

# What Really Matters in Green Infrastructure for the Urban Quality of Life? Santiago de Chile as a Showcase City

Ellen Banzhaf, Sonia M. Reyes-Paecke, and Francisco de la Barrera

## 1 Introduction

The built, green and social environment express the situation of a city and, to a large extent, indicate the development of the urban area. These components of the urban environment have a strong impact on the quality of life of citizens. Along with the concepts of resource efficiency and resilience in cities, the quality of life forms one of the three pillars on which our research on urban transformations is grounded. We approach the concept of quality of life from the environmental perspective and understand the human well-being as an integral part of the broader concept of quality of life. In this study we focus on green infrastructure (GI) as an indication for quality of life research. Here, we measure the extent to which people can access GI as a service and profit from this infrastructure for health-related and social dimensions (Scottish Executive 2005; Bogner 2005). Rapid urbanisation processes accelerate land-use changes that mostly go along with extensive urban land consumption and involve population developments. Such multi-dimensional changes in urban land use and land-consumption patterns are very dynamic and widely ramified.

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E. Banzhaf (✉)

Department of Urban and Environmental Sociology, Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany  
e-mail: [ellen.banzhaf@ufz.de](mailto:ellen.banzhaf@ufz.de)

S.M. Reyes-Paecke

Department of Ecosystems and Environment, Faculty of Agronomy and Forestry Engineering, Pontificia Universidad Católica de Chile. Center for Sustainable Urban Development (CEDEUS), Santiago, Chile  
e-mail: [sreyespa@uc.cl](mailto:sreyespa@uc.cl)

F. de la Barrera

Institute of Geography, Centre for Urban Sustainable Development, Pontificia Universidad Católica de Chile, Santiago, Chile  
e-mail: [fdelabarrera@uc.cl](mailto:fdelabarrera@uc.cl)

They can evoke unsustainable structures that entangle social-spatial differentiations which are discussed in the context of urban growth and shrinkage processes (see Haase et al., “[From Shrinkage to Regrowth: The Nexus Between Urban Dynamics, Land Use Change and Ecosystem Service Provision](#)”, in this volume, dealing with urban dynamics, Seto et al. 2011; Kabisch and Kuhlicke 2014). As land is a limited and contested resource, it demands for infrastructural provision and, particularly with respect to urban quality of life and a sustainable urban development, for the provision of green infrastructure.

Urbanisation affects the development of land use in different ways and with varying consequences for different social strata even within the same urban area. Hence, land-use changes must be geared in a resource-efficient and resilient manner (UN 2016) to secure the environmental quality for all residents regardless their social strata. In this sense, urban land-use structure pictures environmental aspects of the quality of life, and relates to social-spatial disparities (see Kindler et al., “[Socio-spatial Distribution of Airborne Outdoor Exposures – An Indicator for Environmental Quality, Quality of Life, and Environmental Justice: The Case Study of Berlin](#)”, in this volume). Regarding social-environmental aspects, land-use dynamics are the trigger to accelerate or decelerate urban transformations towards a sustainable urban development at various scales (Banzhaf et al. 2017).

A variety of commitments for a sustainable land use have been elaborated at both international and national level, e.g., the Rio 20 outcomes call for a neutral world without land degradation to solve the problem of land consumption (UN 2012). In this respect the EU has an objective of ‘no net land take’ by 2050 (EEA 2015), but Latin America is still far from adopting this type of political agreements because in many cities, major housing and infrastructure deficits persist and also steer further urban expansion (UNEP 2010). Beyond the high share of European and US citizens (82%, UN 2011; UN 2012), more than 90% of Latin Americans live in cities, thus making this continent to be the most urbanised on earth (UN 2012; World Bank 2014). Especially in Latin American countries such as Chile which have a strong socio-spatial differentiation environmental dimensions of quality of life, also depend on the social strata of the population. To illustrate these dimensions we exemplify our study on Santiago de Chile.

## **2 Tackling Questions of Green Infrastructure as a Major Component of Urban Land Use**

Green infrastructure (GI) is defined as the interconnected network of natural and semi-natural areas with other environmental features to secure urban ecosystem services. Therefore it supports plant and animal species, maintains natural ecological processes in rural and urban areas, and contributes to the health and quality of life for human beings (CMP 2013; The Conservation Fund 2016; McDonald et al. 2005).

As mentioned above, Latin America lacks from taking on appropriate political conventions, and cities like Santiago de Chile are exposed to further acceleration

of urban processes such as urban land use change accompanied by shortcomings in environmental quality. In contrast, in Europe, the policy of GI has been elaborated under the EEA guise of ‘Science for Environment Policy’ (EEA 2011). The European Commission (EC 2013) emphasizes that GI policy has the capability to offer win-win, or ‘no-regret’ solutions (see Knapp et al., “Do Urban Biodiversity and Urban Ecosystem Services Go Hand in Hand, or Do We Just Hope It Is That Easy?”, in this volume) and could promote integrated spatial planning by identifying multi-functional zones and by incorporating habitat restoration measures into land use plans and management strategies (EEA 2011). Hence, we want to shed light to the relation between urban quality of life and GI in the Latin American context.

In our view, it is important to analyse the various characteristics of GI for the cornerstones of urban transformations, foremost its role for a resource-efficient handling of urban land and a resilient and well-adapted vegetation cover to secure a sustainable quality of life in cities. Therefore we want to tackle the following question on different spatial scales to understand prospective land-use options related to GI: How can green infrastructure contribute to residents’ well-being and thus maintain or even enhance urban quality of life in changing urban environments? In this sense it is important to evaluate the multiple contributions of GI for ecosystem services, against different socioeconomic conditions, and in different urban and suburban settings by using a refined set of indicators. Comprehending the facets of GI’s regional and local specifications we will shed light to their effects at each particular scale for Santiago de Chile as case study which is characterised by a very fast urban growth and an extreme social-spatial differentiation.

GI covers all kinds of vegetated urban spaces, with diverse forms and structures with contributing multiple functions (Jim et al. 2015) and is one of the major suppliers of urban ecosystem services. Typically, GI refers to an interconnected network of such multifunctional green spaces, gardens, street aligned trees which is strategically planned and managed to supply a range of such services (Benedict and McMahon 2006; Wright 2011). Its development has been driven by changes in local demand and urban form over time, but in the past decade it has attracted burgeoning interest, including notably its potential as a climate change intervention (Hansen et al. 2016; Naumann et al. 2011a). It corresponds to the spatial structure of areas covered by vegetation may it be natural or semi-natural, adjacent to water bodies or to buildings and public infrastructure. Therefore GI is the basis for the provision and regulation of urban ecosystems to serve as multiple benefits for citizens (EC 2016). The high level of return over time gained from healthy GI supplies a higher environmental quality of life and is complementary to the so-called grey infrastructure. Depending on its size, form, location, internal facilities and configuration, the emanating GI can be of advantage for human well-being on the local and regional level of cities.

Citizens have strong needs for GI and related ecosystem services and, at the same time, they produce far-reaching environmental implications. Urban GI is a specific type of goods that supplies services by natural structures designed or conserved (Naumann et al. 2011b), and needs to be constantly maintained in cities. As

land consumption is a critical issue regarding urban sustainability, the maintenance, connectivity and distribution of GI are essential parameters to secure resource-efficient urban land use. Beyond its capacity to amplify resilience of cities (e.g., micro-climate regulation, capture of pollutants, flood regulation) GI can also improve the urban quality of life by ensuring cultural services (e.g., recreation, aesthetics), especially in densely populated cities. Urban ecosystem services are generally understood as the direct and indirect contributions of ecosystems to human well-being (TEEB 2010, p. 33) for which GI in cities accounts for environmental health (De Groot et al. 2010; Haines-Young and Potschin 2010). Being recognized and promoted differently by people and local governments according to their priority needs and values, urban GI offers a great diversity of tangible and intangible benefits for citizens.

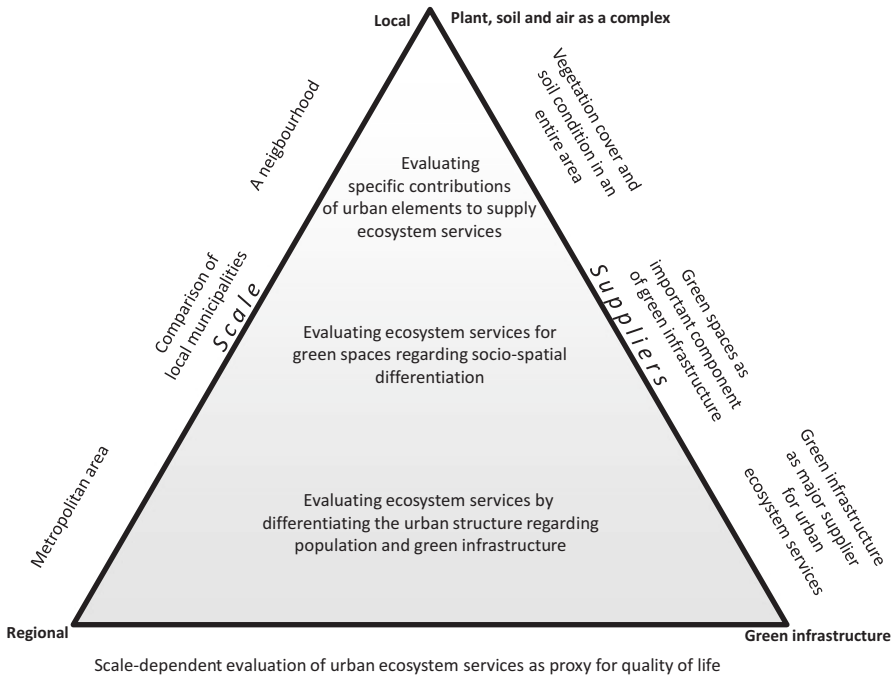
### 3 Methodological Considerations

#### 3.1 *GI from Different Spatial Perspectives*

As GI delivers essential ecosystem services in a multi-faceted way our goal is to understand its regional and local characteristics and their impact better at the respective scale. In a multi-scale approach we assess the quantity and quality of different kinds of GI to get findings on its sensitivity to environmental pressures related to dynamic urban processes (see Fig. 1). Hence, we give spatially explicit evidence on urban GI as a supplier for ecosystem services to preserve or enhance the environmental quality of life. Keeping multifunctional aspects of GI in mind, we refer to the urban quality of life from environmentally driven considerations on human well-being in urban areas.

To comprehend the role of GI as a proxy for environmentally induced quality of life we elaborate a differentiated picture on multiple scales. Key aspects are the urban structure which may result in (un)evenly distributed GI, and potential social inequalities in relation to this structure. Thus, the various facets of GI may be a superior indicator for different urban contexts with different environmental goods expressing different levels of quality of life in the entire urban area of Santiago de Chile. For a differentiated comprehension of its significance, we perform a down-scaling from the urban central municipalities to suburban development, from one municipality to another, and even from one neighbourhood to the adjacent one.

Figure 1 depicts our scale-dependent concept starting from the entire urban area on the regional scale, continuing with comparisons of different municipalities on the intermediate local scale and finally focussing on one suburban municipal neighbourhood. Dependent on the respective scale we evaluate the GI to first illustrate different urban and suburban configurations (urban scale), then discuss green spaces in socio-spatially differentiated urban environments and their corresponding role for ecosystem services, and finally shed light on neatly differentiated vegetation in a newly developed suburban neighbourhood to explain the plant-soil complex.



**Fig. 1** Scale-dependent evaluation of green infrastructure (GI) as main constituent for urban quality of life

Distinctions between GI, green spaces and vegetation cover need to be pointed out. As defined above, GI refers to the performance of green components as functional elements, implies connections and thus establishes a network. Public green spaces are one of the most important components of GI, they are considered as public goods which allow free access to all citizens and represent pockets of nature for all residents, but their coverage of vegetation can strongly differ. Vegetation cover, however, is a broad concept with a diverse structural pattern. It comprises root penetration, ramification, foliation, and adheres to different types of grass, flowers, shrublands, and trees (De la Barrera et al. 2016a, b; Lehmann et al. 2014).

### 3.2 Santiago de Chile as a Showcase City

Many growing cities are characterised by their high heterogeneity and assemble a vast number of large residential and commercial developments reaching from core areas far into the urban fringe, sometimes with much environmentally and economically degraded space in-between (Loibl and Toetzer 2003; Wu 2010). As a complex phenomenon, suburbanisation is thus emerging as intertwined trajectories with locally pronounced developments. The sprawl into suburban areas is not a single

urban feature and does not steadily proceed outwards from a single centre. Urban and suburban dynamics entail multifarious problems, which include various combinations of environmental implications such as superimposed soil sealing, inadequate configuration with GI, and socio-spatial inequalities amongst others.

Like so many other (emerging) megacities, Santiago de Chile has high urban growth, a tremendous increase in population, suburbs and leap-frog development which transforms land use. Such unrestricted urban expansion evolves a high pressure on the urban region, converts open spaces into urbanised land-use types and produces unbalanced distribution and quality of GI due to increasing demand on housing and public infrastructure. There are many reasons to investigate GI in this city. Amongst others our showcase city is located in a valley framed by the Andes and the Pacific Coastal Range with a lack of air ventilation and subsequent episodes of severe air pollution during winter. Santiago is a city with a Mediterranean climate implying long periods of drought in hot summers producing intense urban heat island effects, and short heavy winter rainfalls with flood hazards. The urban landscape comprises a heterogeneous pattern of urbanisation, from densely built to disperse urban areas with a high structural diversity, being surrounded by agricultural land and native vegetation remnants. As such, it is a prime example for a city that can enhance the environmental quality of life for its citizens by establishing a sustainable GI and, consequently, providing and regulating ecosystem services (e.g., cooling effects; Inostroza et al. 2016). Like the strong socio-spatial differentiation in so many soaring cities, Santiago de Chile can be characterised by high urban diversity in terms of (1) population and housing densities, with its highly dynamic processes of urbanisation by encroaching upon the surrounding landscapes; and (2) GI and its extremely different expression in the residential areas. From urban to municipal to neighbourhood scale the different components of GI need to be investigated twofold: in terms of their composition and structure, and their distribution and accessibility (Reyes-Paecke and Figueroa 2010).

### 3.3 *Elaborated Methods*

In our approach we carry out an enhanced multiple scale analysis by means of remote sensing techniques, spatial analysis, population statistics, field mapping and social survey. This mixed method approach allows us to comprehend the significance of GI for urban quality of life at various scales and for selected municipalities and neighbourhoods. For the entire urban area of Santiago de Chile and their respective 34 municipalities we quantify land-use and population dynamics in space and time as well as their share in green spaces. To do so, we need to know the amount, distribution, share, and configuration of GI which we gain on the basis of the following performance and sustainability indicators: fraction of *population density* for the entire administrative units compared to the fraction for the particular *built-up areas*, densities of *built-up areas* regarding their *degree of imperviousness*, as well as *public green spaces*, their *dynamics*, and their ratio *per capita*. To gain all these pieces of

information we combine remote sensing techniques with GIS exploiting satellite data, census data and additional population statistics. Based on that knowledge we then cluster the urban area into *urban* and *suburban* municipalities for which we get findings about their dichotomy and similarities regarding structural characteristics of their environmental quality. Based on this detailed spatial analysis we extract three socioeconomically contrasting municipalities for a further and much more refined picture of the urban and suburban situation regarding their green spaces' *quality*, *quantity*, *spatial distribution* and *accessibility*. For the latter we evaluate these municipalities through social survey techniques. By in-situ observation of people's use of green spaces on a random sample size and further interviews with various users of public green spaces, we gain a deeper understanding about such qualitative aspects as their attitude, perception of safety, social interactions and appreciation. Finally, a special attention is exemplarily paid to a newly constructed suburban area and its respective neighbourhoods, to derive a sophisticated knowledge on its implication for urban ecosystem services within and beyond such a neighbourhood. Here, its vegetation composition is recorded by field mapping, with added value from remotely sensed data to map the dynamics of vegetation cover from the time before the development took place and in the presence of the newly developed suburbs.

## 4 Results: GI Analysis at Multiple Scales

### 4.1 *Mirroring Urban with Suburban Municipalities Auditing Dichotomy and Similarities*

To understand the impact of land-use changes and population dynamics on the urban quality of life we investigate the urban area of Santiago de Chile in the juxtaposition of urban and suburban municipalities. Location and built-up densities form the criteria for this subdivision at municipal level on which we analyse changes in population densities, development of the built-up areas, and of GI. As major drivers of land-use changes we identify *population*, *population density* of urban and suburban municipalities and for the particular *built-up area* to understand local and regional environmental pressures on land. Areas of lower and higher supply by GI are gained from *public green spaces*, especially their *amount*, *distribution* and *dynamics*, to gather a sophisticated insight into their multifunctionality and their configuration regarding the socio-spatial differentiation of Santiago de Chile. These indicators help to measure and compare the urban and suburban patterns and their impact on the urban quality (Briggs 2003; OECD 1997; UNEP 2010). The size and shape of the green areas, as well as the density and diversity of vegetation present therein are key factors to the ability to provide ecosystem services. The larger green areas allow for greater plant diversity, they contribute more effectively to the micro-climatic regulation and to reduce stormwater runoff. Therefore the structural attributes are good proxies for estimating ecosystem services provision (Cilliers et al. 2013; Inostroza et al. 2016; Lehmann et al. 2014).

According to its urban structure, we divided the city into 21 urban and 13 suburban municipalities covering an area of 2274 km<sup>2</sup>. In 2009, Santiago was home to approximately 6.2 million inhabitants, which is equivalent to a population density of 2734 inh./km<sup>2</sup> (Encuesta CASEN 2009). Romero et al. (2012, p. 81) point to the high urbanisation process. They show that the built-up area almost doubled between 1975 and 2009 from approximately 341 km<sup>2</sup> to about 616 km<sup>2</sup>. In this respect urban sprawl has developed in an uneven suburban pattern over space and time being home to low and middle class population in dense settlements and offering space for disperse high-class areas.

Despite a generally very positive population growth, the 21 urban municipalities are characterised by a residential decline of -6.5% (1992–2002) and -10% (2002–2009). Here, approximately 90% of the space is built-up, leaving little area for GI to supply the citizens with ecosystem services. The dynamics of public green spaces is not well pictured by statistics only. Although they increased by 1.5% in the urban municipalities between 2001 and 2006, their spatial distribution varies greatly. In the urban area, parks were created for low-income families and scarce green spaces due to a program of the Ministry of Housing (called Urban Parks Program). In contrast, the 13 suburban municipalities have gained tremendously in the number of residents by 40% and 37% in the respective intervals. Although, in average, suburbs have less than 50% of their surface sealed by building activities, the tendency for further densification is observed if the natural setting (on foothills or along valleys) allow for. Here, public green spaces gain 0.4% in the same period, documenting that in suburban municipalities the values are lower while the built-up areas grow faster (Banzhaf et al. 2013). Differences in municipal policies are reflected in individual positive or negative changes, since some municipalities allocated resources to increase green spaces, other municipalities did not set the same priority. In some suburban municipalities least public green spaces occur where private green spaces are biggest, mirroring the high-income sectors. In these few suburban municipalities private green spaces and the related ecosystems are well supplied and the quality of life secured without much public space needed.

Predominantly though, the spatial analysis shows the necessity to improve environmental quality in GI twofold: in the urban core area most space is being built-up, and most green spaces refer to historical parks. Hence, the environmental quality of life could be improved by more vegetation cover (e.g., street trees, green façades and roofs), so that different types of GI provide benefits for residents. Suburban municipalities of lower to middle classes are densely built-up whereas other municipalities in the outskirts with higher socio-economic classes signify low-density residential areas. Therefore GI varies more in the suburban municipalities and generally provides very little green spaces. Less affluent municipalities offer smaller patches of land to residents with less open areas and have less financial resources to irrigate green spaces. The municipal effort to increase the number of green spaces is a positive planning aspect where urban areas still have a scarce amount of green spaces. Likewise do more affluent municipalities establish few public green spaces, but their local dwellers own large private gardens and have less need for GI on public grounds. They can provide irrigation for public and private spaces for which the



supply with ecosystem services is ensured at local level. Such diverse socio-spatial structures have different physical settings, some of them do not meet the greater needs for GI. For a regional comparison of large agglomerations as exemplified here, the amount of public green spaces per capita serves well to give evidence on socio-ecological priority and deficit areas. Applying this indicator (minimum of 9–11 m<sup>2</sup> of green spaces per inhabitant to contribute to an adequate quality of life) we can estimate the capacity of public green spaces as ecosystem service supplier that serves as a standard quality of life measure (UNEP 2010, p. 157). During the last decade (2001–2006), most of Santiago de Chile showed an increase, but the amplitude differs: in the urban municipalities GI rises from 5.7 to 7.9 m<sup>2</sup>/inh. (+38%) and from 4.0 to 5.7 m<sup>2</sup>/inh. in the suburbs (+44%). The differences could continue to lessen if this trend goes on. Individual distinctions are not related to urban or suburban conditions, since municipalities with very low values (less than 5 m<sup>2</sup>/inh.) exist in both areas. Only seven municipalities exceed 10 m<sup>2</sup>/inh. in 2006, five of which are urban and two are suburban. In urban municipalities the increase is due to two simultaneous processes: the creation of new public green spaces, and the decrease in residents (for further details of this study see Banzhaf et al. 2013).

Other suburban areas of Santiago fulfil the commonly significant and negative relationship between built-up areas and vegetation cover (Banzhaf et al. 2013). From the perspective of GI as supplier for ecosystem services, most of these suburbs are densely built-up, offer little space for vegetation and therefore experience a shortage in regulating, providing and cultural ecosystem services. Although having increased their public green spaces after 2000, the overall vegetation cover has remained little in the built-up area of these municipalities (Banzhaf et al. 2013, p. 188). Only those newly developed suburbs along the Andean piedmont differ substantially for which we discuss their value in a subsequent section (see Sect. 4.4 in this chapter).

## ***4.2 Inter-Municipal Inequalities in the Supply of Green Spaces***

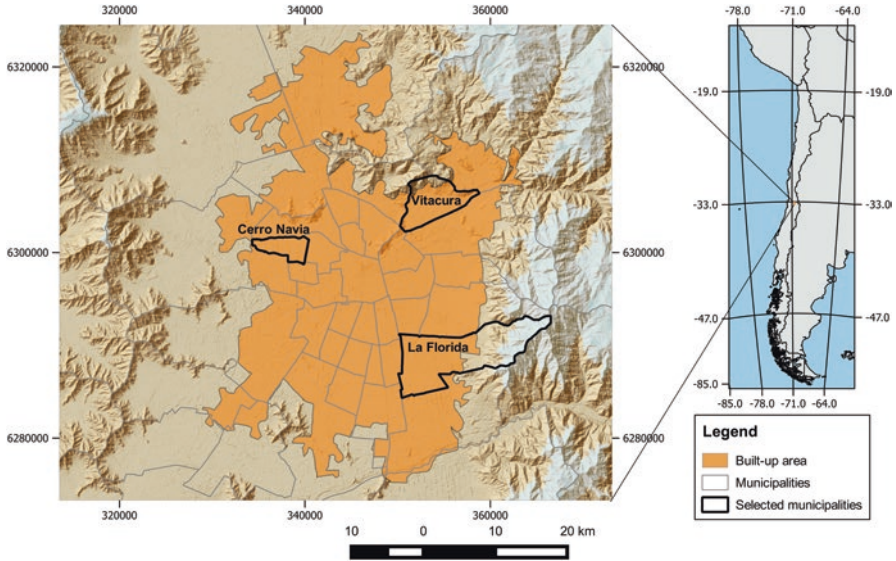
For the socio-ecological situation complementary indicators must still be considered to get a more comprehensive view when testing the relationship between environmental and socio-spatial inequalities. While GI are suppliers for ecosystem services and especially trees are relevant at the regional and even global level for carbon sequestration, other services are also important at less aggregated levels, where GI provides microclimate regulation, flood and landslide mitigation and cultural services such as recreation and beautification of the urban landscape. The municipal level is defined here as spatial units smaller than the urban area, according the administrative organization of each city.

Inequalities in the spatial distribution of GI generate uneven ecosystem services (in quantity and quality) throughout the urban area. The magnitude of these inequalities

in Santiago de Chile have been analysed by applying a set of spatially explicit indicators for measuring green spaces' quality, quantity, spatial distribution and accessibility (De la Barrera et al. 2016a). The study results by Banzhaf et al. (2013) provides the prerequisite to select three socioeconomically differentiated municipalities (see Fig. 2) for which the elaborated indicators are applied. The municipality with the lowest income level (Cerro Navia) has the least area of green spaces per inhabitant ( $2.6 \text{ m}^2/\text{inh.}$ ) although these spaces occupy a larger proportion to the built-up area (4.3%) compared to the municipalities with middle-income population ( $2.8 \text{ m}^2/\text{inh.}$  and 3.1% of built-up area) and high income population ( $7.7 \text{ m}^2/\text{inh.}$  and 3% of the built-up area). These seemingly contradictory values are due to the marked difference in population density whose highest value is 166 inh./ha in the poorest municipality and reaches only 37 inh./ha in the municipality (Vitacura) with highest incomes. The differences for GI are magnified on the municipal surface in municipalities of low (15%), medium (25%) and high income (41%) respectively. As family income increases, the share of private spaces also increases and with it the amount of GI and thus ecosystem services supply, while in low-income municipalities public green spaces are the major suppliers (for further details see De la Barrera et al. 2016a). The comprehensive results are depicted in Table 1. They show strong differences associated with the different income levels of the population.

In Table 1 the quantity, quality and spatial distribution of public green spaces refers to the respective municipality. In Santiago de Chile, public green spaces are publicly assigned areas belonging to the respective municipality. It is of greatest relevance that their furnishing with plants and their maintenance underlies the municipal budget which must settle the score of high water prices. Significantly, vegetation cover of the poorer municipality Cerro Navia is mainly found on public green spaces, which allows for the conclusion that there is hardly any vegetation outside public green spaces, but these spaces are not well covered by vegetation either. Coincidentally, the urban structure limits the available private space for vegetation to small gardens. In relation to the high number of inhabitants there are obviously disproportionately few public green spaces in this representative municipality. Therefore the share of population supplied by green spaces reaches 70% in general, but this share decreases to 41% if we define the size of a green space to be larger than 0.5 ha. Vitacura, in contrast, has rather few inhabitants but large public green spaces, which are well covered with vegetation. Hence, the share of population supplied by green spaces reaches almost 82%, and even if the size of a green space is larger than 0.5 ha the supply for inhabitants still reaches 67%. For the latter it can be observed that vegetation cover of this municipality is mainly on private grounds, explaining for the share of *public* green spaces per entire vegetation cover being comparatively low (De la Barrera et al. 2016a, Table 3).

Regulating and supporting ecosystem services can be supplied by public and private spaces, e.g., tree cover helps to mitigate the urban heat island and provides a suitable habitat for wildlife (Soule 1991). Further references support the findings of this study in which neighbourhoods with highest incomes show higher vegetation cover in general, thus lower temperatures in summer situations and even increased presence of native birds than lower-income ones (Díaz and Armesto 2003; Romero



**Fig. 2** Location of the urban area of Santiago de Chile (*grey* feature is the built-up area). For the study of inter-municipal inequalities three contrasting municipalities are selected: Cerro Navia (low incomes), La Florida (middle incomes), and Vitacura (high incomes) – highlighted in **bold lines** (Source: Own sources, De la Barrera et al. (2016a))

et al. 2012). Most cultural services require direct contact of citizens with nature through recreation, nature trails, socialising amongst others. As a consequence, private spaces (residential gardens, private parks) supply these services solely or mainly to their owners or to those with access to such places. For this reason public green spaces are relevant for supplying cultural services even if there are private green spaces in the vicinity. Hence, public green spaces are even more important in densely urbanised areas where many houses have no gardens. Shortages of a municipality in (public and private) GI cannot be compensated by some vegetation cover on green spaces only, because the urban structure limits any available space to be converted into new green spaces. Central urban municipalities, being poorer or richer, are mainly built-up, although some of them possess large historical parks or some vacant land. Generally speaking, they are much less flexible when it comes to developing new GI. Therefore we made our selection of contrasting municipalities along the eastern suburban fringe and in the urbanised central west.

Beyond, specific GI such as tree canopies on public land has a significant role for social, aesthetic and environmental benefits for residents (Troy et al. 2012; Salmond et al. 2016). Due to the need to build housing and infrastructure, growing cities such as the study area face a constant pressure on land. The combination of population and economic growth (which facilitates real-estate investment) and high density of urbanisation restricts the presence of environmental amenities (Livert Aquino and Gainza 2014) which include GI, and even threatens existing green spaces.

**Table 1** Set of indicators for public green spaces (GS) evaluated in three contrasting urban settings

Indicators	Low income municipality Cerro Navia	Medium income municipality La Florida	High income municipality Vitacura
<b>Quantity of GS</b>			
GS per inhabitant			
GS per vegetation cover			
<b>Quality of GS</b>			
Mean size of GS			
Mean vegetation cover per GS			
Vegetation cover on GS per inhabitant			
<b>Spatial distribution and accessibility to GS</b>			
Share of population supplied by GS			
Share of population supplied by GS > 0,5 ha			

The positive correlation between the household incomes and the abundance of vegetation has been demonstrated in other cities, e.g., city of Tampa, Florida, USA (Landry and Chakraborty 2009) and Montreal, Canada (Pham et al. 2012). In Santiago de Chile, poorer and richer municipalities invest a similar share (4.1–4.7%) of their budget to tree management on green spaces (Escobedo et al. 2006) achieving different results, not only because their municipal budgets are quite different. This study shows how a high income municipality keeps an abundant vegetation cover in private gardens and on green spaces of public use that would not survive unattendedly in such a semi-arid environment where urban vegetation is dominated by exotic species requiring irrigation and maintenance. In cities located in arid and semiarid regions the correlation between income level and vegetation cover is rather evident (Jenerette et al. 2007; Halper et al. 2012). In these municipalities the low-income population faces a double constraint in regards to the maintenance of vegetation. Those contrasts are land and water scarcity. The lowest income groups live in smaller properties which again reduce the area that could be planted, and cannot devote a lot of water to irrigate the plants, due to the cost of drinking water. It also emphasizes the demand of lavishly planted public green spaces for poorer municipalities to balance out the deficiency of vegetation cover on private spaces. The mentioned evidences also suggested that the higher the household incomes,

the richer the structural diversity (e.g., tree, shrub and herbs) (Reyes-Paecke and Meza 2011).

Generally speaking, the supply of multiple ecosystem services depends on the amount and diversity of GI and especially tree cover (Dobbs et al. 2011). As mentioned before, many cultural services such as recreation, contact with nature, rest and social interactions depend on the actual use of green spaces by people. The use of green spaces ensures that these services are actually delivered, but it is greatly influenced by structural attributes such as size, quantity and quality of equipment and vegetation, lighting and cleanliness, accessibility and proximity to the population (Giles-Corti et al. 2005; Lapham et al. 2016). In addition, it also depends on residential characteristics such as age, gender, physical limitations (disability), and their perception regarding the safety of these spaces (Parra et al. 2010; Lapham et al. 2016).

### ***4.3 The Benefits of Green Spaces for Different Neighbourhoods***

It is important to evaluate the use of green spaces in neighbourhoods of different socioeconomic status in order to know which factors are more decisive or better explain their use in different urban contexts. If these factors are known, they could contribute to better planning and maintenance of green spaces, which is a very important issue for local governments. For several reasons, Santiago is a representative for complex cultural perceptions occurring in many big and diverse cities. First, despite the differences between the three analysed neighbourhoods described above, in all cases the people that effectively use green spaces positively value their existence and their environmental and social role. Most of them consider them to be especially important for children, and also as spaces to be in contact with nature, for sports and leisure. Regarding the physical characteristics of green spaces, users consider the spaces with more trees and grass more attractive, with playgrounds, benches and lighting and those where they feel safe. To conclude, residents benefit from green spaces as cultural ecosystem services in cities.

#### **4.3.1 The Perception of Safety**

The sense of security appears to be linked to the knowledge residents have of other users, i.e., they are not perceived as strangers, but as part of the community. Insecurity seems to correspond to certain types of activities of other external users, factors such as the use of alcohol and drugs, and the absence of people during extended periods of time (De la Barrera et al. 2016c). In high income neighbourhoods the presence of security guards is frequent. According with studies conducted in other Latin-American cities (Bogotá, Colombia and Santa Cruz, Bolivia) the perception of safety is also influenced by cleanliness, lighting, the presence of guards

and other visitors (Parra et al. 2010; Wright-Wendel et al. 2012). Meanwhile Lapham et al. (2016) analyse the interactions between parks equipment and perceived safety in four urban areas of the U.S. They find that parks with several different facilities – as playgrounds, tennis courts, basketball courts - were perceived as rather safe and report less incivilities which give evidence about perceived quality and safety as key factors for the quality of green spaces.

### **4.3.2 Socially Explicit Usage Categories**

Santiago shows interesting differences in the intensity of the use of public green spaces between different neighbourhoods. In the lowest income neighbourhoods different types of users and uses are observed simultaneously. In these spaces a mixed age structure with children, youth, adults and seniors performing different planned and spontaneous activities coexist even if green spaces are smaller than 1000 m<sup>2</sup>. In contrast, in higher income neighbourhoods the users are almost exclusively children accompanied by caring adults (parents or nannies), with little presence of youth, adults and seniors, not accompanying children (De la Barrera et al. 2016c). Consequently, the use of green spaces contrasts between planned meetings or chance encounters of neighbours in low income neighbourhoods and very low interaction in green spaces among residents of high income neighbourhoods.

### **4.3.3 Perception of Ecosystem Services by Residents**

Despite that citizens are not explicitly aware of the concept of ecosystem services, they clearly perceive social and environmental benefits provided by green spaces, most prominently the contact with nature, physical activity, leisure, socialising with friends or neighbours, and the aesthetic value it brings to the neighbourhood. Furthermore, regulating services such as pollution abatement and temperature mitigation are appreciated by those interviewees regularly using the analysed green spaces and even by residents infrequently visiting the respective sites. Both, air pollution and high temperatures are serious environmental problems affecting Santiago at different times of the year with a rising awareness of its residents.

## ***4.4 The Importance of GI in Neighbourhoods of Newly Constructed Suburban Areas***

The suburban landscape changes fast in expanding cities like Santiago where the new urban settings have different forms, densities and landscaping depending on the concept of their development. In suburbs, population and built-up densities vary more than in central parts thus affecting the urban ecosystem services supplied by the newly planted and designed GI. In such newly built suburban neighbourhoods

design options could take advantage of the GI concept to bring ecological and social systems closer together leaving soils unsealed to offer more available spaces for conservation of remnants of vegetation (Margules and Pressey 2000). Options exist to select adaptive species and to design the spatial pattern of built and green infrastructures in a more sustainable way.

The suburban area of Santiago has experienced a replacement of vegetated areas with natural and semi-natural vegetation or crops by residential uses (Romero and Vásquez 2005; Romero 2007; Pavez et al. 2010). Fuentes et al. (1984) and Holmgren (2002) also describe the replacement of native dense vegetation by a low dense open savannah of thorny vegetation. The latter represents natural but degraded vegetation, typical of agricultural abandoned lands or landscapes after fires. It used to have annual exotic grasses which increase the risks because such grasses are easy to ignite. In addition, the open savannahs facilitate the presence of exotics herbivores. All these factors obstruct the establishment and conservation of native vegetation less resistant to fires and herbivory. In addition, it can provide much less ecosystem services because of its lower biomass (Holmgren 2002; De la Barrera et al. 2016b). Thus, all these land-use changes suggest a critical loss in the composition and quality of GI, if they assume urbanisation being just sealing of soils and newly developed real estates.

Exemplified in this study is a suburban area located in the Andean piedmont where the current built-up area was a mosaic of active and abandoned agricultural lands about 60 years ago with only 68.4 ha of urbanised area, having been transformed into 1916.6 ha of suburban area by 2010 (De la Barrera et al. 2016b). Meanwhile local population increased from 13,092 to 106,187 inhabitants between 1970 and 2016 according to official data. In 2009 its population density was only 60 inh./ha in the urbanised part of the municipality thus evincing a much lower figure than the average of suburban and urban municipalities of Santiago (97 and 100 inh./ha respectively; Banzhaf et al. 2013).

These fast land-use changes brought an increase in an index referred to healthy vegetation and quantity not only at the extension of the new suburban area but also in the entire mostly rural watershed. In general, the trend shows that more urbanisation renders more vegetation cover. This trend is explained by the sustained increase of vegetation cover by replacing bare soils by a structural diversity of GI, such as street trees, green spaces and private gardens. Those changes result in an increase of three ecosystem services. First, the service of maintaining or improving air quality is reinforced because there is more biomass to capture pollutants. Secondly, rainwater infiltrates better because areas with low vegetation cover are replaced by densely vegetated areas, offsetting the increase in sealed soils. Thus, the hazard of landslides decreases in this hilly area making the area more resilient against such a natural hazard. Finally, microclimate regulation is favoured by newly planted trees providing shade. These types of GI supply the currently new suburban developed area along the foothills in a higher quantity compared to the previous historical suburban situation. Beyond, accumulated anthropogenic disturbances in rural conditions produce poor vegetation cover with less abundant biomass such as firewood, charcoal production, agricultural activities, pasture (De la Barrera et al. 2016b).

As a consequence, only those low density new suburban areas developed along the Andean piedmont mostly coincide with a high GI coverage which is configured by trees and other native plants to secure high benefits of ecosystem services. These affluent neighbourhoods have more available private spaces to maintain vegetation and their socio-economic situation allows keeping their gardens lush. On the one side this observation confirms the simple suggestion that some specific types of urbanisations constituting of affluent residents are well supplied with provisioning of ecosystem services. On the other hand the privately established GI serves as a regulating ecosystem service reducing flooding, preventing landslides or diminishes transmitting of pollution, waste or exotic species from urban to rural settings beyond their own privileged neighbourhoods with a positive effect on the piedmont region. In particular, suburban areas can serve as a buffer between the rural surroundings and the urban core helping to mitigate these adverse effects.

## 5 Conclusions

Our multi-scale investigation gives empirical evidence on the differentiated evaluation of GI for the urban quality of life, exemplified by one of the fastest growing cities in Latin America. In Santiago de Chile, different urban environments can sustain the high value that GI provides for the supply of ecosystem services like increasing the cooling effects, maintaining or enhancing cultural and aesthetical values, decreasing inundations and landslides to name the most important. But these services can only be secured at neighbourhood and municipal level. Besides, GI can enhance resilience, ensuring the human well-being, and thus securing the urban quality of life at neighbourhood scale.

As a showcase city, Santiago de Chile reveals that GI can greatly contribute to the urban quality of life valued in neighbourhoods. Restrictions refer to decisions on GI that depend on the authorities at different levels of governance and the municipal budget. When we sum up our answers to the question “*What really matters in green infrastructure for the urban quality of life?*” we can state the following points of view: The most obvious implication is that the creation and conservation of public green spaces really matters, because these places are one of the most important and equitable contributors of GI and, additionally, they are highly appreciated by users. Secondly, the urban structure (i.e. patterns of spatial heterogeneity and land use) and the dynamics in urbanisation are significant factors when creating or maintaining GI as it requires available space. Finally, the structure of GI really matters, and as land is limited, this vegetation composition must ensure the quality and supply of ecosystem services in a resource-efficient way, for instance by including native plants with low water requirements. In this regard, there is a strong recommendation to other cities to consider vegetation species that are naturally adapted to the local climate which has strong advantages. Only urban planning that takes a well-adapted GI into account provides a more resilient environment to citizens and cares for a more sustainable urban development.



Cities like Santiago de Chile are facing multiple challenges: they must sort out the deficit in social infrastructures, improve their urban governance and also incorporate the scientific knowledge advances into decision making and, in parallel, they must adapt to a changing climate scenario. Regarding GI, these challenges can be solved only with a greater integration of scientific research and citizen participation in decision-making. Changes are required in current maintenance practices in order to ensure the ecosystem services provision without increasing unsustainable levels such as by high irrigation water consumption. Governance constraints become obvious as changes must be supported by the municipalities for their successful implementation. For example, in urban landscaping sustainable GI involves an important change that must be accepted by the community, understanding that this is an imperative measure for sustainability of both green spaces and the entire urban environment.

In the developing world, urban transformations have some particular complexities. What is striking in Santiago de Chile like in so many other large agglomerations (e.g., Mexico City, Buenos Aires, Pearl River Delta, Calcutta, etc.), it either does not have a central authority or the administrative boundaries do not include the urban area. The lack of this level of management makes a normative approach difficult, as a central authority could design an integrated land-use planning. Impeding is the individual land-use planning of each municipality, and the lack of strategic land-use planning for the entire urban area. This situation causes larger differences between municipalities, since each of them defines its environmental and land-use policies independently. Although there are some regional institutions (Regional Secretariat of Housing and Urbanism, Regional Government) that try to regulate regional policies (in an indicative, not in a normative way, and only by suggestions), they are not always mandatory for municipalities; one reason for the heterogeneity found in several of the studied dimensions. Therefore the role of the urban area as a political decision actor would be important for territorial choices and a sustainable development to safeguard the current and future urban quality of life.

The numerous civil society initiatives seeking to improve GI and public policies going in the same direction allow setting up the basis to design a more liveable environment and thus a consistent or even better quality of life. It must be based on the recognition that today we are building the GI that people will need throughout the next century.

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