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Understanding the effect of three decades of land use change on soil quality and biomass productivity in a Mediterranean landscape in Chile

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ABSTRACT

Land-use and land-cover change (LUCC) can deeply alter soil quality (SQ), affecting important productivity functions like vegetation biomass. A further understanding of the history of LUCC is essential to explain natural or anthropic landscape cover. The Mediterranean region of central Chile has historically been affected by LUCC impacts on the vegetation gradient of the landscape, which ranges from natural cover to anthropic cover like grazing pastures and crop lands. The main objective of this study is to define the historical impact of LUCC on SQ in a Mediterranean landscape in central Chile. To conduct the study, historical LUCC trends between 1975 and 2011 were analyzed. A Soil Quality Index (SQI) was developed to comparatively assess six types of land use (Annual Crops, Perennial Crops, Grazing, Espinal, Dense Espinal and Native Forest); and finally, SQI was interpolated at landscape scale using the soil-adjusted vegetation index (SAVI) as an auxiliary variable. SAVI was selected to represent indirect information on vegetation biomass productivity. The results indicate that most LUCC dynamics were observed in the Espinal woodland, where agriculture and grazing activities have been developed historically. The SQI showed significant SQ deterioration when Native Forests (SQI = 0.82) degrade and are transformed by anthropic interventions like Annual Crops (SQI = 0.27), Perennial Crops (SQI = 0.34) or Grassland (SQI = 0.36). However, a slight improvement in SQ compared to the other land uses was identified in the Dense Espinal (SQI = 0.46). Finally, the quality model at landscape scale showed clear differences in SQI values for all landscape covers.

1. Introduction

LUCC is a representative consequence of the pressure of human development on natural landscapes occurring at different spatial and temporal scales (Conacher and Sala, 1998; Geist and Lambin, 2002; Lambin et al., 2001). Depending on the type and the intensity of LUCC, ecosystems end up reflecting different structures, functions, and dynamics, creating new and complex interactions among the elements vegetation, soil, and nutrients (Adeel et al., 2005). Current landscapes are the result of natural and anthropogenic processes, thus a historical perspective is required to understand the dynamics that led to current conditions (Russell, 1997).

The resulting landscape incorporates physical and biological components (DeFries et al., 2004; Foley et al., 2005), reflecting changes in soil properties and consequently in biodiversity and vegetation productivity (Matson et al., 1997; Tscharntke et al., 2005). Several studies have demonstrated the close relationship between LUCC, soil properties and vegetation productivity in different systems (Dörner et al., 2010; Sharma et al., 2011; García-Orenes et al., 2013). In agroforestry systems, most of the land use conversion moves between grassland, new crops, forest substitution, and crop abandonment (Etter et al., 2006; Kastner et al., 2014). In many cases, the consequences of poor agricultural management practices have led to severe degradation that impairs natural functions, mainly regarding soil fertility, and productivity (Kang and Juo, 1986; Nael et al., 2004; Nardi et al., 1996; Zornoza et al., 2007).

The effects of LUCC on soil erosion and vegetation coverage are a common problem in several agroecosystems in Mediterranean regions (Conacher and Sala, 1998; Geri et al., 2010). The Chilean Mediterranean region is recognized as a critical biodiversity spot in the southern hemisphere (Myers et al., 2000). It is also the most important agricultural zone in the country, where most of the population is located (Schulz et al., 2011). This region has historically been subject to intensive land use, mainly by overgrazing and overexploitation, resulting in high levels of erosion and loss in agricultural productivity (Ovalle et al., 1999). Between 1975 and 2008 changes from forest to agricultural land, timber plantations and urban areas were reported, with annual average growth rates of 1.1%, 2.7% and 3.2%, respectively (Schulz et al., 2010).

To understand historical LUCC trends and effects on ecosystems, it is necessary to correlate the different land use (Otto et al., 2007; Symeonakis et al., 2007), and their possible impacts on biomass productivity and SQ in agroforestry ecosystems (Andrews et al., 2002b; Glover

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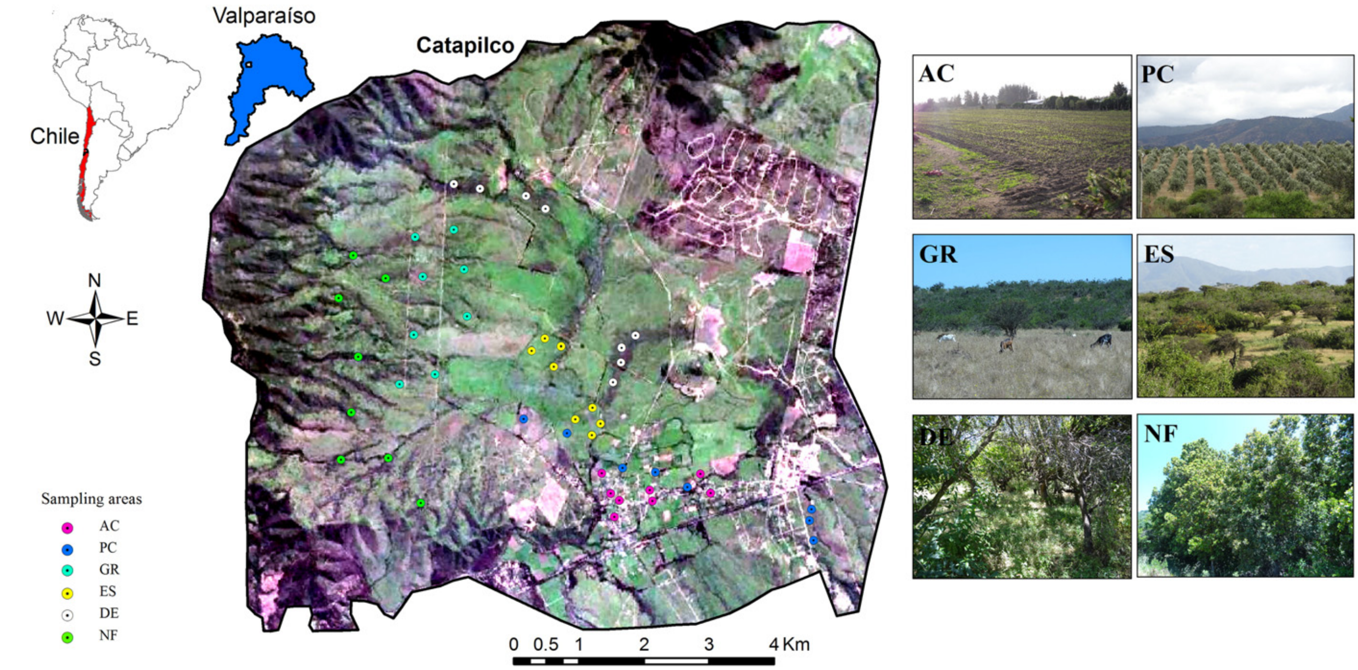

Fig. 1. Study location in the town of Catapilco located in the Mediterranean region of central Chile in Valparaiso Region. Each dot indicates a soil sampling site in different land use areas: AC: Annual Crop, PC: Perennial Crop, GR: Grassland, ES: Espinal, DE: Dense Espinal, and NF: Native Forest.

et al., 2000; Raiesi, 2007). Biomass productivity is an important variable to evaluate ecosystem functionality and health (Whittaker and Likens, 1997). It reflects the amount of energy available to be transferred through vegetation throughout the ecosystem (Gaston, 2000; Erb et al., 2009; Kay et al., 1999). Land use change and soil degradation reduce biomass productivity, influencing biodiversity and the general state of the ecosystem (Erb et al., 2009).

There is a close relationship between vegetation biomass and soil quality (Paz-Kagan et al., 2014). However, the perception of what constitutes good soil varies depending on priorities with respect to soil function (Armenise et al., 2013; Zornoza et al., 2008). Doran and Parkin (1994) defined soil quality as the capacity of specific soils to sustain biological productivity and generate the bases for ecosystem health. One of the most commonly used techniques to quantitatively assess SQ is to transform and assign weights to soil indicators, and their combination in an index (Andrews and Carroll, 2001; Bastida et al., 2006; Karlen et al., 1994; Zornoza et al., 2007). Several local studies of Mediterranean systems show that poor soil quality due to poor management has resulted in degraded natural (Bastida et al., 2006; Trasar-Cepeda et al., 1998; Zornoza et al., 2007) or productive systems (Armenise et al., 2013; Imaz et al., 2010).

In a Mediterranean landscape, the current ecosystem function is a consequence of historical connections of all the elements that are part of the landscape. These connections are rarely considered in soil quality models that focus on specific soil parameters (Paz-Kagan et al., 2014). Nevertheless, the inclusion of additional ecosystem functions in models can be a useful way to improve soil quality interpretation (Herrick, 2000). Some studies have attributed the degradation of the vegetation cover in the Mediterranean area of central Chile to LUCC (Balduzzi et al., 1982; Fuentes et al., 1989), land use pressures (Ovalle et al., 1996b) and the changing dynamics in land cover (Schulz et al., 2010). However, to improve our understanding of the effects of land use change, it is necessary to integrate specific SQ models with vegetation productivity and the current landscape. The objective of this study was to determine the impact of historical LUCC on SQ for typical Mediterranean landscapes, using vegetation biomass productivity as a specific function in a vegetation gradient with different levels of human disturbance over 36 years. The study, which considered a Mediterranean landscape in the Valparaiso Region, Chile, was developed in three steps: 1) definition of historical LUCC trends between 1975 and 2011, 2) development and implementation of a SQI, and 3) proposal of a SQ model based on vegetation productivity at a landscape scale.

Table 1
Average values of the main soil properties in the studied sites.

	AC[a]	PC	GR	DE	ES	NF
pH	6.9 ± 0.8	6.2 ± 0.4	5.8 ± 0.1	5.9 ± 0.1	6.6 ± 0.8	5.7 ± 0.3
TC (%)	1.59 ± 0.44	1.22 ± 0.21	5.8 ± 0.1	5.9 ± 0.1	6.6 ± 0.8	5.7 ± 0.3
TN (%)	0.11 ± 0.03	0.08 ± 0.02	0.08 ± 0.02	0.10 ± 0.02	0.10 ± 0.06	0.19 ± 0.04
AP (mg/kg)	68.18 ± 47.07	13.95 ± 5.74	11.60 ± 3.14	22.73 ± 6.95	8.92 ± 2.22	8.75 ± 3.00
OM (%)	2.93 ± 0.45	2.51 ± 0.25	2.58 ± 0.38	3.08 ± 0.38	2.73 ± 0.91	5.18 ± 1.00
SR ($g\ h^{-1}\ m^{-2}$)	0.38 ± 0.20	0.31 ± 0.12	0.23 ± 0.06	0.43 ± 0.09	0.26 ± 0.05	0.61 ± 0.15
BD ($g\ cm^{-3}$)	1.20 ± 0.11	1.22 ± 0.12	1.39 ± 0.08	1.35 ± 0.13	1.22 ± 0.10	0.95 ± 0.13
WSA (%)	0.17 ± 0.21	0.10 ± 0.07	0.13 ± 0.07	0.11 ± 0.04	0.15 ± 0.07	0.45 ± 0.10
Clay (%)	25.5 ± 4.2	23.3 ± 3.7	21.8 ± 2.7	26 ± 6.5	25 ± 5.9	27.5 ± 4.8
Silt (%)	33.8 ± 4.0	35.9 ± 4.1	39.8 ± 2.5	43.5 ± 13.8	39.9 ± 7.1	39.3 ± 7.4
Sand (%)	40.8 ± 7.2	39.3 ± 6.9	38.5 ± 3.3	30.5 ± 19.9	35.1 ± 12.7	33.3 ± 11.7

[a] AC: Annual Crop, PC: Perennial Crop, GR: Grassland, DE: Dense Espinal, ES: Espinal, NF: Native Forest.