape goods be fully taken into account in planning and decision-making (Costanza et al., 2006; De Groot, 2006). Landscape can take the terms of monetary units though indirect methods such as travel cost, hedonic technique and contingent valuation (CVM). CVM is the main stated preference method over the last three decades (González and León, 2003; MacMillan et al., 2006; Grammatikopoulou and Olsen, 2013; Chen and Hua, 2015; Chatterjee et al., 2017). In spite of the CVM limitations (Schläpfer et al., 2004; Hynes et al., 2011), this methodology has been used in studies in order to facilitate the comparison of different management alternatives to mitigate forest fires (Molina et al., 2016).

Different studies have evaluated the economic damages caused by fire (Butry et al., 2000; Morton et al., 2003; Barrio et al., 2007), and even some of them (Rodríguez y Silva et al., 2010; Castillo et al., 2013) have been developed in Andean Range. However, one of the most difficult things to do in valuing the economic impact of fire on natural resources is to determine the economic value lost (Rodríguez-Silva and González-Cabán, 2010; Román et al., 2013). Potential damages can be quantified as the percentage net value change (CNV) depending on fire intensity and resources sensibility (Thompson et al., 2011). In this sense, taking potential fire behavior into account is fundamental to determine the economic efficiency of fire prevention and suppression activities (Duguy et al., 2007; Thompson et al., 2013). Fire behavior was included by fire intensity levels (FIL) which are closely related to the impact caused by the amount of heat emitted (Rodríguez-Silva et al., 2012; Castillo et al., 2017). The identification of CNV caused by wildfires was expressed as depreciation rates according to FIL based on the simplicity required by forest managers (Zamora et al., 2010; Molina et al., 2011). These depreciation ranges were identified based on the social perception using the stated social preferences. In the last part of the contingent valuation questionnaire, panoramic photographs were used to estimate depreciation rates or visits frequency depending on three outstanding FIL (Molina et al., 2017b).

Development of a multidiscipline forestry policy is not possible without considering landscape susceptibility, because of the importance of recreation activities for rural development and territorial planning (Molina et al., 2016). This paper aims to develop a social approach for the economic assessment of the landscape susceptibility to fire. The sense of this study is the identification of the landscape resource affectation and its economic valuation based on tourism and recreational impacts using three important natural protected areas in Chile. By extending landscape approach from the traditional point of contingent valuation studies, we have incorporated landscape susceptibility in order to identify effects of fire occurrence. Our approach proposes an economic framework for annual landscape susceptibility (Scott and Thompson, 2015) based on landscape value and net-value change (CNV). While landscape resource has been valued according to CVM, CNV has been estimated based on three potential fire intensity levels using estimated post-fire number of visitors. The landscape susceptibility model is more complete than the former studies, since it includes economic landscape value and potential fire impacts. The results could emphasize in the meaningful role of the recreation resource on natural protected areas, and as a consequence, the importance of fire prevention activities to landscape conservation. Landscape susceptibility approach would add to learning community knowledge the non-market fire impacts according to the higher probability of future large fires or "firestorm" in several countries.

2. Material and methods

2.1. Study area

The climate of the Andean Range has a Mediterranean influence reflected by a winter-maximum in precipitation and relatively dry summers. Annual precipitation varies between 1500 and 3000 mm, although at higher altitudes the precipitation can reach >4000 mm, the majority falling as snow. In this mountain range, most of the soils are derived from ash deposited by volcanic activity (Donoso, 1998). About 97% of the Araucaria forests are restricted to the upper elevations of the Andean mountain range from Region VIII to Region XIV. In this study, we used three natural protected areas of the IX Region of Chile ("Araucania Region") within the "Araucarias Biosphere Reserve" (Fig. 1).

- "Conguillio National Park": this area occupies about 608 km^2, formed mainly by *Araucaria araucana* and *Nothofagus* spp. The shape of the Monkey Puzzle trees, lakes and Llaima volcano increases the scenic beauty of this park. In this sense, Conguillio was the most visited park in the IX Region (111,709 visitors in 2016). "China Muerta", which is an adjoining National Reserve with similar landscapes, was severely burned in a 2015 fire.
- "Tolhuaca National Park": this park encompasses part of the forested foothills and part of the upper elevations of Andean mountain range covering about 6500 ha. Their main attractions are mixed forest landscape, wildlife, Tolhuaca volcano, small lakes and thermal waters. The visitors' number was 11,270 in the last year. The Park and the adjoining "Malleco National Reserve" were affected by severe forest fires in 2002 and 2015.
- "Malalcahuello National Reserve": this northern area combines *Araucaria–Nothofagus* forests with a charcoal desert landscape of ash and sand (Lonquimay volcano and Navidad Crater). The reserve has a surface area of about 13,800 ha including the ash volcano

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