Land Use Policy 79 (2018) 725–733

Contents lists available at ScienceDirect

Land Use Policy

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

The effects of urban expansion on green infrastructure along an extended latitudinal gradient (23°S–45°S) in Chile over the last thirty years

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ARTICLE INFO

Keywords:
Small and medium-sized cities
Green spaces
Landscape metrics
Vegetation cover
Urban growth

ABSTRACT

Green infrastructure (GI) contributes to environmental quality and human well-being in urban environments by providing a number of ecosystem services. There is evidence that urban expansion negatively impacts on GI, but most studies have focused on large cities at the expense of an understanding of these processes in smaller cities. Here we assess the urban expansion and spatio-temporal dynamics of GI in small and medium-sized Chilean cities over a period of three decades. Seven cities were selected along a latitudinal gradient extending from 23 °S to 45 °S, and covering a wide variety of climates including: arid, semi-arid, mediterranean and temperate. Remote sensing and landscape analysis techniques were employed to assess changes in urban areas and GI spatial patterns. The cities that were analyzed showed a continuous expansion over the last 30 years associated with high population growth rates. Landscape analysis also evidenced an increasing level of GI fragmentation in most cities. Population growth, economic growth, and public policies seem to have a greater influence on long-term changes in GI than climate or geographic location. Our study highlights the need for better urban policies that protect and develop GI because of its crucial role in human well-being and urban sustainability.

1. Introduction

Throughout the 20th century there has been an unprecedented urban expansion worldwide. Many factors can contribute to this expansion, the most important being population growth, economic growth, land use policies, and transportation costs (including monetary prices and time) (Seto et al., 2011). Presently, Latin America is the most urbanized region in the world; around 80% of the population now live in urban areas (UN-Habitat, 2012) following the massive migration of rural population and the explosive urban growth that occurred between the 1950s and 1990s. Although migration has slowed down, and the urban population now grows at much lower rates than during the last century (UN-Habitat, 2012), urban expansion has continued significantly (Inostroza et al., 2013).

To date, studies on urban expansion processes have generally focused on large metropolitan areas, because of their significant environmental and social impacts (Catalán et al., 2008; Deng et al., 2009; Inostroza et al., 2013; He et al., 2014; Lu et al., 2017), whilst expansion of smaller urban centres has largely been ignored. Nevertheless, medium-sized and small cities can play an important role in urban dynamics, particularly in developing countries, and since the late twentieth century population growth in smaller cities has steadily increased and can even exceed growth rates in metropolitan areas. In 2014, nearly 50% of the global human population lived in cities with fewer than 500,000 inhabitants (United Nations, 2014). Since the 1990s, small and medium-sized cities have grown at higher rates than larger cities in Latin America (UN-Habitat, 2012), a phenomenon that can be explained by national economic policies that have promoted exportation of raw materials. In this context, smaller urban centres fulfill an intermediate function between rural surroundings and capital cities (Bolay and Rabinovich, 2004; Salazar et al., 2017).

One of the most significant changes associated with urban expansion is the loss of vegetation cover around the periphery as a result of the replacement of agricultural land by built up areas. However, several studies have shown that urban expansion is also associated with a decrease of vegetation cover in the urban core, due to the continuous increase in building density and paving of green spaces (Rashed et al., 2005; Haas and Ban, 2014; Escobedo et al., 2016; De la Barrera and Henríquez, 2017; Dobbs et al., 2017). This pattern has been noted even in desert cities where the limited agricultural land - typically located close to the cities - can be readily transformed into urban land (El Garouani et al., 2017; Mosammam et al., 2017). These internal

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https://doi.org/10.1016/j.landusepol.2018.09.008
Received 4 December 2017; Received in revised form 7 September 2018; Accepted 7 September 2018
0264-8377/

modifications represent physical manifestations of social, environmental, economic, cultural and political dimensions related to urban dynamics (Rashed et al., 2005).

GI comprises the entire network of natural, semi-natural and artificial spaces, both public and private, where urban vegetation is present (Tzoulas et al., 2007; Banzhaf et al., 2017). GI refers to the range of physical structures that contain urban vegetation (i.e. green spaces, tree-lined streets, residential gardens, urban parks), and recognizes them as a single entity to be considered in urban planning alongside other urban infrastructures (referred to as gray structures). This concept emphasizes the connectivity between all types of green spaces and defines them as a coherent planning entity (Tzoulas et al., 2007) that is both a vital element of cities, and one which provides important ecosystem services. The loss or degradation of GI clearly has negative consequences for biodiversity, urban ecosystems, and human populations (Zhou and Wang, 2011).

Urban expansion in Latin America has generally occurred without adequate planning, resulting in cities typically characterized by a lack of basic services and infrastructure (both grey and green) within the low-income sectors (UN-Habitat, 2012; Álvarez-Berríos et al., 2013; Inostroza et al., 2013; García-Ayllón, 2016; Banzhaf et al., 2017; Inostroza, 2017). This lack of urban planning may also have contributed to a fragmented GI that is unevenly distributed across cities.

During the last decade, urban research in Chile has increasingly focused on the role of vegetation. The concepts of "urban vegetation" and "vegetation cover" have been adopted to refer to a range of vegetation types found in cities; most of this research has been based on satellite imagery and remote sensing techniques (De la Maza et al., 2002; Azócar et al., 2003; Escobedo et al., 2008; Molina et al., 2009; Romero and Vásquez, 2009; Puertas et al., 2014; Escobedo et al., 2016). Other studies have specifically analyzed green spaces or peri-urban vegetation (Romero and Vásquez, 2005; Pauchard et al., 2006; Reyes-Paecke and Figueroa, 2010; Reyes-Paecke and Meza, 2011; Rojas et al., 2013). However, despite considerable research effort, important questions remain such as: Does GI increase at a similar rate to that of the total urban area? How do spatial patterns of specific GI components evolve during the process of urban expansion?

The present study aims to assess the urban expansion and related spatio-temporal dynamics of GI within small and medium-sized Chilean cities over the last 30 years. Seven cities were selected along a lengthy (> 4000 km) latitudinal gradient that extends from 23 °S to 45 °S, and covers a wide variety of climates including arid, semi-arid, mediterranean and temperate. This research should provide valuable data not only for planning and decision-making processes in these Chilean cities, but also for similar sized cities in Latin American and other developing countries.

2. Methods

2.1. Study area

Seven Chilean cities were selected for the analysis: 1) Antofagasta, 2) Copiapó, 3) La Serena, 4) Concepción, 5) Temuco, 6) Puerto Montt, and 7) Coyhaique (Fig. 1). These cities are located along a latitudinal gradient that extends from the Atacama Desert in the North to Patagonia in the South. Antofagasta is located on the coastal edge of the Atacama Desert. Its main economic activity is mining, with records of copper mining extending back to pre-Columbian times. At the southern edge of the Atacama Desert, and located in the Copiapó River valley, is Copiapó, a mining city with nearby deposits of copper, gold and iron, but also an important centre for agricultural production. Further south, and located on the Pacific coast, La Serena is a tourist city located at the mouth of the Elqui River. The main economic activities of La Serena are agriculture and wine production, with some copper and iron mining in the upper regions of the valley. Almost 800 km to the south, Concepción is a coastal city located on the Bio-Bio River estuary, one of the largest rivers in the country, with its main economic activities being industry, commerce and services. The city also houses important universities and heads one of the three metropolitan areas of Chile. Temuco, a multicultural city, is the main urban centre of the Mapuche region, and its main economic activities are agriculture, commerce and services. The coastal city of Puerto Montt is a centre of services and commerce for an extensive region whose main economic activities are agriculture, fishing and livestock. Located in Chilean Patagonia, Coyhaique is a small city specializing in tourism, services and commerce, and is also the headquarters of universities and research centres. Founded in 1929, Coyhaique is one of the youngest cities in the country. Despite being located in different climatic regions, these seven study areas share the same normative framework and have similar land use regulations, together with similar economic and social policies. Table 1 shows the geographical and climatic characteristics of the seven cities.

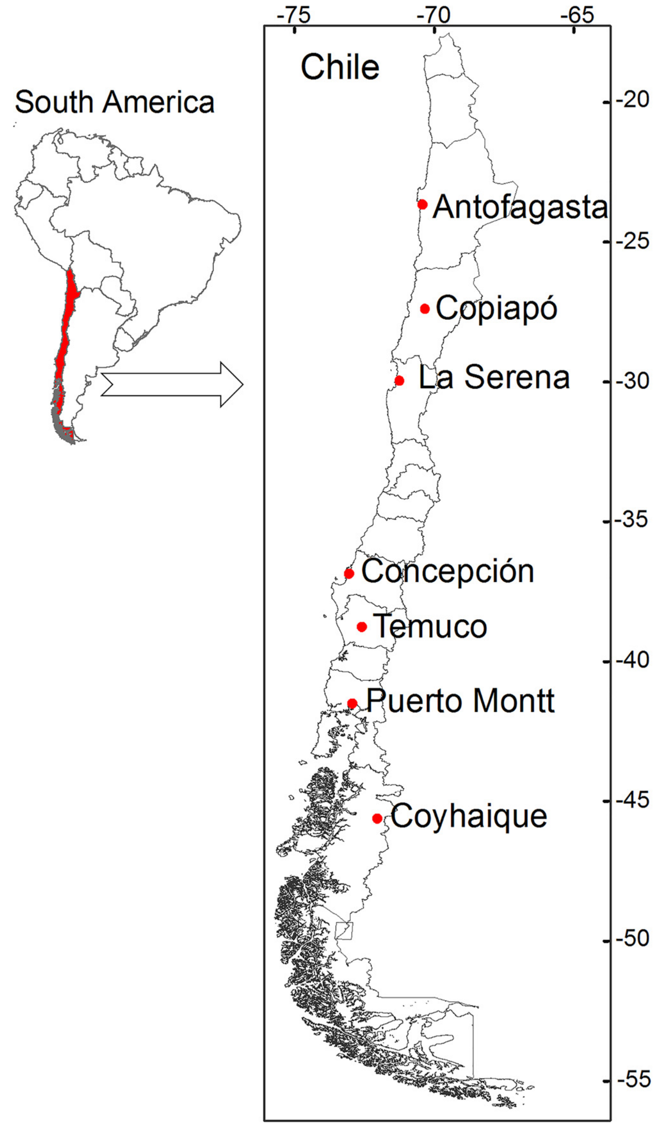

Fig. 1. Geographic location of the seven cities examined in this study.

2.2. Spatial data selection and processing

The data used to assess the spatial and temporal dynamics of GI of the seven cities were obtained from 21 satellite images, three for each city (LANDSAT, resolution 30 m x 30 m; more details in Table 2). Images with similar acquisition dates were chosen, corresponding to spring and summer seasons in the southern hemisphere, in order to