Journal of Arid Environments 127 (2016) 74–81

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Landscape trajectories and their effect on fragmentation for a Mediterranean semi-arid ecosystem in Central Chile

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A R T I C L E I N F O

Article history:
Received 20 March 2015
Received in revised form
1 October 2015
Accepted 7 October 2015
Available online xxx

Keywords:
Landscape structure
Landscape monitoring
Landscape metrics
Land change

A B S T R A C T

Changes in land use and land cover reflect anthropogenic effects in areas with a long history of human occupation, such as Mediterranean regions. To understand the landscape dynamics of a semi-arid Mediterranean ecosystem in Chile, we evaluated land-cover trajectories and their effects on landscape spatial patterns over a period of 36 years (1975–2011). We used landscape metrics combined with surveys of landowners to distinguish the main drivers of landscape change. General results indicated that changes in forest area followed both natural (64%) and human-induced (36%) trajectories. At the landscape level, fragmentation for all forest cover types increased, whereas at the class level, fragmentation of Native Forest decreased. The landscape changed from a homogeneous mosaic dominated by grazing and agriculture to a more heterogeneous environment, where natural cover had become more dominant. Thus, the use of a landscape ecology approach together with field information improved our understanding of the spatiotemporal dynamics in this landscape. This study is one of the first to assess landscape dynamics of the Mediterranean semi-arid region of Chile. This is important because it aids decision-making for biodiversity conservation in a global hotspot and land-use planning.

1. Introduction

A landscape is a dynamic entity constantly changing its spatial, biotic, and abiotic patterns (Forman, 1995). Many of the dynamics occurring at the landscape level have profound consequences for the structure and function of ecosystems (Forman, 1995; Gustafson, 1998; Parcerisas et al., 2012). Major landscape changes have occurred as a consequence of changes in land use and land cover (Foley et al., 2005). Land use is defined by its anthropogenic use, such as agriculture, forestry, built-up areas, pasture, and others, which all alter the structure and function of the landscape. Land cover refers to the physical and biological surface cover of the land, including water, vegetation, bare soil, and/or artificial structures (Meyer and Turner, 1994). This is particularly relevant for areas with a long history of human occupation (Foley et al., 2005; Mitsuda and Ito, 2011), such as Mediterranean landscapes.

In Mediterranean landscapes, changes in cover and land use have been profound, particularly because these ecosystems are considered particularly vulnerable to land changes given their semi-aridity and high biodiversity (Sala et al., 2000). Mediterranean landscapes represent <5% of the surface of the Earth; however, they support nearly 20% of the plant species of the world, many of which are endemic (Cowling et al., 1996). Research on landscapes dynamics in Mediterranean ecosystems and the ecological consequences of changes in cover and land use have mainly occurred in Europe (Foggi et al., 2014; Geri et al., 2010; Preiss et al., 1997; Saura et al., 2011), with some examples from North America (Gerlach, 2004) and Australia (Seabrook et al., 2007). In South America, the only Mediterranean ecosystem occurs in Central Chile and has received little attention from landscape ecologists.

Research on landscape changes in Mediterranean landscapes in Chile are still in their infancy. Patterns in the reduction of natural vegetation have been qualitatively described by Armesto et al. (2007) and Aronson et al. (1998) and, more recently, Schulz et al. (2010) explored the landscape dynamics (2010). These studies highlight the importance of understanding landscape changes at the local scale to provide a robust understanding of the processes

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http://dx.doi.org/10.1016/j.jaridenv.2015.10.004
0140-1963/

and effects resulting from changes in landscape dynamics.

Understanding historical changes of land use and cover shed light on the environmental and social impacts that result from the new landscape configuration (Mitsuda and Ito, 2011). One of the most common ways of analyzing landscape configuration is to distinguish the spatial pattern of land cover in an area. Changes in the spatial patterns and ecological processes of a landscape can have positive effects on anthropogenic land use by increasing habitat connectivity; however, they can also have negative effects by fragmenting natural landscapes, with substantial consequences for biodiversity (Elena-Roselló et al., 2013; Forman, 1995; Gustafson, 1998).

Land-cover trajectory analyses have been used to better understand how historical processes have driven changes in cover and land use. This type of analysis enables us to identify the direction of change for different land-cover and land-use types to determine how landscapes change temporally (Ruiz and Domon, 2009), and how the local context and public policies shape those trajectories (Wang et al., 2013). Land-cover trajectory analysis has been used previously in Chile by Carmona and Nahuelhual (2012) to evaluate landscape dynamics in Southern Chile, where the main trajectories associated with fragmentation were derived from landscape conversion to agricultural land.

To our knowledge, little is known about the impacts of historical changes in cover and land use on semi-arid Mediterranean landscapes of Central Chile, determinant factor for land-use planning. This study evaluated changes in cover and land use and their trajectories over a period of 36 years (1975–2011), assessing the effects of fragmentation on natural vegetation for this type of landscape. Remote-sensing data, in combination with Geographic Information Systems (GIS), were used to obtain land-use and/or land-cover maps to analyze the main trajectories of change. To evaluate the spatial patterns of the landscape, we quantified commonly used metrics for fragmentation analysis.

2. Materials and methods

2.1. Study area

This research was conducted in the semi-arid Mediterranean zone of Chile, specifically in the rural area of Catapilco (32°34′6.20′S − 71°16′31.48′W), Valparaíso Region (Fig. 1). The study area covered approximately 10,000 ha. The climate is typically Mediterranean, characterized by irregular and intense rainfall events and a harsh dry summer period (Luebert and Pliscoff, 2012). The average annual precipitation is 547.8 mm, distributed mainly between May and August, with a prolonged dry season of 6 months between October and March. The average annual temperature is 15.4 °C; the warmest month is January, with a maximum average temperature of 27.6 °C, and the coldest month is July, with a minimum average temperature of 5.4 °C.

This area was selected because it has a long and known history of changes in land cover and land use. We used it as a case study because it is representative of land cover and land use in most Mediterranean landscapes of central Chile. The vegetation mosaic is typical of this ecosystem, where the highest elevations are dominated by sclerophyll forest, hillsides by arborescent shrubland, and the valleys by extensive *Acacia caven* (espinal) scrubland, and agriculture, livestock, and urban areas.

2.2. Analysis of spatial data

The assessment of change in land use and land cover was performed over a 36-year period (1975–2011). A set of four classified Landsat images: one MSS image (1975) and three TM5 images (1992, 2001, and 2011) were used in the study. Details of image processing and classification, in addition to accuracy assessment, can be found in Hernández et al. (2015). Land-cover and land-use types were identified in Hernández et al. (2015) and corresponded to: (1) Native Forest; (2) Arborescent Shrubland; (3) Dense Espinal; (4) Espinal; (5) Grassland; (6) Agricultural; (7) Water; (8) Urban and Bare Land; and (9) Plantations (Table 1, Appendix B).

2.3. Trajectories and drivers of change

Two steps were followed to determine the trajectories of change for land use and land cover. First, land-use and land-cover maps for the four years previously mentioned were obtained from the previously classified Landsat images, using ArcGIS 10 (ESRI, Redlands, Calif.). Second, changes in land cover and land use were evaluated

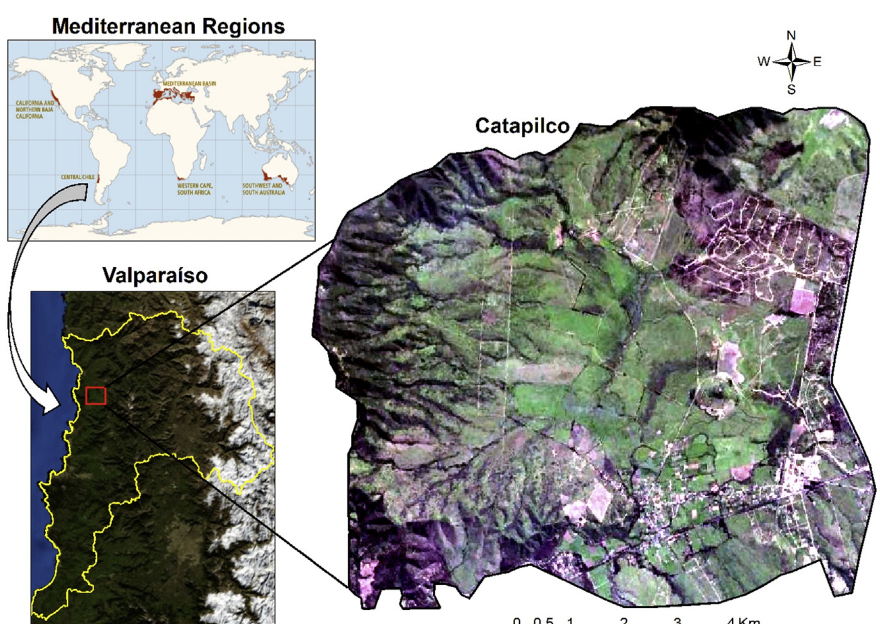

Fig. 1. Study area, with the visible spectrum (image composite RGB bands 3, 2, 1) of the Landsat image from 2011.