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Vegetation cover change in growing urban agglomerations in Chile

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ABSTRACT

Cities in Latin America expose high rates of urbanization and poorly controlled processes of creation of new urban peripheries. In this study we evaluated the changes in vegetation cover as a proxy of the success of urban planning in the creation or conservation of elements able to provide ecosystem services to citizens and therefore strengthening urban sustainability. Three urban agglomerations in Chile located in different climates were analysed. Four indicators were processed to understand the changes and correlations between vegetation and urban dynamics: normalized difference vegetation index (NDVI), vegetation cover, normalized difference built-up index (NDBI) and built-up area. The indicators were calculated for a period over 20 years covering two parts of the city as an urban development: the urban core and the new peripheries. An overall loss of vegetation was observed in all cities has a consequence of urban expansion despite their geographical location. Moreover, the greatest losses were in new peripheries. Santiago broke this pattern of change. First its urban core showed a small increase in indicators for vegetation cover despite the increase in indicators for urban dynamics. Secondly, despite their peripheries experiencing a decrease in vegetation cover, a more detailed analysis found differences on the northern and eastern peripheries where increases of vegetation cover were observed, and other new peripheries where vegetation loss was massive. Urban planning needs to play a role not only to facilitate the creation of green spaces or other public spaces able to host vegetation, but also to form an urban structure supported by regulations that facilitate the planting and maintenance of vegetation in private spaces.

1. Introduction

The rapid population growth and economic dynamics of southern developing countries have transformed the size of cities and the population living there (Cohen, 2006). Asia leads the figures in urban sprawl and population growth (UN, 2014). However, Latin America has been the continent with the highest urbanization in the last century and has one of the largest segments of urban population (near 80%, UN, 2014). In the future it is expected that cities will concentrate an even higher quantity of urban inhabitants (UN, 2014).

Urban planning and design has included a complex set of structures for offering comfort and opportunities to citizens. Beyond artificial infrastructures, cities include vegetation patches as a consequence of deliberate landscaping, looking to increase aesthetic value and provide recreational spaces. There are other benefits pursued such as fresh places for hot summer days as people seek refuge in tree shade, and improving air quality using vegetation to capture air pollutants, among others (Tyrväinen et al., 2005; Escobedo and Nowak, 2009; Escobedo et al., 2011; De la Barrera et al., 2016b). These benefits are broadly conceptualized as ecosystem services and the elements or structures able to provide them are conceptualized as ecosystem service providers (Burkhard et al., 2012; Frank et al., 2012). Ecosystem services and their providers can be used as sustainability indicators: the higher the provision of ecosystem services or the quantity of ecosystem service providers, the higher the sustainability (Burkhard et al., 2012; Wu, 2013). Thus, the concept of ecosystem services has become a good articulator tool in-between of sustainability, human well-being and urban vegetation (Andersson, 2006; Carpenter et al., 2009; Vejre et al., 2010; Seppelt et al., 2011; Reyers et al., 2013; Haase et al., 2014; Fischer et al., 2015). Finally, the pursuit of sustainable provision of ecosystem services transforms urban ecosystem services providers, i.e. vegetation within and around cities, into subjects of policy, planning and management (Forman, 2008; Colding 2012; Koschke et al., 2012; Lafortezza et al., 2013; Kopperoinen et al., 2014).

The vegetation in urban ecosystems found in cities is comprised of native and exotic species. Plants (trees, shrubs, lawn, flowers, etc.), animals (birds, mammals, lizards, etc.) live in cities thanks to the existence of vegetation patches. The concept of urban vegetation is also applied to urban forests, green spaces and green infrastructure, among other related concepts (e.g. Tyrväinen et al., 2005; Tzoulas et al., 2007; Escobedo et al., 2011; Lafortezza et al., 2013; Dobbs et al., 2014; De la Barrera et al., 2016a,b). All they have in common to be distinctive

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spatial green elements of cities. Private and public areas, small and large green spaces, as well as woody and herbaceous vegetation can be included in the aforementioned concepts (De la Barrera et al., 2016a). However, the broadest concept among them is vegetation cover; they all consist of vegetation in several strata with differences between them defined by property (private or public green spaces), connectivity (whether they form a network of green infrastructure concepts or remain isolated), form and size.

Urban planning defines zones allocated to hosting vegetation that also offer other cultural services valued by the community (e.g. recreation) such as natural hazard management (e.g. protection from flooding or landslides) (Tyrväinen et al., 2005; Tzoulas et al., 2007; La Rosa et al., 2016). However, urban planning cannot plan nor manage how much vegetation urban designers and inhabitants decide to include in their neighbourhoods. On the other hand, local authorities decide on matters regarding street tree management, green landscaping and where, how and how much to expand urban limits. These decisions have an effect on land use changes in rural environments, and all these changes have effects on the total vegetation cover of urban agglomerations and their surroundings, and consequently, on urban sustainability. Given the previous, monitoring urban vegetation should be key to understanding the provision of ecosystem services and might be a major driver for urban planners and managers (Tzoulas et al., 2007; Colding, 2012; Ahern et al., 2014). Consequently, the status of urban vegetation over a given time is a good proxy for urban sustainability and its change.

Most cities in Latin America are subject to lack of urban planning and management and to poorly controlled urban expansion (Inostroza et al., 2013; UNEP, 2010; Sperandelli et al., 2013). Rural surroundings mostly covered by vegetation tend to be replaced by new urban peripheries which lack vegetation (Merlín-Uribe et al., 2013; Ravetz et al., 2013). New peripheries have opportunities for conserving vegetation since they possess valuable vegetation remnants and constitute the few remaining places where city dwellers can come into contact with nature (Huang et al., 2011; Radford and James, 2013). On the other hand, their city centres or cores also change in response to urban dynamics. They accurately represent the transformation of urban land use and how urban vegetation is both planned and managed. Both, urban cores and new peripheries can host valuable vegetation patches able to supply urban inhabitants with important ecosystem services.

Our goal is to understand the effects of urban growth by analysing the changes in vegetation in two distinctive parts of cities: urban cores and peri-urban areas. This will help to get a better understanding of urban dynamics and their effects on urban sustainability.

2. Methodology

We explored the changes in urban vegetation resulting from urbanization by evaluating four indicators. Two indicators refer to vegetation change and two indicators to changes in the urbanization rates. Finally, we calculated spatial statistics for one of the urban vegetation indicators.

2.1. Case studies

Three Chilean urban agglomerations were selected as case studies: Santiago, La Serena and Concepcion (Fig. 1). Santiago is a metropolitan area consisting of 34 municipalities. La Serena and Coquimbo constitute a conurbation, and Metropolitan Concepcion is made up of 9 municipalities. They are located in Mediterranean ecosystems but ranging from 29.5 to 36.5° latitude South, from dry to rainy climatological zones with annual rainfalls between 78 to 1110 mm. Together they are home to almost half of the country's population, approximately 8 million inhabitants in total.

Population density in these urban agglomerations varies from 63.6 to 80 inh./ha (Data 2002 from www.observatoriourbano.cl) in Concepcion and Santiago, while the population growth for the 2002–2012 period was 0.22 for Santiago and 2.23 for La Serena. The geographic context is very different given Santiago is located in land in a longitudinal valley surrounded by The Andes mountains and Coastal

range, while the others are in coastal areas. La Serena-Coquimbo has an arid climate while Concepcion is predominantly a rainy temperate climate. In general, these cities are restricted by their geographical contexts placed as such between mountains, slopes and bodies of water. They are part of Central and Central South Chile where reports indicate significant increases in urban land cover (Schulz et al., 2010; Inostroza et al., 2013; Rojas et al., 2013a,b,c).

2.2. Urban growth and new peripheries

In order to understand urban growth and the consequent creation of new peripheries we delimitated the built-up areas for the three urban agglomerations measured four times over a four-year period. The urban core (UC) was defined as the consolidated areas at *T1*. The new peripheries are operatively represented as the area of urban growth in a temporal window (Fig. 2).

Landsat imagery was used to delimitate built-up areas and the images were geometrically and radiometrically corrected. Images were selected according to age from the earliest and latest available imagery, using satellite pictures from March (a summer month) at a spatial resolution of 30 m with clear skies. Images for each time interval were selected to reflect urban growth trends, specifically for the 1990s and the 2000s.

2.3. Vegetation and urbanization dynamics

Two indicators were used to calculate the changes in vegetation. First, the NDVI (Normalized difference vegetation index), based on red and near-infrared bands (NIR), served as a simple indicator for vegetation vigour. Plants absorb the spectrum of visible light and reflect near-infrared light, a phenomenon easily calculated using Landsat imagery making it an indicator commonly used in urban analyses (Stefanov and Netzband, 2005). The second indicator is the area covered by vegetation, i.e. vegetation cover (area or total share). The latter was a by-product of supervised classification using the NDVI figures calculated earlier. By training urban vegetated areas, a threshold was defined by the NDVI average for these areas. Then the total area covered by vegetation and the share of the total urban unit (UC or NP) were calculated.

Complementary to the vegetation analysis, urbanization changes were also calculated using two indicators: the aforementioned delimitation of built-up areas and the NDBI (Normalized difference built-up index). The NDBI allows analysts to identify built-up areas at a pixel-by-pixel scale given that sealed areas (e.g. pavement covered, roofs) have a higher reflectance of light in the shortwave-infrared (SWIR) band, compared to near-infrared (NIR) (Zha et al., 2003). The index was calculated using the same set of imagery used for vegetation analyses.

All indicators helped visualize the relation between changes in urbanization and changes in vegetation. We used NDVI and NDBI figures for all the pixels of the built-up area for the following temporal and spatial groups. Changes in urban cores (UC) and new peripheries (NP) were compared over the established temporal trajectory. The overall timeframe was set as the period – or temporal window – between T1 (1989 or 1987) and T3 (2009 or 2008). We selected images taken in these years because they came from the same satellite sensor (Landsat TM) and therefore comparisons are better grounded. The significance of correlation coefficients were analysed using Pearson ($p = 0.01$). Additionally, changes were compared by calculating on-site averages and the ANOVA for one factor (groups). Then, post hoc calculations were performed with a $p < 0.05$ for Games-Howell and T3 Dunnet.

Vegetation cover in UCs and NPs was analysed for the same years, looking to corroborate trends found in NDVI analyses. Lastly, landscape