

Monitoring the Change in Urban Vegetation in 13 Chilean Cities Located in a Rainfall Gradient. What is the Contribution of the Widespread Creation of New Urban Parks?

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Abstract. The well-being of people living in cities is strongly dependent on the existence of urban vegetation because of the ecosystem services or benefits it provides. This is why governments develop plans to create green spaces, plant trees, promote the maintenance of vegetation in private spaces and also monitor their status over time. In Latin America, and particularly in Chile, the increase of urban vegetation has been stimulated through different initiatives and regulations. However, development of monitoring programs at the national level is scarce, so it is yet unknown if these initiatives and regulations have had positive effects. In this article, we monitor the change in urban vegetation in 13 Chilean cities located in a latitudinal gradient of practically zero to almost 1800 mm of annual rainfall. We calculated the trends in NDVI (2000-2016) as an indicator of change in urban greenery using data from the MODIS Subsets platform. Likewise, to assess whether the initiatives have had an effect we quantified the number of urban parks existing at the beginning of the period and how many were created during the study period. For this, we analysed official databases and high spatial resolution satellite images. Armed with said data, we assessed whether these new parks had impacted the tendency toward change in urban greenery. The results indicate that, in general, Chilean cities vary greatly inter-annually in urban greenery and have lost urban vegetation in the last 16 years, with significant losses in four of those cities. Two cities located in desert ecosystems represent an exception and showed positive trends in their urban vegetation. The rainfall in cities has an impact on the amount of vegetation, but not on their tendency to change, i.e. there are cities with loss of vegetation at all levels of precipitation. The creation of parks has not been able to reverse negative trends, which indicates the prevalence of other drivers of change that are not sufficiently compensated by initiatives and regulations that seek to increase urban vegetation. Today, planning and management of urban vegetation is a challenge for urban sustainability and must be addressed systematically, integrally and implemented via urban regulations. It is imperative to focus on cities *in extenso*, taking into consideration residential areas, private spaces, peri-urban areas, etc. Likewise, climate in each city, inter-annual variability and future changes must also be considered when designing green areas to make them resilient, prevent increases in maintenance costs and provide benefits for the inhabitants in perpetuity.



1. Introduction

People live mostly in cities [1]: 52% of the world's population and 83% of the Latin American population inhabit urban areas. This makes cities a focal point for public health and well-being for current and future generations [2-3]. It has often been described that urban vegetation, presented in varying types of green infrastructure, is strongly associated with human well-being due to the ecosystem services or benefits they provide [4-6]. Said green infrastructure can come in the form of traditional urban green spaces, i.e. public spaces with vegetation, as well as privately maintained spaces, urban forests planted in streets, squares, urban green corridors, natural and semi-natural remnants, or even farms within the city and in its direct surroundings [6-11].

The importance of vegetation for human well-being forces and encourages sustainable planning and management to develop and maintain green infrastructure [12-13]. It also requires regular monitoring of status and tendency to increase or decrease, taking appropriate action in the event of losses [14].

In Latin America, and particularly in Chile, initiatives and regulations dedicated to building new green spaces, and urban greening initiatives such as tree-planting programs, have been oriented on reducing the shortages and inequities in distribution and accessibility to green spaces and, increasing urban vegetation [8,15-20]. In addition, spatial planning tools help to plan the creation of new green spaces in expansion areas, leaving free of construction sites and buildings. However, spatial planning trends oriented to develop dense residential areas, freeways, commercial centres and industrial areas contribute to the decline and disappearance of vegetated areas in the city. As monitoring at a regional scale is scarce and is yet undeveloped, it is not known if the aforementioned initiatives and regulations have had positive effects on urban vegetation cover. Such is the lack of consideration that in Chile regional land cadastres monitoring changes in land use and vegetation, mask cities as urban land uses, disregarding the vegetation they contain, and subsequently ignore how it changes over time. In regards to the latter, vegetation is highly dynamic over time, both annually, in sites with marked seasons, and interannually, as a result of inter-annual climatic variability [21].

In Chile, there have been programs that have stimulated the creation of new green spaces, both for reasons associated with environmental decontamination, and to provide public spaces for recreation. In 1992, the "Urban Parks Program" was implemented to create new urban parks in Santiago. A decade later, a complementary "Green Space Plan", also known as "Santiago Verde Plan", was institutionalised. In the last decade, the program "A Chilean, a Tree" (2010), later renamed "More Trees for Chile" (2014) was conducted by two different national governments aimed at increasing tree cover in Chile (not only in urban areas) and the Urban Parks Program at a national scale was revived with greater impetus.

Chilean cities expand rapidly and the proportion of urban population continues to rise, having already reached 89% [1]. In the periphery of the cities, previously vegetated areas (e.g. wetlands or remnants of forests or natural or semi-natural scrub) have been replaced by residential areas of varying densities. While, in the centre of cities, as part of a strategy of urban densification, neighbourhoods with large gardens and backyards dominated by vegetation have been replaced by buildings, leaving little space for vegetation [22]. On the other hand, some real estate projects have incorporated landscaping full of vegetation, in stark contrast to the arid and semi-arid conditions of the north and centre of Chile [23-25].

The objective of the present study is to monitor urban vegetation over time in a set of Chilean cities located in a climatic-latitudinal gradient. It also seeks to assess the effect of new large urban parks on the process of change described earlier. The research questions are:

- How has the vegetation coverage of Chilean cities changed between 2000 and 2015? Is this change modulated by annual rainfall?
- Does the creation of new urban parks increase vegetation coverage significantly in each city as a whole?
- How does the vegetation cover change in neighbourhoods close to new urban parks? Do parks serve as a stimulus for neighbours to plant or conserve vegetation in their own private spaces?

A cost-effective way to monitor urban greenery is through ad hoc indexes calculated using satellite imagery taken at different times. Among them, the Normalized Difference Vegetation Index (NDVI) has demonstrated its effectiveness in urban environments [26]. From this index, it is possible to deduce vegetation cover, after selecting a range of values for vegetation. Numerous studies have used NDVI as a proxy for vegetation cover [e.g. 27-28] and for urban environmental quality. In this paper, the indicator will be used in two different spatial and temporal scales to monitor urban vegetation.

2. Methodology

Urban vegetation in a group of Chilean cities was monitored by analysing information from a free spatial data platform. The information was complemented by a quantitative analysis of the variation in the total area of urban parks, for the same period, using official data. Lastly, by using high spatial resolution images, the effect of the parks on urban vegetation was monitored locally.

2.1. Selected cities

A set of 13 cities with an urban population of over 150,000 inhabitants was selected. These cities are representatives of the latitudinal gradient of annual rainfall in northern, central and southern Chile (table 1, figure 1).

Table 1. Cities analysed, their geographical latitude and their average annual rainfall

Cities	Geographical latitude	Average annual rainfall (mm/year)
Arica	18.4° S	1.9
Iquique	20.2° S	0.8
Antofagasta	23.6° S	1.9
Copiapo	27.3° S	20.5
Greater La Serena	29.9° S	78.5
Metropolitan Area of Valparaiso	33.0° S	372.0
Metropolitan Area of Santiago	33.4° S	367.3
Talca	35.4° S	676.2
Chillan	36.6° S	1127.6
Metropolitan Area of Concepción	36.8° S	1110.1
Gran Temuco	38.7° S	1212.2
Valdivia	39.8° S	1787.5
Osorno	40.5° S	1384.0

2.2. Monitoring NDVI as indicator of vegetation cover change

NDVI data was obtained through the MODIS Subsets platform (<http://daac.ornl.gov/MODIS>). This platform offers free products based on satellite images captured every 16 days with a spatial resolution of 250 m [29]. It also categorizes land use according to a 2005 classification for the same (MODIS Land Cover Classification, <http://glcf.umd.edu/data/lc>), which includes the “urban and built-up” class.

For each of the 13 chosen cities, the daily NDVI average was extracted for all available data between January 2000 and March 2016 ($N = 368$ per city), selecting pixels classified as urban. The data was then reduced to analyse exclusively data representing the dry season in each year, i.e. January to March, bringing data entries down to 97 for each city for the whole period. This was done to rule out the effect of spontaneous vegetation lasting only a few months.

The last step consisted in calculating trends in NDVI changes between the year 2000 and 2016 using a linear regression. Significance was determined using Pearson's r^2 .

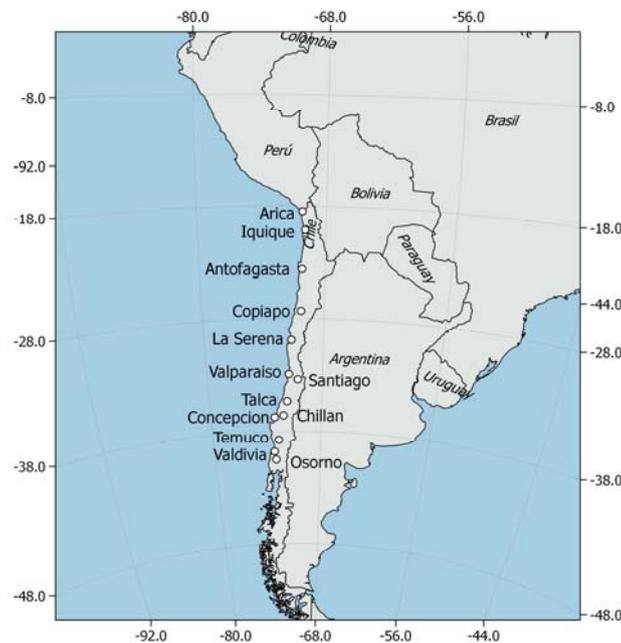


Figure 1. Location of analysed cities

2.3. Monitoring the effect of an increase in the total area of urban parks on vegetation cover

An official database of all existing urban parks at the national level [30] was analysed to evaluate the city-scale effect of the creation of urban parks between 2000 and 2015. This cadastre was validated in each of the analysed cities by reviewing very high resolution satellite images (approx. 1m) available in Google Earth Pro. In some instances urban parks not included in the official database were included in the analysis. The area of each park was calculated and only parks larger than 2 hectares located in urban areas were selected. This was intended to eliminate squares or small green spaces mistakenly considered parks. Each park was classified in the following ranges: (i) urban parks built before 2000 and (ii) urban parks built between 2000 and 2015. Finally, in each city the total area of parks built between 2000 and 2015 was calculated to obtain the relative change between 2000 and 2015, expressed as a percentage. Then, the existence of significant correlation between the percentage of change in the total park area (2000-2015) and the slope of the change of the inter-annual NDVI at city level (between 2000 and 2016) was determined to evaluate whether the construction of new parks influenced the greenery indicator (NDVI).

At the local level, new urban parks were assessed to determine if they have had an effect on the vegetation cover of the neighbourhoods they are located in. Two assumptions were evaluated: 1- the construction of a park involves the incorporation of vegetation in a site that previously had no vegetation, and 2- living next to a park encourages residents to plant more vegetation within the residential space, especially in gardens. Three units of analysis were established for each park: 1- within park boundaries, 2- in a buffer area of 100 m from the park boundary, and 3- in a buffer area of 600 m from the park boundary (Figure 2). To assess the aforementioned assumptions, a sample of urban parks from (N=14) Greater La Serena, the Metropolitan Area of Santiago and the Metropolitan Area of Concepcion were analysed. Vegetation cover was calculated with a procedure called supervised classification based on NDVI data using 30 m spatial resolution satellite images. Landsat TM, ETM + and OLI images for March of 1989, 2002, 2009 and 2015 – March being the end of the dry season – were used to calculate the NDVI. Geometric, radiometric, atmospheric, and topographic corrections were made to each image to make them comparable. Select areas (sets of pixels) covered by vegetation in each image were used to calculate vegetation cover, and subsequently used to calculate the average NDVI for all those areas. The average served as the threshold above which a pixel is defined as covered by vegetation. In this manner, vegetation cover represents the portion of the total analysed area covered by vegetation. For each park the vegetation cover was calculated from all the pixels contained in each of the units of analysis.

3. Results and discussions

3.1. Vegetation cover change

All the cities analysed in this research, except for two of the cities in more arid climates (Iquique and Antofagasta), tend toward decreasing urban vegetation (table 2), and in four cities urban vegetation decreases significantly (r^2 pearson > 0.75). The latter are Arica, Copiapo, Santiago and Talca, and are located in a rich latitudinal gradient of annual rainfalls and temperatures. In the case of Iquique and Antofagasta, there is a statistically insignificant increase in urban greenery (table 2). The higher NDVI figures are associated with higher annual precipitations, and in this case Valdivia leads the table (figure 2). Likewise, the lowest NDVIs were reported in the cities in the Atacama Desert: Antofagasta and Iquique (table 2, figure 2). The lowest inter-annual variability is found in these two cities, in addition to Arica and Copiapo (figure 2), all of which are located in the north of the country; the first three have less than 2 mm annual rainfall while Copiapo has approximately 20 mm (table 1). Santiago can be added to this group considering there are few changes between contiguous years (Figure 2). The rest of the cities fluctuate greatly from year to year, such as Temuco which registered changes of up to 19% between 2009 and 2010 (table 2, figure 2).

The results indicate there is a loss of vegetation cover in most of the analysed cities, regardless of their climate. This loss of urban vegetation occurs despite the existence of national and local programs designed to incentivise the building of new green spaces, plant trees and establish urban regulations that require the creation of green spaces in new urban developments and prevent urbanization in other areas suitable for vegetation. On the contrary, it reflects the government's systematic lack of planning and management that goes so far as to impinge on planning and management at the local level.

It is noteworthy that two cities (Iquique and Antofagasta) located in the desert zone of the country and in one of the most arid zones of the world present a slight tendency to increase urban vegetation. This is indirectly related to the economic impact of mining activities in these cities as they consist of the centre of operations and residential area for workers' families. Although many parks are managed by the municipalities or by the Ministry of Housing and Urbanism, the transformative effect of mining in large cities is massive, attracting new inhabitants, generating economies of scale and greater economic dynamism,

increasing revenue from municipal taxes, and therefore, local government budgets, etc. [31]. This would explain, on the one hand, a greater pressure exerted on new inhabitants by residents to have greener cities and, on the other hand, the provision of greater resources for green construction projects such as urban parks and their irrigation needs, water being extremely scarce and expensive in these arid regions.

Table 2. Average and trend of change (slope) of the NDVI in the cities analysed. *: significant correlation

Cities	Average of NDVI 2000-2016	Slope of NDVI linear regression 2000-2016	r ² Pearson of linear regression
Arica	0.15	-0.10%	0.76*
Iquique	0.08	0.10%	0.30
Antofagasta	0.06	0.10%	0.43
Copiapo	0.16	-0.30%	0.89*
Greater La Serena	0.30	-0.40%	0.50
Metropolitan Area of Valparaiso	0.46	-0.10%	0.06
Metropolitan Area of Santiago	0.31	-0.40%	0.84*
Talca	0.45	-0.40%	0.78*
Chillan	0.41	-0.40%	0.58
Metropolitan Area of Concepción	0.46	-0.30%	0.55
Temuco	0.40	-0.40%	0.49
Osorno	0.50	-0.40%	0.33
Valdivia	0.55	-0.20%	0.23

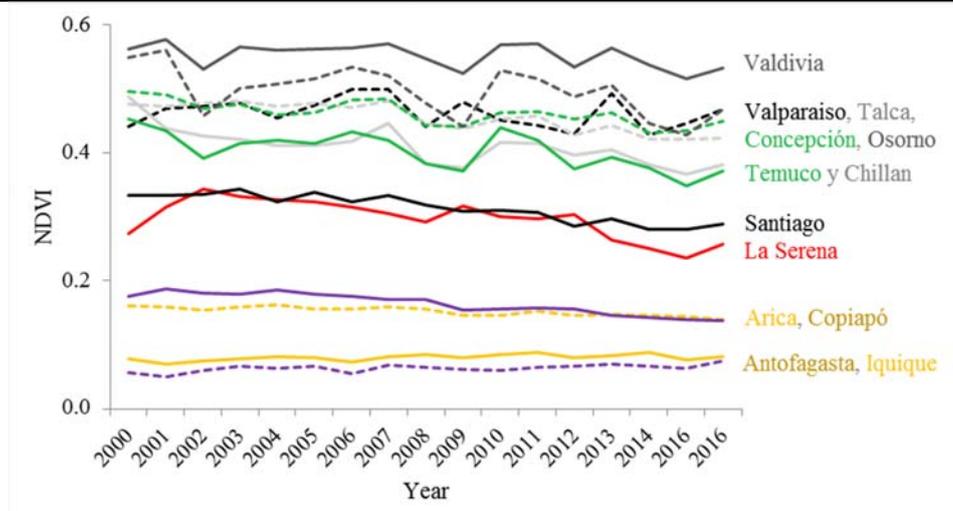


Figure 2. Inter-annual NDVI change in the analysed cities

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In the near future, urban vegetation could be significantly affected by climate change. As in other regions of the world, changes to climate patterns have also been projected in Chile. Projections indicate an increase in extreme events and a decrease in precipitation in the northern, central and southern regions of the country [32-33]. Conditions will become more arid, especially in the northern coasts of the country (where most cities are located), an increase in temperatures in the central area, as well as a significant decrease in precipitation in both the central and southern areas [33].

On the other hand, urban growth models in Chile predict that urban areas will continue to grow, especially medium-sized cities linked to the exploitation of natural resources (e.g. mining, forestry, agriculture). Depending on design and respect for the regulations that protect green spaces, urban structures for new developments and the transformation of existing urban areas will influence vegetation cover in the whole city. If no bold changes to regulations or the way they are controlled are made, cities will continue to lose plant cover.

3.2. Effects of the new urban parks on vegetation cover at an urban scale

The current area of all urban parks, in each of the 13 cities, varies from 13.2 ha in Chillan, which has 5 parks, to 2045.8 ha in Santiago, which has 156 parks. However, in the case of Chillan, it represents the largest increase considering only those parks built between 2000 and 2015 (77% increase), followed by Osorno with 60% (table 3), which currently has 159.4 ha distributed among 7 urban parks, and Iquique with 49% with only 19.2 ha in 4 parks. Other cities in the arid north (Arica, Antofagasta and Copiapo) have larger areas of parks (64.4, 30.7 and 25.8 ha respectively), which, over the last 15 years, have increased from 20 to 26% (table 3). The lowest increases in the total area of parks were Concepcion (12%) and Temuco (16%), both cities in the south of Chile, with 22 and 8 urban parks respectively (table 3). Concepcion is similar to Valparaiso and Santiago, in the fact that they have a large area assigned to urban parks as a result of greater urban extension, all three considered metropolitan areas in Chile (table 3). In this respect, Santiago has the fourth largest urban park in the world (<http://www.parquemet.cl>) with more than 700 ha.

The analysis of the increase in surface area assigned to urban parks in the last 15 years, and its effect on urban vegetation at a city scale indicates that, although there has been significant, widespread increase of urban parks in all cities, this has not generated a significant effect on plant cover at a city scale (r^2 Pearson $\ll 0.75$). In other words, the increase in the total area of parks does not correlate with an increase in NDVI in the same period.

3.3. Effects of new urban parks on vegetation cover at a local scale

At the local level, the creation of new parks has an immediate effect on the area covered by the park, significantly increasing vegetation cover after its inauguration, though vegetation cover in some parks does in fact decrease after they are built and inaugurated. Meanwhile, high variability is observed in the immediate surroundings and while there are some parks that increase coverage in their respective environment, most of them lose plant cover (figure 3). As a result, there is a tendency to decrease both in

the buffer area closest to the park (100 m) and also in the buffer zone farthest from the park (600 m), from 5 to 36% (figure 3).

Table 3. Current total area of urban parks for the selected cities and changes occurring between 2000 and 2015

Cities	Number of urban parks (in 2015)	Total area of urban parks (in 2015) [ha]	Total area of new urban parks (built between 2000 and 2015) [ha]	Relative increase in total area of urban parks between 2000 and 2015
Arica	7	64.4	13.5	21%
Iquique	4	19.2	9.3	49%
Antofagasta	8	30.7	6.0	20%
Copiapo	3	25.8	6.7	26%
Greater La Serena	12	157.8	36.1	23%
Metropolitan area of Valparaiso	9	523.0	113.8	22%
Metropolitan area of Santiago	156	2045.8	527.2	26%
Talca	5	30.7	14.5	47%
Chillan	5	13.2	10.2	77%
Metropolitan area of Concepcion	22	240.2	30.0	12%
Gran Temuco	8	122.4	19.7	16%
Valdivia	5	103.6	33.0	32%
Osorno	7	159.4	96.2	60%

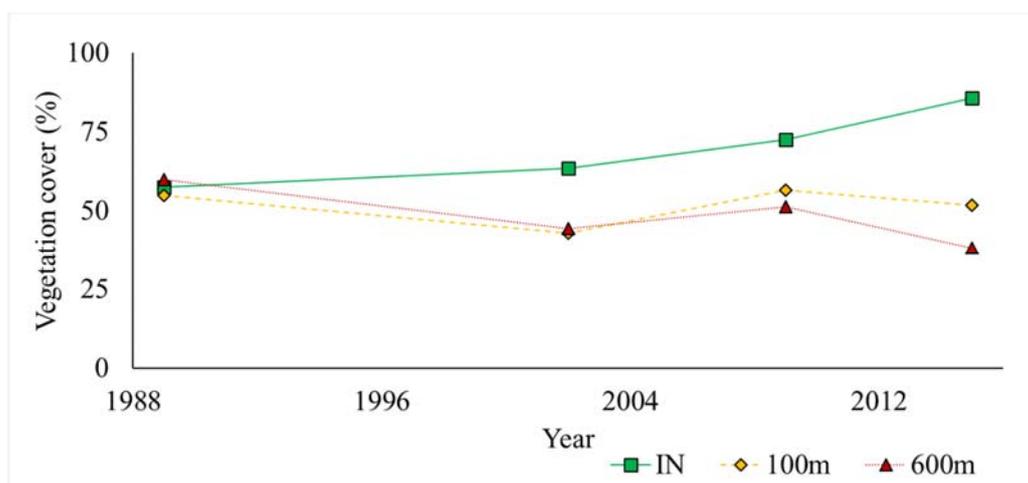


Figure 3. Change in average vegetation cover inside parks (IN) and neighbourhoods adjacent to parks (in a buffer area of 100m and 600m from the park boundary)

The widespread creation of new urban parks in the last 15 years has not had a significant effect in increasing vegetation coverage at a city-wide scale. That is to say, although the parks add square meters of vegetation and green spaces, vegetation tends to decline in cities, even in the cities that have increased park surface area the most. Results obtained at a local level indicate that there is a loss of vegetation cover in private residential spaces. This means that the creation of new parks contributes to curbing the rate of urban

vegetation loss. Therefore, it remains a challenge to encourage people living near-to parks (especially new parks) to plant and conserve vegetation in their own private spaces, expanding the vegetated area leaving the park at the core, and enlarging green areas within neighbourhoods and subsequently extending the benefits parks and vegetation provide.

4. Conclusions

One of the goals of urban planning is to serve as a tool to ensure sustainable provision of benefits through the creation and conservation of urban green infrastructures in their vast diversity, through urban vegetation in general, and especially through large urban parks. This study describes indicators that can monitor ~~the~~ how urban vegetation behaves at both city and local level in general, and specifically in urban parks. Thus, it serves as a proxy indicator to evaluate the capacity of cities to provide benefits by means of urban vegetation. It also proposes a useful cost-effective tool to show whether government programs, planning instruments and urban regulations associated with the creation or maintenance of green infrastructure and urban vegetation have been effective in increasing the provision of these green infrastructures or at least, in preserving existing areas.

At the moment, Chilean cities are not able to retain or increase urban vegetation cover, simply adding to the environmental injustices that still exist in terms of access to green spaces and poorly distributed urban vegetation. Urgent challenges remain unresolved regarding how planning and urban management can help to solve these problems. However, it is clear that it is not enough to focus exclusively on creating new green spaces in public spaces, it is also necessary to regulate and encourage the existence of vegetation in private property (e.g. residential or industrial) in cities.

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