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Landscape dynamics and their effect on the functional connectivity of a Mediterranean landscape in Chile

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ABSTRACT

Land use and cover changes have been identified as a major factor contributing to shape landscape structure and biodiversity patterns, particulary in areas with a long history of human occupation and habitat fragmentation, such as the Mediterranean landscapes. However, the existing studies on landscape change indicators for Mediterranean areas have mostly focused in Europe, while for other Mediterranean zones, and especially for South America, there is a serious lack of knowledge concerning the impact of landscape dynamics on ecological processes. Further research on this topic is urgently needed, given the high biodiversity levels and the rapidly increasing rates of human modification in the Mediterranean landscapes of South America. For this purpose, we investigated the dynamics of a landscape in the semiarid region of the Mediterranean zone of Chile, and measured the effect of those dynamics on functional connectivity, during a period of about four decades (1975–2011). Landscape connectivity indicators were extracted from a series of Landsat images. The Equivalent Connnected Area index (ECA) was used as indicator of connectivity trends, and was evaluated for three representative distances of seed dispersal in the study area (150 m, 500 m and 1000 m). In addition, the patches that most contribute to maintain the present connectivity, and their roles as connectivity providers, were identified through a set of commensurable indicators: betweenness centrality and the fractions (intra, flux connector) of the Integral Index of Connectivity. We found that these indicators were useful to detect and summarize a number of previously unreported trends in these Mediterranean landscapes. First, population growth and economic development were compatible with an increase in functional connectivity for forest habitats, mainly because the abandonment of marginal agricultural lands and their subsequent conversion to espinals (*Acacia caven)* triggered vegetation succession towards secondary forests. Second, increased forest connectivity was not associated to a decrease in the characteristic heterogeneity of Mediterranean landscapes. Third, many patches of espinal, despite being commonly regarded as of poor conservation value, were crucial to promote connectivity by acting as stepping stones among other patches with higher habitat quality. The approach here presented provides a combined assessment of landscape structure, function and change that should be valuable and applicable to deliver operational indicators in dynamic landscapes in South America and other Mediterranean regions.

1. Introduction

Land use and cover change (LUCC) has been identified as an important factor determining the structure and functionality of the landscape, especially in regions having a long history of human occupancy (Parcerisas et al., 2012). Socio-economic changes are the main drivers of LUCC and have a strong impact on landscape structural patterns and ecological processes, improving or degrading their capacity to support a variety of species and ecosystem services (Forman, 1995; Stoms et al., 2002; Potschin and Haines-Young, 2006). Recent work has shown the dramatic changes which have taken place during the past few years in South American landscapes (García et al., 2001; Echeverría et al., 2008; Armenteras et al., 2013). In particular, the Mediterranean region of Chile, classified as

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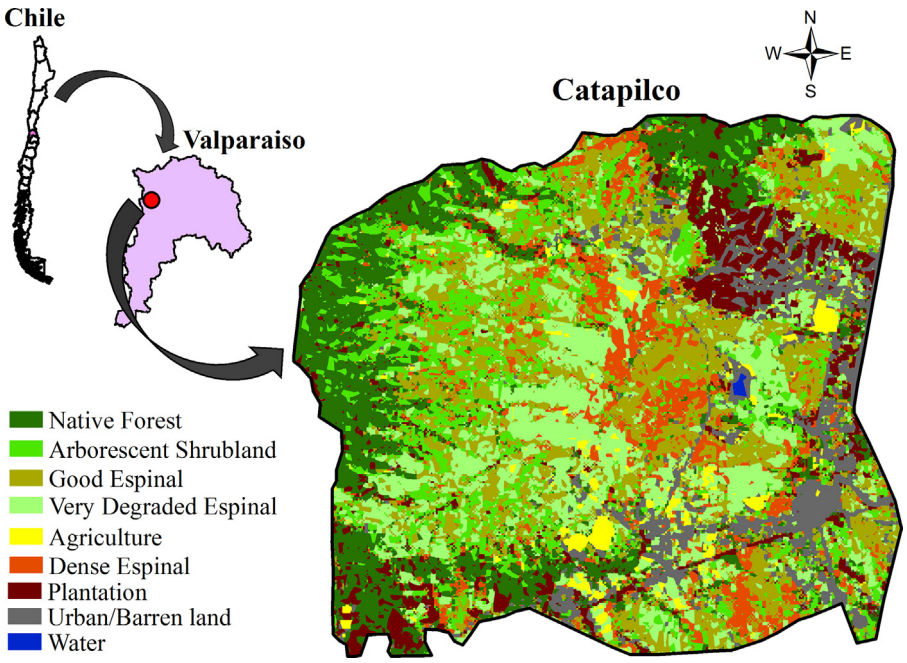

Fig. 1. Study area and distribution of the land use and land cover classes in 2011.

a biological hotspot due to its high endemism (Myers et al., 2000), is being severely affected by LUCC (Aguayo et al., 2009; Schulz et al., 2010).

Habitat fragmentation is one of the main consequences of LUCC, and can result in a loss of connectivity for different species (e.g., Pereira et al., 2011). Connectivity is the degree to which the landscape helps or impedes the movement of organisms and other ecological fluxes between habitat patches (Taylor et al., 1993; Tischendorf and Fahrig, 2000). This definition stresses that connectivity depends not only on the characteristics of the landscape (structural connectivity), but also on the movement abilities of the organism (functional connectivity) (Tischendorf and Fahrig, 2000; Moilanen and Hanski, 2001). Connectivity is considered crucial for the conservation of biodiversity and for mitigating the negative effects of habitat fragmentation and climate change on native biota (Crooks and Sanjayan, 2006). Corridors and stepping stones have been proposed as strategies to foster connectivity and promote the flow of genes and individuals among fragmented populations (Simberloff et al., 1992; Haddad, 2000).

The Mediterranean region furnishes good examples of complex and dynamic landscapes, because the strong human intervention has built a heterogeneous mosaic of agriculture, shrublands and forest patches (Blondel and Aronson, 1999). Research on the ecologic consequences of Mediterranean landscape heterogeneity and habitat fragmentation have focused almost exclusively on Europe (Preiss et al., 1997; Bielsa et al., 2005; Geri et al., 2010; Saura et al., 2011a,b), while other Mediterranean zones and especially the Mediterranean Chilean landscape, unique in South America, have received scant attention from researchers, especially considering the high ecological and socioeconomic relevance of these landscapes (Preiss et al., 1997; Rocamora, 1997).

To tackle this lack of knowledge and provide novel insights into the Mediterranean landscape changes in South America, we have evaluated the spatio-temporal dynamics and their effects on functional connectivity in a Mediterranean landscape in the Valparaíso region of Chile during a period of almost four decades (1975–2011). For this purpose, we used a set of recently developed, but so far untested in this continent, indicators of connectivity that can account for both temporal trends (Saura et al., 2011a) and for spatial variability in the contribution of habitat patches to landscape connectivity (Bodin and Saura, 2010; Saura and Rubio, 2010). These indicators were used to identify patches functioning as stepping stones that uphold connectivity between other habitat areas. The temporal trend indicators were extracted from satellite images covering the study area in four different dates along the 36-year period. By combining temporal and spatial indicators of connectivity and LUCC impacts, we were able to integrate the analysis of landscape structure, function and change, which is rarely achieved despite all these three aspects being recognized as fundamental for the analysis of landscape dynamics (Forman and Godron, 1986; Turner, 1989). Our hypothesis was that given the intense LUCC in these Mediterranean landscapes, and the subsequent alteration of their habitats and spatial patterns, connectivity would diminish along time. These changes could therefore have negative impacts on different species of this ecosystem. However, our aim was not to focus on the details of a single specific species, but rather to deliver indicators that could be relevant for a broad spectrum of the forest tree species in these Mediterranean landscapes.

2. Materials and methods

2.1. Study area

The study area is located in the semi-arid Mediterranean zone of Chile, specifically in the rural area of the Catapilco locality (32°34′6.20′S–71°16′31.48′O), Valparaíso Region (Fig. 1). Mediterranean ecosystems are a special type of dry lands, representing less than 5% of the surface of the Earth. However, they hold 20% of the plant species of the world, many of them endemic (Cowling et al., 1996). The Mediterranean landscape of Chile has suffered constant changes, due to the intensive use of the land, mainly for livestock farming and agriculture (Ovalle et al., 2006). The climate is characterized by cold rainy winters and dry hot summers. The average yearly precipitation reaches 548 mm and the average yearly temperature is 15.4 °C.

The study area has a surface of approximately 10,000 ha. It shows a vegetation mosaic typical from Mediterranean ecosystems: sclerophyll forests in the mountainous areas, arborescent