



**FACULTAD DE CIENCIAS AMBIENTALES  
CARRERA PROFESIONAL DE INGENIERÍA AMBIENTAL**

**“ON THE USE OF HEDONIC PRICE INDICES TO UNDERSTAND  
ECOSYSTEM SERVICE PROVISION FROM URBAN GREEN  
SPACE IN FIVE LATIN AMERICAN MEGACITIES”**

**“Sobre el Uso de Índices de Precios Hedónicos para Comprender la Provisión  
de Servicios Ecosistémicos de las Áreas Verdes Urbanas en Cinco  
Megaciudades de América Latina”**

**Tesis para optar el Título profesional:  
INGENIERA AMBIENTAL**

**Presentado por:  
URSULA LORET DE MOLA LEÓN  
Asesor:  
PhD. BRENTON LADD**

**LIMA – PERÚ  
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**ACTA DE SUSTENTACIÓN DE TESIS**

Lima, 10 de julio de 2018.

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**On the use of Hedonic Price Indices to Understand Ecosystem Service Provision from Urban Green Space in Five Latin American Megacities**

**Sobre el uso de Índices de Precios Hedónicos para Comprender la Provisión de Servicios Ecosistémicos de las Áreas Verdes Urbanas en Cinco Megaciudades de América Latina.**

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Para optar el Título Profesional de **Ingeniero Ambiental**

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## RESUMEN

Las megaciudades de América Latina (AL) se enfrentan a enormes desafíos para brindar bienestar a millones de personas que viven en ellas. Las altas tasas de urbanización y la limitada capacidad administrativa de las ciudades de AL para planificar y controlar el crecimiento urbano han conducido a un déficit crítico de áreas verdes y, por ende, a resultados no óptimos en términos de sostenibilidad urbana. Este estudio busca evaluar la posibilidad de emplear los precios inmobiliarios para proveer una estimación del valor monetario de los servicios ecosistémicos proporcionados por las áreas verdes urbanas, en cinco megaciudades de América Latina: Bogotá, Buenos Aires, Lima, Ciudad de México y Santiago de Chile. Utilizando imágenes de Google Earth para cuantificar las áreas verdes y el análisis de regresión múltiple, evaluamos el impacto de las áreas verdes urbanas, las tasas de criminalidad, la densidad de negocios y la densidad poblacional en los precios inmobiliarios en las cinco megaciudades mencionadas. Además, para un subconjunto de datos (Lima y Buenos Aires) analizamos los efectos de las variables de ecología del paisaje (tamaño del parche de área verde, conectividad, etc.) en los precios de bienes raíces. Ello, para facilitar una primera idea de cómo los atributos ecológicos de las áreas verdes urbanas pueden determinar el nivel de provisión de servicios ecosistémicos en diferentes contextos urbanos en América Latina. Los resultados muestran una fuerte relación positiva entre la presencia de áreas verdes urbanas y los precios inmobiliarios. Las áreas verdes explican el 52% de la variabilidad en los precios inmobiliarios en las cinco megaciudades estudiadas. La densidad poblacional, la densidad de negocios y la delincuencia solo representaron un impacto menor en los precios inmobiliarios. Nuestro análisis de las variables de ecología del paisaje en Lima y Buenos Aires muestra que la relación entre las áreas verdes y el precio inmobiliario es específica del contexto; requiriendo mayor investigación para comprender cuándo y dónde los atributos ecológicos de las áreas verdes afectan los precios inmobiliarios. Todo ello, necesario para que los administradores de las áreas verdes urbanas en las ciudades de AL puedan optimizar su configuración ecológica y así maximizar la provisión de servicios ecosistémicos de las áreas verdes, a menudo limitadas.

**Palabras clave:** Áreas verdes urbanas; precios inmobiliarios; megaciudades de América Latina; Google Earth; Índices de Precios Hedónicos

## ABSTRACT

Latin American (LA) megacities are facing enormous challenges to provide welfare to millions of people who live in them. High rates of urbanization and limited administrative capacity of LA cities to plan and control urban growth have led to a critical deficit of urban green space, and therefore, to sub-optimal outcomes in terms of urban sustainability. This study seeks to assess the possibility of using real estate prices to provide an estimate of the monetary value of the ecosystem services provided by urban green space across five Latin American megacities: Bogota, Buenos Aires, Lima, Mexico City and Santiago de Chile. Using Google Earth images to quantify urban green space and multiple regression analysis, we evaluated the impact of urban green space, crime rates, business density and population density on real estate prices across the five mentioned megacities. In addition, for a subset of the data (Lima and Buenos Aires) we analyzed the effects of landscape ecology variables (green space patch size, connectivity, etc.) on real estate prices to provide a first insight into how the ecological attributes of urban green space can determine the level of ecosystem service provision in different urban contexts in Latin America. The results show a strong positive relationship between the presence of urban green space and real estate prices. Green space explains 52% of the variability in real estate prices across the five studied megacities. Population density, business density and crime had only minor impacts on real estate prices. Our analysis of the landscape ecology variables in Lima and Buenos Aires also show that the relationship between green space and price is context-specific, which indicates that further research is needed to better understand when and where ecological attributes of green space affect real estate prices so that managers of urban green space in LA cities can optimize ecological configuration to maximize ecosystem service provision from often limited green spaces.


**Keywords:** Urban green space; real estate prices; Latin American megacities; Google Earth; hedonic price indices

**I. ARTICULO CIENTIFICO**



Article

# On the Use of Hedonic Price Indices to Understand Ecosystem Service Provision from Urban Green Space in Five Latin American Megacities

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**Abstract:** Latin American (LA) megacities are facing enormous challenges to provide welfare to millions of people who live in them. High rates of urbanization and limited administrative capacity of LA cities to plan and control urban growth have led to a critical deficit of urban green space, and therefore, to sub-optimal outcomes in terms of urban sustainability. This study seeks to assess the possibility of using real estate prices to provide an estimate of the monetary value of the ecosystem services provided by urban green space across five Latin American megacities: Bogota, Buenos Aires, Lima, Mexico City and Santiago de Chile. Using Google Earth images to quantify urban green space and multiple regression analysis, we evaluated the impact of urban green space, crime rates, business density and population density on real estate prices across the five mentioned megacities. In addition, for a subset of the data (Lima and Buenos Aires) we analyzed the effects of landscape ecology variables (green space patch size, connectivity, etc.) on real estate prices to provide a first insight into how the ecological attributes of urban green space can determine the level of ecosystem service provision in different urban contexts in Latin America. The results show a strong positive relationship between the presence of urban green space and real estate prices. Green space explains 52% of the variability in real estate prices across the five studied megacities. Population density, business density and crime had only minor impacts on real estate prices. Our analysis of the landscape ecology variables in Lima and Buenos Aires also show that the relationship between green space and price is context-specific, which indicates that further research is needed to better understand when and where ecological attributes of green space affect real estate prices so that managers of urban green space in LA cities can optimize ecological configuration to maximize ecosystem service provision from often limited green spaces.

**Keywords:** Urban green space; real estate prices; Latin American megacities; Google Earth; hedonic price indices

## 1. Introduction

Between 1700 and 2000, 55% of the Earth's ice free land cover was transformed by human activities, leaving less than 45% of the terrestrial biosphere natural or semi natural [1]. Also, humans have changed the way they use the environment and their distribution within it. World population has gone from living mainly on semi natural lands in 1700 [2], to living mostly in dense settlements (cities) by 2016 [3]. Nowadays, cities are home for more than half of the world's population [4], and cities are expanding on average at twice the rate of the human population [5–7].

In Latin America (LA), three-quarters of the population already lives in cities [8], making it one of the most urbanized regions in the world. Moreover, LA cities, and megacities increasingly play a key role in the economies of the region [9]. However, LA cities can also be characterized by deep social and spatial segregation, crime, income inequality, and poverty [10]. High population densities and the high concentration of human activity in LA megacities have led to a number of negative environmental impacts [11] and there are significant challenges in terms of meeting the demand for new physical infrastructure, which is often achieved at high social and/or-environmental costs [12].

Many city planners and policy makers consider urban green space and vacant lots as potential land to be converted to infrastructure [13,14] without taking into account the fact that cities depend on the ecosystem services that urban green space provides to sustain human well-being [15,16]. Urban green space, defined as vegetated natural and human-modified outdoor spaces [17] including parks and urban forests, greenways, trails, community gardens, street trees, cemeteries, and others [18], occurs as patches embedded in the urban matrix, where its connectivity and continuity is often endangered by other land allocation priorities [19]. Thus, cities in Latin America are characterized by a critical deficit of urban green space [8], which impairs human well-being [20].

Urban green spaces provide both environmental and social benefits, as they help to ameliorate several problems that occur in cities by supplying numerous ecosystem services. Ecosystem services are the direct and indirect contributions to human well-being, in this case, from urban ecosystems and their components [15] and their provision is related to an increased quality of life [21] and urban resilience [22]. Urban green spaces may improve air quality by filtration of pollutants, regulate water flux and urban temperature, reduce the heat island effect generated by concrete and combustion motors as well as reduce noise pollution [23,24]. Urban green space also improves the mental and physical health of citizens, and supports social interactions [18,25–27].

However, these benefits have a non-market price, so that they cannot be traded in an existing market [28], leading to insufficient consideration of green spaces in public urban-planning policies.

One of the main challenges that LA urban planners face in order to achieve welfare for millions of urban residents in LA megacities is related to large, uncontrolled and informal urban development that places pressure on the provision of basic services, increases a city's vulnerability and has a number of negative environmental consequences [29–31]. This informal growth also tends to occur independently and apart from formal urban expansion which leads to the consolidation of spatial segregation socioeconomically [32]. Green spaces are important in urban areas as they support ecological integrity of cities, provide ecosystem services, and improve the livability of cities [18,24,25], which clearly needs to be taken into account in urban planning activities [33,34]. If the economic value of urban green space could be demonstrated through a premium on real estate, the importance of the ecosystem services provided by urban green space would be reinforced in the political decision-making process [35]. This is important because financing public infrastructure and public services depends heavily on governmental institutional arrangements [36].

One approach to quantify the value of ecosystem services is through the use of hedonic price indices [37]. Hedonic price indices are based on correlations between prices in existing markets (i.e., the real estate market) and specific ecosystem services (i.e., air quality) or bundles of ecosystem services, as, for example, provided by urban green spaces [18,25]. An open question for the LA region is whether hedonic price indices can be used to estimate the value of ecosystem service provision from urban green space in its megacities. Another open question for LA cities is how the ecological attributes of

urban green space might impact the capacity of urban green spaces to provide ecosystem services. Here, we provide some insight into these two issues for LA cities. We specifically test the following hypotheses: (1) hedonic price indices can provide reliable estimates of the value of ecosystem service bundles generated by urban green space across Latin American megacities, and (2) the information that we can obtain from hedonic price indices may be context specific and vary across cities.

## 2. Methods

### 2.1. Characteristics of the Cities Used in the Comparison of Hedonic Price Indices Across Cities

This study is focused on LA megacities (as opposed to cities more generally) due to the high concentration of the LA population in megacities compared to other regions of the world [38]. According to UN Habitat (2012), there are eight megacities in LA: Buenos Aires, Mexico City, Rio de Janeiro and São Paulo (with more than 10 million inhabitants) and Belo Horizonte, Bogota, Lima and Santiago (with populations approaching 10 million) [8]. Among these eight we were able to obtain real estate prices at district level for the following five megacities: Bogotá in Colombia, Buenos Aires in Argentina, Lima in Peru, Mexico City in Mexico and Santiago in Chile (Appendix A).

Although these five megacities present common urban development challenges, the intensity of specific aspects related to sustainability and resilience changes from one city to another [10] (Table 1).

Bogotá is located in the center of Colombia, on the eastern flank of the Andes, at 2625 m above sea level [39]. The city has an extension of 1637 km<sup>2</sup> [40] and is politically divided into 20 *localidades* [26]. Bogota has an annual population growth rate of 1.3%, with a mean population density of 4876 inhabitants/km<sup>2</sup> [41]. It has a relative compact structure with high consolidation of population density, with an increased concentration of informal development in peripheral areas [42]. Growth of informal settlements and pronounced income inequality levels are the most important challenges in Bogota. The estimation of green space per inhabitant is 10 m<sup>2</sup> [43].

Buenos Aires is located in the central-eastern region of the country, on the western shore of the La Plata river, on the Pampean plain, at 25 m above sea level [44]. The city's extension is 204 km<sup>2</sup> [45]. Buenos Aires is officially divided into 48 *barrios*; however, the political and administrative management of the city is distributed across fifteen *comunas* that, in most cases, cover more than one Buenos Aires *barrio* [44]. It has an annual rate of population increase of 1.5%, with a mean population density of 14,970 inhabitants/km<sup>2</sup> [45]. Buenos Aires presents pronounced socio-spatial differentiation with a strong suburban and peri-urban growth [29]. Growth of informal and precarious housing, poverty, inequality, and crime are the most urgent challenges in Buenos Aires [10]. The estimation of green space per inhabitant is 6 m<sup>2</sup> [44].

Lima is located on the coast and in the center of the country, on the shores of the Pacific Ocean and is limited by the coastal desert and formal construction of the city, which has occurred mostly on ex agricultural land on flood plains of three rivers: Chillón, Rímac and Lurín. Lima is 154 m above sea level [46]. The city has an extension of 2812 km<sup>2</sup> and is divided into 43 *distritos* [47]. Lima's annual population growth rate is 1.6% [48] and its population density is 3328 inhabitants/km<sup>2</sup> [49]. Lima is a highly segregated metropolitan agglomeration with deep contrasts between high income and low-income sectors of the population [50]. In Lima there is a large amount of informal urban growth and an unsatisfied demand for basic services like drinking water, transport, and housing [10]. The city has 3 m<sup>2</sup> of green space per inhabitant [51].

México City is located in the Mexican Valley at 2240 m above sea level [52]. The city has an extension of 1485 km<sup>2</sup> and is divided into 16 *delegaciones* [53]. Mexico city's annual population growth rate is 0.3% and its population density is 5967 inhabitants/km<sup>2</sup> [54]. Growing insecurity, social-spatial fragmentation and precarious housing conditions are the most important social challenges in Mexico City [10]. Mexico City has 13 m<sup>2</sup> of green space per inhabitant [55].

Santiago is located in the Santiago valley surrounded by the Andes, at 520 m above sea level [56]. The city has an extension of 640 km<sup>2</sup> and is politically divided into 32 *comunas* [57]. It has an annual

population growth rate of 1.0% and a population density of 2304 inhabitants/km<sup>2</sup> [58]. Santiago’s housing policies have reduced informal housing issues; nevertheless, these policies have led to profound social segregation [10,59]. Santiago has 4 m<sup>2</sup> of green space per inhabitant.

**Table 1.** Selected Latin American megacities and respective relevant information.

	<b>Bogota</b>	<b>Buenos Aires</b>	<b>Lima</b>	<b>Mexico City</b>	<b>Santiago</b>
Country	Colombia	Argentina	Peru	Mexico	Chile
Mean altitude (AMSL)	2625	25	154	2240	520
Extension (km <sup>2</sup> )	1637	204	2812	1485	640
City administrative divisions	20 localidades	48 barrios	43 distritos	16 delegaciones	32 comunas
Green space (m <sup>2</sup> /inhab)	10	6	3	13	4
Mean annual precipitation (mm)	818	1040	16	749	390
Mean annual temperature (°C)	13.5	16.8	18.8	15.7	14.4
Population growth rate (%)	1.3	1.5	1.6	0.3	1.0
Most Significant Challenge	Informal settlement growth	Insecurity	Lack of basic services	Insecurity	Spatial-Social segregation

### 2.2. Green Space Quantification across the 5 Megacities

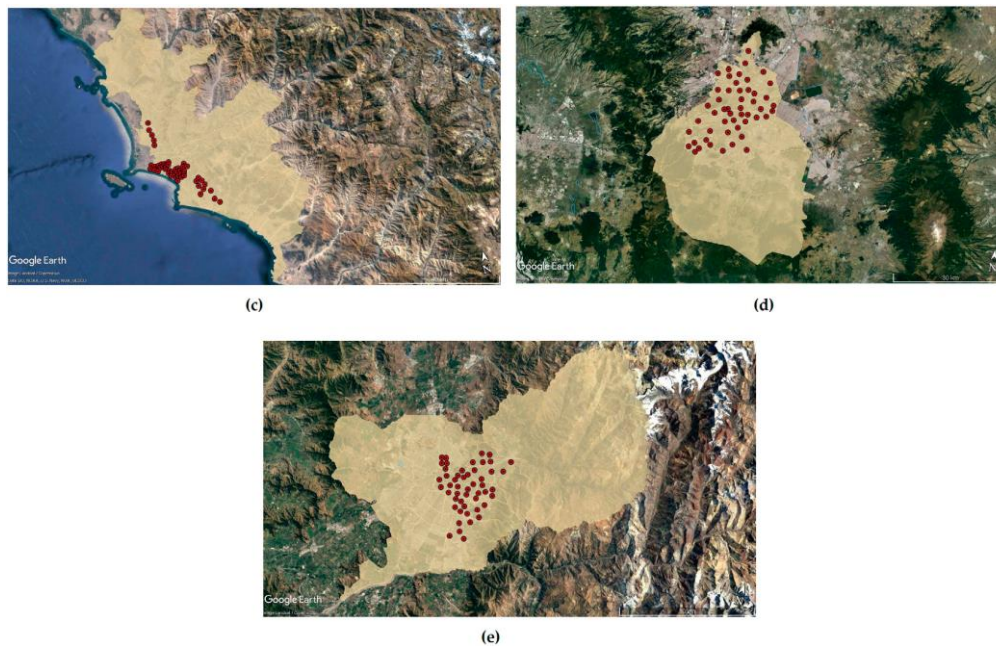
LA megacities occupy different amounts of physical space and have been built over different types of original land cover. Thus, three characteristics were considered to define the districts included in this study: (1) percentage of rural population; (2) location; and (3) size.

Districts that had more than 50% rural population and/or were predominantly rural or adjacent to the sea shore were excluded. Within and between the five megacities, districts sizes are different. San Telmo in Buenos Aires is the smallest district with an area size of 1.2 km<sup>2</sup>; and Tlalpan in Mexico City is the largest district with 312 km<sup>2</sup>. Districts smaller than 3 km<sup>2</sup> and/or larger than 100 km<sup>2</sup> were excluded. To create a comparable sample, ten districts per city were randomly selected from the districts that were larger than 3 km<sup>2</sup> and smaller than 100 km<sup>2</sup>.

Google Earth Pro (version 7.3) was used to obtain land cover data with images from 2013. Total area sampled per district was 2.5 km<sup>2</sup>, divided into five randomly selected polygons of 0.5 km<sup>2</sup>, which accounted for the majority of the area in the majority of the districts sampled. In summary, this study considered five polygons per district equivalent to 50 polygons per city, with a total number of 250 polygons (Figure 1). Green space measurements were established at an altitude of 500 m above ground level. Urban green spaces were defined as areas covered with any type of vegetation as described by Wolch et al. (2014) [18]. Thus, all types of vegetation cover were sampled inside all polygons, from single trees to urban forests to measure the total availability of green space including public and private spaces.



**Figure 1.** Cont.



**Figure 1.** 250 sampled polygons distributed within five megacities. (a) Bogota; (b) Buenos Aires; (c) Lima; (d) México City; (e) Santiago. Image Landsat/Copernicus downloaded Google Earth.

### 2.3. Socio-Economic Variable Estimation across the Five Megcities

**Population Density:** This variable was estimated as the number of inhabitants per km<sup>2</sup> of each district area in 2013 (Appendix B). This variable was included in the analysis across cities because Garcia & Riera (2003) have shown that individuals are willing to pay in order to live in less densely populated suburbs [60]. Other studies also have shown that people prefer neighborhoods with low population density and low dwelling-unit density [61,62].

**Business Density:** This variable is the ratio resulting from dividing the total number of businesses by total district area in 2013 (Appendix B). This variable shows the probable relationship between a more economically active area and willingness to pay to live in said area. According to Des Rosiers et al. (2000) and Yu et al. (2012), there is a positive relationship between real estate prices and proximity to shopping centers, suggesting that the attractiveness of commercial facilities impacts on households' decisions and translates into a higher demand, and therefore higher prices and rent [63,64].

**Crime Density:** This variable is calculated as the number of crimes recorded per km<sup>2</sup> in each district in 2013 (Appendix B). Previous findings suggest that there is an important relationship between crime rates and property values. Ihlanfeldt & Mayock (2010) suggest that home buyers are willing to pay nontrivial premiums for housing located in neighborhoods with less aggravated assault, robbery and crime [65]. Indeed, crime rate reduction has an immediate benefit on real estate prices but also, benefits that are derived over a 4–6 year period [66].

### 2.4. Case Study: The Effect of Landscape Ecology Variables on Hedonic Price Indices

Buenos Aires and Lima were chosen as case studies for a more profound analysis in which we assessed how landscape ecology variables (mean patch size, patch connectivity, etc.) affect real estate prices in an effort to obtain a deeper understanding of how and when differences in the ecological attributes of green space can impact the potential for ecosystem service provision from urban green space. In this dataset, Buenos Aires and Lima represent the extremes of climatic conditions with the lowest mean annual precipitation in Lima (16 mm) and highest in Buenos Aires (1040 mm).



Satellite images of Buenos Aires and Lima from March 2013 were downloaded from Google Earth Pro (Version 7.3, Google Inc., Mountain View, CA, USA) and processed in ArcGIS 10.3 (ESRI, Redlands, CA, USA). Images were first georeferenced and projected in geographic form, and then areas of interest were extracted from the previous five randomly selected polygons of 0.5 km<sup>2</sup> per district. We used the Segment Mean Shift from the Spatial Analyst toolbox to segment the images into objects of at least 10 pixels. We then manually selected objects that corresponded to our definition of urban green areas or “green patch” within the areas of interest. The area of each patch was calculated using the calculate geometry function in the attribute table of ArcGIS. Average Nearest Neighbor distance between green patches were calculated using Euclidean Distance in the Spatial Statistics toolbox.

### 2.5. Statistical Analysis

To homogenize data and simplify interpretation for the analysis of hedonic price indices across cities, independent and dependent variables were normalized prior to statistical analysis with the following transformation:

$$X_i^* = X_i / X_{max}$$

where  $X_i^*$  is each dependent variable after normalization.  $X_i$  is the variable prior to normalization and  $X_{max}$  is the maximum value obtained for the variable in the respective city.

For the case studies (Lima and Buenos Aires) no normalization of data was performed before analysis since differing scales are not an issue within single cities.

Transformed and non-transformed data were analyzed using multiple linear regression using XLStat (Version 2014.5, Addin Soft, Paris, France).

## 3. Results

### 3.1. Comparison of Hedonic Price Indices across the Megacities

From a multiple regression with four independent variables, we obtained a model with admissible accuracy ( $R^2 = 0.62$ ; Table 2A; Figure 2). The  $\eta^2$  values indicate that urban green space was the most important predictive variable explaining 52% of the variability in real estate prices across the megacities considered in this analysis. Business density also had a modest influence on real estate prices with a  $\eta^2$  value of 10, whereas crime rate and population density had non-relevant impacts (Table 2). However, there was also considerable error with unexplained variability accounting for 39% of the sum of squares; therefore, a complete understanding of the factors that determine real estate pricing was not obtained from the analysis across cities.

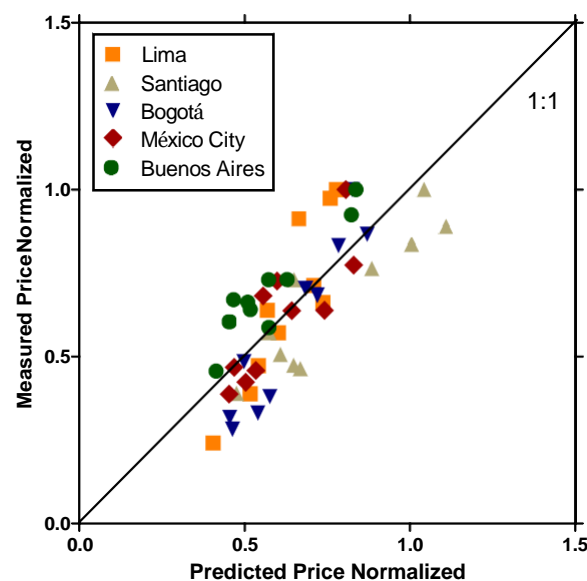
**Table 2.** (A) Summary statistics for the multiple regression models in which (A) real estate prices were correlated with four variables: green space, population density, business density and crime rate, (B) green space and green patch attributes vs. real estate prices in Lima, and (C) green space and green patch attributes vs. real estate prices in Buenos Aires. Variables: AV/at = green space/total area, TGS = Total green space, TNP = Total number of patches, MPS = Mean patch size, LPS = Largest patch size, ANN = average nearest neighbor, PopDen = Population Density, BusDen = Business Density, CrimDen = Crime Rate.

Source	df	SS	MS	F	Pr > F	$\eta^2$
(A) Analysis hedonic price indices across cities						
AV/AT *	1	1.14	1.14	60.16	<0.0001	51.5
Pop Den *	1	0.00	0.00	0.03	0.87	0.0
Bus Den *	1	0.22	0.22	11.5	0.002	9.8
Crim Den *	1	0.00	0.00	0.24	0.63	0.2
Error	45	0.85				38.5
Corrected Total	49	2.21				100

Table 2. Cont.

Source	df	SS	MS	F	Pr > F	η <sup>2</sup>
(B) Analysis of green space and patch attributes vs. real estate prices in Lima						
TGS	1	2,663,521.6	2,663,521.6	42.9	0.0	83.8
LPS	1	223,703.7	223,703.7	3.6	0.1	7.0
TNP	1	18,053.0	18,053.0	0.3	0.6	0.6
MPS	1	21,708.4	21,708.4	0.3	0.6	0.7
ANN	1	2851.4	2851.4	0.0	0.8	0.1
Error	4	248,443.6	62,110.9			7.8
Corrected Total	9	3,178,281.6				100.0
(C) Analysis of green space and patch attributes vs. real estate prices in Buenos Aires						
TGS	1	213,044.0	213,044.0	1.7	0.3	12.5
LPS	1	393,208.9	393,208.9	3.1	0.2	23.0
TNP	1	88,816.9	88,816.9	0.7	0.5	5.2
MPS	1	131,095.6	131,095.6	1.0	0.4	7.7
ANN	1	375,692.7	375,692.7	3.0	0.2	22.0
Error	4	508,002.4	127,000.6			29.7
Corrected Total	9	1,709,860.5				100

df, degrees of freedom; SS, sum of squares; MS, mean squares; F, F-test; Pr, probability, η<sup>2</sup> percentage of variation of the R<sup>2</sup> explained for each independent variable, η<sup>2</sup> is obtained from the SS partial value between the SS total value per 100. \* Variables after transformation (normalization) used for multiple regressions for first analysis. Normalization:  $X_i^* = X_i / X_{max}$ .  $X_i$ : variable prior to normalization.  $X_{max}$ : maximum value obtained for the variable in the city in which the district occurs.



**Figure 2.** Relationship between measured prices and predicted price at district level. Predicted values obtained via multiple regression: Predicted Price Normalized (NOR) = 0.35 + 0.71\*av/at NOR – 0.053\*Population Density NOR + 0.34\*Business Density NOR – 0.061\*Crime Density NOR. See Table 2 for details. Diagonal line indicates the 1:1 relationship. The normalized data used in this analysis adhere closely to the 1:1 line (which indicates close correspondence between the measured and predicted values and shows the robustness of the multiple regression model).

### 3.2. Case Study: The Effect of Landscape Ecology Variables on Hedonic Price Indices

Results from the case studies (Lima and Buenos Aires) provided a strong hint that the effectiveness of hedonic price indices for constraining the value of the ecosystem services provided by urban green space can be context specific.

The Lima data showed a strong relationship between the amount of green space and real estate prices, in which the amount of green space explained 83.8% of the variability in real estate prices (Table 2B). The positive and significant impact of total green space (TGS) further confirmed that the

amount of urban green spaces is strongly valued by Lima’s residents. Largest patch size (LPS) of green space in Lima had a minor impact on real estate prices ( $\eta^2 = 7$ ), whereas mean patch size (MPS), total number of patches (TNP) and the average nearest neighbor (ANN) or connectivity between patches were irrelevant.

In contrast, for Buenos Aires, the most important variables for explaining variation in real estate prices was largest patch size (LPS) with a  $\eta^2$  value of 23 (Table 2C), followed by the average nearest neighbor (ANN) or connectivity with a  $\eta^2$  value of 22. Total green space (TGS) had a modest impact explaining 12.5% of variance in real estate prices. Mean patch size (MPS) of urban green space in Buenos Aires also had a small impact explaining 7.7% of the variance in real estate prices. In Buenos Aires, there was a considerable error with unexplained variability accounting for 29.7% of the variance. In contrast the error term for Lima was 7.8%.

## 4. Discussion and Conclusions

### 4.1. General Considerations

The results of this study reinforce prior findings showing that urban green space is an important determinant of real estate prices [35,67–69], and that hedonic price indices can provide a robust estimate of the value of the ecosystem services provided by urban green spaces across LA cities. However, the unexplained variability in the multiple regression model for the analysis across cities (38.5%) was also significant and could be related to a variety of factors which were not taken into account in this study. Some social variables such as economic status perceptions [26], income dynamics [70], school quality [71] and/or cultural—spiritual values like sense of place, social cohesion [24,72] may provide further insights into the underlying factors that impact real estate prices.

In addition, the use of landscape ecology variables in the case study of Lima and Buenos Aires demonstrates that despite regional similarities, the relationship between green space and real estate prices is context-specific, and that the ecological attributes of green space can impact strongly the potential for ecosystem service provision. These preferences could be related to several factors like city growth tendency, government policy or, as we suspect, the physical environment. It seems logical that amount of green space should be more highly prized in a hyper arid city like Lima than in a city like Buenos Aires where rainfall is sufficient to support growth of rainforest. This we believe can explain why we see a more nuanced valuation of green spaces in Buenos Aires focused on spatial patterns of the green space, specifically related to the size of green spaces and the connectivity. However differences in the quality of city planning may also be important in this specific comparison between Buenos Aires and Lima [50,73] and a larger analysis that includes data from more cities could provide further insight.

Also, the relevance of ecosystem services differs according to the specific environmental and socio-economic characteristics of a city [24]. For example, urban green spaces can buffer extreme weather events like floods, which may be important for cities like Buenos Aires, but for cities like Lima with little to no rainfall, this ES is not important. Air quality regulation is critical for all megacities, but possibly most important in cities like Santiago and Mexico City where topography favors the concentration of aerosol contaminants. Urban forests stabilize slopes, preventing damage from natural hazards, which is crucial for Bogota, but not important for Buenos Aires, located on a coastal plain. A context-specific classification of ecosystem services in LA urban areas is needed to secure resilience-oriented planning [74] as it will be important to consider the role of culturally specific features of people-nature relationships for increasing the quality of life of LA city residents [26].

### 4.2. Methodological Reflections

Urban planners require up-to-date and accurate spatial data at a city scale to understand urban dynamics and processes [75]. In Latin America, robust data at city and local scale are difficult to obtain due to limited interest and investment in preliminary research and there is little effort to ensure open access of relevant data.

Our results demonstrate the important role that hedonic price indices can play in helping us to understand how green space generates ecosystem services in different situations (i.e., Buenos Aires vs. Lima). Further research is needed to better understand how when and why ecological attributes of green space impact real estate prices so we can optimize the way we invest in and manage green spaces in LA cities so that our investments in urban green space generate the maximum amount of ecosystem services possible. However, our ability to achieve this will depend heavily on data availability and a common frame for comparisons as we have attempted here across the LA megacities. Improving quality and quantity of data acquisition and availability could significantly improve urban planning processes for Latin American cities, which would be directly in line with the United Nations Sustainable Development Goals aiming to improve good health and well-being and supporting development of sustainable cities and communities (<http://www.un.org/sustainabledevelopment/sustainable-development-goals/>, accessed on 3 November 2017).

#### 4.3. Relevance of the Results for Urban Planning Strategies

High rates of urbanization in Latin America continue to pose direct threats to the preservation of urban green space [76] due to limited administrative capacity in LA cities to plan and control urban growth causing conversion of urban green space into houses and infrastructure. Further, creating new urban green space is becoming increasingly problematic due to a high levels of urban land consolidation [77] and overlapping demand of land for multiple purposes (e.g., urban green space vs. infrastructure) [78].

On the other hand, green space planning is not only guided by urban theories but also from the values people assign to green spaces [79]. Our results demonstrate that the people living in LA megacities value green space significantly, expressing their preferences through the real estate market. However as the case study clearly shows there is significant scope to conduct new research that will enable us to better understand how when and why the ecological attributes of urban green space can help to ensure, maintain or even enhance a range of different ecosystem services [80]. Being able to do more with less in terms of ecosystem service provision from urban green space is especially important for the urban poor in LA cities who generally live in the metropolitan peripheries with critical deficits of urban green space.

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**Author Contributions:** B.L. conceived the research idea. U.L.d.M. obtained the real estate data and measured urban green space availability. B.L. and U.L.d.M. carried out the statistical analysis. B.L. supervised the whole research process and the findings of this work. S.D. processed climatic variables information and provided the maps. N.B. and R.A.L.R. provided critical feedback and helped shape the analysis and manuscript. B.R.Z. defined and performed the GIS analysis for case study section. U.L.d.M. wrote the paper with authors inputs.

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**Appendix A**

**Table A1.** Real Estate Data: US\$/m<sup>2</sup> at district level (2013).

Country	City	Neighborhood	Price (US\$)
Colombia	Bogotá	Antonio Nariño	870
Colombia	Bogotá	Barrios Unidos	1493
Colombia	Bogotá	Bosa	570
Colombia	Bogotá	Engativa	1228
Colombia	Bogotá	Fontibon	1263
Colombia	Bogotá	Kennedy	682
Colombia	Bogotá	Rafael Uribe Uribe	506
Colombia	Bogotá	San Cristobal	594
Colombia	Bogotá	Suba	1555
Colombia	Bogotá	Teusaquillo	1794
Argentina	Buenos Aires	Almagro	1830
Argentina	Buenos Aires	Caballito	1993
Argentina	Buenos Aires	Mataderos	1648
Argentina	Buenos Aires	Nueva Pompeya	1245
Argentina	Buenos Aires	Palermo	2523
Argentina	Buenos Aires	Parque Chacabuco	1749
Argentina	Buenos Aires	Parque Patricios	1603
Argentina	Buenos Aires	Recoleta	2730
Argentina	Buenos Aires	Saavedra	1995
Argentina	Buenos Aires	Villa Devoto	1809
Perú	Lima	Jesus Maria	1679
Perú	Lima	Los Olivos	1113
Perú	Lima	Miraflores	2293
Perú	Lima	Pueblo Libre	1345
Perú	Lima	San Borja	2148
Perú	Lima	San Isidro	2355
Perú	Lima	San Miguel	1504
Perú	Lima	San Juan Miraflores	914
Perú	Lima	Surquillo	1559
Perú	Lima	Villa María del Triunfo	568
México	Mexico City	Alvaro Obregon	1824
México	Mexico City	Miguel Hidalgo	2358
México	Mexico City	Azcapotzalco	1103
México	Mexico City	Benito Juarez	1712
México	Mexico City	Coyoacan	1502
México	Mexico City	Cuauhtemoc	1504
México	Mexico City	Gustavo A. Madero	998
México	Mexico City	Iztacalco	915
México	Mexico City	La Magdalena Contreras	1607
México	Mexico City	Venustiano Carranza	1081
Chile	Santiago	Vitacura	2795
Chile	Santiago	Santiago	1325
Chile	Santiago	Providencia	2333
Chile	Santiago	Peñalolen	1599
Chile	Santiago	Ñuñoa	2041
Chile	Santiago	Macul	1416
Chile	Santiago	Las Condes	2486
Chile	Santiago	La Reina	2134
Chile	Santiago	La Florida	1297
Chile	Santiago	Independencia	1089

Appendix B

**Table A2.** Independent social variables used in the study (2013). All data were divided between the area of each district.

Country	City	Neighborhood	Population (Inhabitants) *	Business (Number of Businesses) **	Security (Number of Crimes Recorded) ***
Colombia	Bogotá	Antonio Nariño	108,607	4660	1428
Colombia	Bogotá	Barrios Unidos	236,433	15,932	1502
Colombia	Bogotá	Bosa	612,754	11,803	1725
Colombia	Bogotá	Engativa	858,935	29,469	3327
Colombia	Bogotá	Fontibon	362,167	15,909	2153
Colombia	Bogotá	Kennedy	1,042,080	28,787	3889
Colombia	Bogotá	Rafael Uribe Uribe	376,767	8196	1520
Colombia	Bogotá	San Cristobal	408,477	5646	1285
Colombia	Bogotá	Suba	1,120,342	36,856	4669
Colombia	Bogotá	Teusaquillo	149,166	13,266	2316
Argentina	Buenos Aires	Almagro	93,571	2437	1062
Argentina	Buenos Aires	Caballito	183,662	5171	1837
Argentina	Buenos Aires	Mataderos	55,633	1176	797
Argentina	Buenos Aires	Nueva Pompeya	62,791	1142	1012
Argentina	Buenos Aires	Palermo	255,358	10,771	5751
Argentina	Buenos Aires	Parque Chacabuco	109,541	2423	1550
Argentina	Buenos Aires	Parque Patricios	62,791	1142	1012
Argentina	Buenos Aires	Recoleta	187,141	8987	2267
Argentina	Buenos Aires	Saavedra	49,910	1157	561
Argentina	Buenos Aires	Villa Devoto	49,443	1163	512
Perú	Lima	Jesus Maria	71,439	13,634	1021
Perú	Lima	Los Olivos	360,532	32,874	7929
Perú	Lima	Miraflores	83,649	27,303	2364
Perú	Lima	Pueblo Libre	76,743	9877	1114
Perú	Lima	San Borja	111,688	16,424	2634
Perú	Lima	San Isidro	55,792	19,445	1019
Perú	Lima	San Miguel	135,226	15,408	3565
Perú	Lima	San Juan Miraflores	397,113	26,725	4323
Perú	Lima	Surquillo	92,012	14,293	2318
Perú	Lima	Villa María del Triunfo	433,861	21,023	2542
México	Mexico City	Alvaro Obregon	734,290	20,170	10,902
México	Mexico City	Miguel Hidalgo	380,608	23,724	11,013
México	Mexico City	Azcapotzalco	410,475	16,928	8561
México	Mexico City	Benito Juarez	397,446	24,293	12,042
México	Mexico City	Coyoacan	618,265	22,142	11,826
México	Mexico City	Cuauhtemoc	536,086	66,587	26,542
México	Mexico City	Gustavo A. Madero	1,180,559	46,007	21,980
México	Mexico City	Iztacalco	380,259	16,955	7825
México	Mexico City	La Magdalena Contreras	242,355	6094	2385
México	Mexico City	Venustiano Carranza	424,962	30,763	10,337
Chile	Santiago	Vitacura	87,792	14,519	1382
Chile	Santiago	Santiago	331,325	56,651	16,459
Chile	Santiago	Providencia	144,169	44,699	4998
Chile	Santiago	Peñalolen	240,304	8690	4319
Chile	Santiago	Ñuñoa	212,163	15,328	4347
Chile	Santiago	Macul	122,966	5533	2389
Chile	Santiago	Las Condes	279,760	51,167	4893
Chile	Santiago	La Reina	101,358	6327	1633
Chile	Santiago	La Florida	387,352	15,696	8939
Chile	Santiago	Independencia	80,476	4868	1899

\* Secretaría de Planeación—Alcaldía Mayor de Bogotá (Colombia), Dirección General de Estadística y Censos—Gobierno de la Ciudad Autónoma de Buenos Aires (Argentina), Dirección Técnica de Demografía e Indicadores Sociales del Instituto Nacional de Estadística e Informática—INEI (Peru), Consejo Nacional de Población—CONAPO (Mexico), Instituto Nacional de Estadísticas Chile—INE (Chile); \*\* Cámara de Comercio de Bogotá—CCB (Colombia), Subsecretaría de Trabajo, Industria y Comercio—Ministerio de Desarrollo Económico (Argentina), Instituto Nacional de Estadística e Informática—INEI (Peru), Instituto Nacional de Estadística y Geografía—INEGI (Mexico), Departamento de Estudios Económicos y Tributarios—Subdirección de Estudios del Servicio de Impuestos Internos (Chile); \*\*\* Observatorio de Seguridad en Bogota (Colombia), Instituto Superior de Seguridad Pública (Argentina), Observatorio Nacional de Seguridad Ciudadana—OBNASEC (Peru), Dirección General de Política y Estadística Criminal—Procuraduría General de Justicia del Distrito Federal—PGJ DF (Mexico), Carabineros—Instituto Nacional de Estadísticas Chile—INE (Chile).

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## II. VERSION INICIAL



Communication

# Quantifying the impact of urban green space on real estate prices in five mega cities of Latin America

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**Abstract:** This study seeks assesses the possibility of using real estate prices to provide an estimate of the monetary value of ecosystem services provided by urban green space across five Latin American mega cities: Bogota, Buenos Aires, Lima, Mexico City and Santiago de Chile. Using Google Earth to map urban green space with images from 2013 and through analysis with a multiple regression model, we evaluated the influence of urban green space, crime rates, business density and population density on real estate prices. The results show a strong positive relationship between the presence of urban green space and real estate prices. Green space explains 52% of the variability in real estate prices across the five studied megacities. Population density, business density and crime had only minor impacts on real estate prices. These results reinforce the idea that urban green spaces are important providers of ecosystem services and that the values of these ecosystem services can be estimated using willingness to pay for real estate. The results further also the need for additional study of ecosystem service provision by urban green space in LAC cities which should include study of how ecological and social factors interact to determine the level of ecosystem service provision from urban green spaces.

**Keywords:** Urban green space; real estate prices; Latin America mega cities; Google Earth

## 1. Introduction

Urbanization is a global phenomenon that is happening rapidly: cities are expanding on average at twice the rate that population is growing [1-3]. In Latin America and the Caribbean, three-quarters of the population already live in cities [4], and cities play a key role in the economies of the region [5]. High population densities and the high concentration of human activity in LAC cities generate negative environmental impacts [6] and cause significant challenges in terms of meeting the demand for new infrastructure, which is often achieved at high social and/or-environmental cost [7].

Many cities consider urban green space and undeveloped areas as potential land to be converted to infrastructure [8,9] without taking into account that the fact that cities depend on the ecosystem services that urban green space provide to sustain human well-being [10,11]. Ecosystem services provided by urban green space are numerous. For example, urban green space may improve air quality, regulate water flow and urban temperature, reduce noise pollution etc. [12-14]. Hence, if the economic value of urban green space could be demonstrated through a premium on real-estate, the importance of the ecosystem services provided by urban green spaces would be reinforced in the political decision-making process [15]. This is important because financing public infrastructure and public services depends heavily on governmental institutional arrangements [16].

One approach to quantify the value of ecosystem services is through the use of hedonic price indices [17]. Hedonic price indices are based on correlations between prices in existing markets (i.e. the real estate market) and specific ecosystem services (i.e. air quality) or bundles of ecosystem services, as for example may be provided by urban green space [13,14]. An open question for Latin America and the Caribbean is whether hedonic price indices can be used to estimate the value of ecosystem service provision from urban green space in LAC cities. In addition to services provided by urban green space, other factors might influence real estate prices, such as opportunities for shopping (or business density), population density, and/or crime frequency.

Hence, this study seeks to estimate the influence of urban green space on real estate prices (US\$ per m<sup>2</sup>) at district level in five Latin American mega cities: Bogota, Buenos Aires, Lima, Mexico City and Santiago de Chile. The influence of urban green space on real estate prices is also compared with the influence of crime rates, and business and population density. Thus, this study provides information to urban planners, practitioners and stakeholders about the willingness of communities to invest in preserving urban green space in order to provide a first measure of willingness to pay for urban ecosystem services in LAC cities and compare this to willingness to pay for ease of access to commerce, low crime rates and population density

## 2. Materials and Methods

### 2.1. Study area

Based on national data compiled by Economic Commission for Latin America and the Caribbean - ECLAC (2013) [18] and real estate information available for each city, five mega cities were selected: Bogotá in Colombia, Buenos Aires in Argentina, Lima in Peru, Mexico City in Mexico and Santiago in Chile.

Each city is politically divided into districts or administrative units with 20 districts in Bogota, 48 districts in Buenos Aires, 43 districts in Lima, 16 districts in Mexico City, and 32 districts in Santiago. For this study, districts and administrative units that were predominantly rural or close to water bodies, and/or smaller than 3 km<sup>2</sup> and/or larger than 100 km<sup>2</sup> were excluded. Size and location of urban green space in remaining districts or administrative units, were collected from 10 randomly selected districts or administrative units.

### 2.2. Data

There is no free access to real estate information in Latin America. Real estate companies and government institutions do not publish their databases. Not all real estate companies generate data for all districts within their respective cities, and there is only a very limited set of institutions that own this information on real estate prices. It therefore required significant research efforts to determine who owned information on real estate prices in the LAC mega cities. In addition, these institutions are generally unwilling to provide free access to their databases since they generate income from them. Hence, convincing these organizations to collaborate with us on this study involved much effort and constant follow-up.

The price per square meter of real estate in 2013 at district level (US\$ per m<sup>2</sup>) was used as the dependent variable and provided by the Cámara Peruana de Construcción (CAPECO) for Lima, Portal Inmobiliario for Santiago de Chile, Cámara Colombiana de la Construcción (CAMACOL) for Bogota, Metros Cúbicos for Mexico City, and Reporte Inmobiliario for Buenos Aires (Appendix A).

Independent variables used in this study were urban population density in 2013 (inhabitants per km<sup>2</sup>), business density in 2013 (number of businesses per km<sup>2</sup>; any type of business) and security data (number of crimes recorded 2013 per km<sup>2</sup>; any type of crime) for each district or administrative unit (i.e. comunas in Buenos Aires). These data were provided by the following institutions: Secretaría de Planeación - Alcaldía Mayor de Bogotá (Colombia), Cámara de Comercio de Bogotá – CCB (Colombia), Observatorio de Seguridad en Bogota (Colombia), Gobierno de la Ciudad Autónoma de Buenos Aires (Argentina), Ministerio de Desarrollo Económico (Argentina), Instituto Superior de Seguridad Publica (Argentina), Instituto Nacional de Estadística e Informática – INEI (Peru), Observatorio Nacional de Seguridad Ciudadana – OBNASEC (Peru), Consejo Nacional de Población - CONAPO (Mexico), Instituto Nacional de Estadística y Geografía – INEGI (Mexico), Procuraduría General de Justicia del Distrito Federal - PGJ DF (Mexico), Instituto Nacional de Estadísticas Chile – INE (Chile), Departamento de Estudios Económicos y Tributarios (Chile), and Instituto Nacional de Estadísticas Chile – INE (Chile) (Appendix B).

### 2.3. Urban green space

Google Earth was used to obtain land cover data with images from 2013. Total area sampled per district was 2.5 km<sup>2</sup>, divided into five randomly selected polygons of 0.5 km<sup>2</sup>, which accounted for the majority of the area in the districts and administrative units sampled. In summary, this study considered five polygons per district equivalent to 50 polygons per city, with a total number of 250 polygons (Figure 1.). Altitude differs between and within cities, and so to control for this we established as a measuring point at an altitude 500 meters above ground level. In this study, urban green areas are areas covered with any type of vegetation as described by Wolch et al (2014) [14]. Thus, all types of vegetation cover were sampled inside all polygons, from single trees to urban forests using FreeMapTools.com to assess their size in m<sup>2</sup>.



**Figure 1.** Sampled polygons. From top to bottom: Bogotá, Buenos Aires, Lima, Mexico City, and Santiago de Chile

### 2.4. Statistical analysis

To homogenize data and simplify interpretation, we normalized both the independent (Table 1.) and dependent (price of real estate in US\$ per m<sup>2</sup>) variables prior analysis with the following transformation:

$$X\text{ NOR }_i = X_i/X_{max} \quad (1)$$

Where  $X_i$  is the variable prior to normalization and  $X_{max}$  is the maximum value obtained for the variable in the respective city. Transformed data were analyzed using multiple linear regression using XLStat (Addin Soft, Paris).

**Table 1.** Variables after transformation (normalization) used for multiple regressions. Av/at = Area Verde / Area total muestreada (green space / total area), Pop.Den = Densidad Poblacional (Population Density), Bus.Den = Densidad Empresarial (Business Density), Crim.Den = Tasa de Delincuencia (Crime Rate)

Variable Name	Definition
av/at NOR	Green space per total area
Pop.Den NOR	Inhabitants per district area
Bus.Den NOR	Business per district area
Crim.Den NOR	Crime per district area

Normalization:  $X\text{ NOR }_i = X_i/X_{max}$  .  $X_i$ : variable prior to normalization.  $X_{max}$ : maximum value obtained for the variable in the city in which the district occurs.

### 3. Results

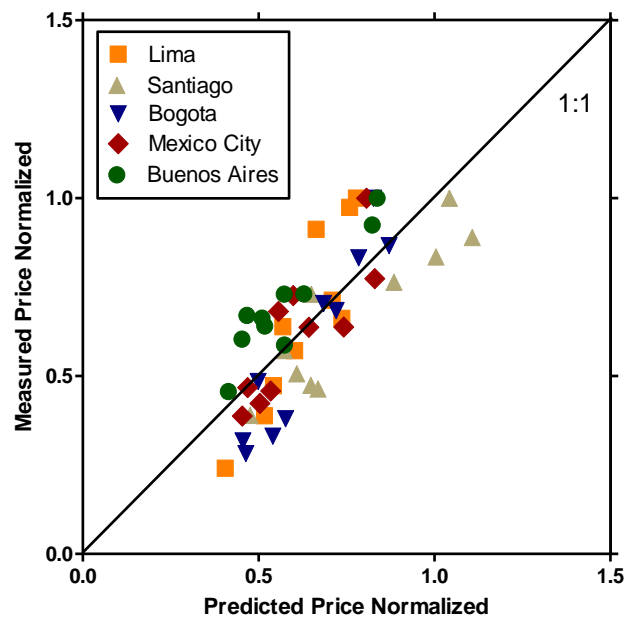
From a multiple regression with four independent variables, we obtained a model with admissible accuracy ( $R^2=0.62$ ; Table 2.). The  $\eta^2$  values indicate that urban green space was the most important predictive variable explaining 52% of the variability in real estate prices. Business density also had a modest influence on real estate prices with a  $\eta^2$  value of 10, whereas crime rate and population density had little impact (Table 2.). However, there was also considerable error with unexplained variability accounting for 39% of the sum of squares, therefore a complete understanding of the factors that determine real estate pricing remains unknown ( $\eta^2=38.5$ ).

**Table 1.** Summary statistics for the multiple regression model which correlated real estate prices with four variables in review: Green space, Population density, Business density and Crime rate

Source	df	SS	MS	F	Pr>F	$\eta^2$
av/at NOR	1	1.14	1.14	60.16	< 0.0001	51.5
Pob.Den NOR	1	0.00	0.00	0.03	0.8690	0.0
Bus.Den NOR	1	0.22	0.22	11.50	0.0015	9.8
Crim.Den NOR	1	0.00	0.00	0.24	0.6283	0.2
Error	45	0.85				38.5
Corrected Total	49	2.21				100.0

SS sum of squares, df degrees of freedom, Pr probability,  $\eta^2$  percentage of variation of the R2 explained for each independent variable.

The normalized data used in this study adheres closely to the 1:1 line (Figure 2.) which indicates close correspondence between the measured and predicted price values, and shows the robustness of the multiple regression model.



**Figure 2.** Relationship between measured vs. predicted price values of m<sup>2</sup> at district level. Predicted values using multiple regression: Predicted Price NOR = 0.35 + 0.71\*av/at NOR - 0.053\*Pob.Den NOR + 0.34\*Buss.Den NOR - 0.061\*Crim.Den NOR. See Table 2 for details. Diagonal line indicates 1:1 relationship.

#### 4. Discussion

This study presents a multiple regression model derived from 50 neighborhoods located in five Latin American mega cities. The model showed a strong positive relationship between presence of urban green space and real estate prices, and revealed minor impacts of business density, population density and crime rates on real estate prices. Thus, our results reinforce prior findings showing that urban green space is an important determinant of real estate prices which can provide a robust estimate of the value of the ecosystem services provided by urban green spaces [15]. The unexplained variability in the multiple regression model (38.5%) was also significant and could be related to a variety of factors which were not taken into account in this study. A more sophisticated classification of urban green space, for example, differentiation between different categories of green space could lead to a more accurate model [19]. Candidates for inclusion in a more sophisticated classification of urban green space include “ecological factors” such as “stem diameter structure, leaf area index, basal area, soil quality” and the relative representation of different plant functional traits. Social factors such as changing perceptions that occur with economic status [20] may likewise provide further insights into how green spaces generate ecosystem services in LAC cities. This in turn would provide natural resource managers in LAC cities with the information needed to optimize the configuration urban green space to maximize ecosystem service provision from the limited green areas LAC cities contain.

High rates of urbanization in Latin America and the Caribbean continue to pose direct threats to the preservation of urban green space [21] due to limited administrative capacity of LAC cities to plan and control urban growth causing conversion of urban green space into houses and infrastructure. Further, the complexity of creating new urban green space has been increasingly problematic due to a high level of urban land consolidation [22] and overlapping demand of land for multiple purposes (e.g. urban green space vs. infrastructure) [23]. Thus, cities

in Latin America and the Caribbean are characterized by a critical deficit of urban space [4], which impairs human well-being [24].

Green spaces are important in urban areas as they support ecological integrity of cities, provide ecosystem services, and improve the livability of cities [13,14,25], which clearly needs to be taken into account in urban planning activities [26,27].

Urban planners require up-to-date accurate spatial data at city scale [28] to understand urban dynamics and processes [29]. In Latin America, robust city data is difficult to obtain due to limited interest in investing in basic research and there is little effort to ensure open access of relevant data. Improving quality and quantity of data acquisition and availability could significantly improve urban planning processes for Latin American and Caribbean cities, which would be directly in line with the United Nations Sustainable Development Goals <http://www.un.org/sustainabledevelopment/sustainable-development-goals/>, accessed on 28th April 2017) aiming to improve good health and well-being and supporting development of sustainable cities and communities.

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**III. CARTAS DE PRESENTACIÓN Y  
RESPUESTAS A LOS REVISORES**

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Giovanni Sanesi  
Guest Editor  
*Special Issue - Forests*  
October, 7th, 2017

Dear Giovanni Sanesi:

We are very grateful for the opportunity to resubmit an improved version of our manuscript identified with ID forests-222942 and to have the manuscript considered for the Special Issue "What Role Can Ecological Factors Play in Supporting Ecosystem Services in Urban and Peri-Urban Forests?".

We have followed reviewer one's very helpful recommendation and performed an additional more detailed analysis/ case study for two of the five selected cities: Lima and Buenos Aires; including the following landscape ecology variables: largest Patch size ( $m^2$ ), total number of patches of green space, mean patch size of green spaces ( $m^2$ ), and Average Nearest Neighbor between patches (m).

The results from the new case studies of revealed that the relationship between green space and real estate prices is context-dependent. The most important variable in Lima is green space / total space, explaining 83.8% of real estate price variability; in Buenos Aires, the most relevant variables are Total number patches (23%) and Average nearest neighbor, or connectivity between patches of green space (22%).

After modifying the manuscript in line with the helpful comments from the reviewers, especially the recommendation to expand the analysis with a more detailed case study we believe the new set of results better align with the central theme of the special issue showing context dependence of ecosystem service provision from urban green space and a potentially productive strategy for future research to better understand how and when spatial patterns of urban green spaces matter for ecosystem service provision

Below are point by point explanations of how we have modified the manuscript in response to the reviewer comments.

Thank you for your consideration  
Sincerely,

Ursula  
Undergraduate Thesis Candidate  
Universidad Científica del Sur, Lima, Perú

Comments for the Author:

Reviewer #1:

My major concern on the paper is related to its focus.....In case of a “Communication” – as it was presented here – the reader would expect no “extensive” data analysis but rather a critical literature review (...). Another possibility – that in my point of view would be very valuable – is to extend this manuscript in terms of content and data analysis and to resubmit it as “Research Article”.

**ANSWER:** We thank the reviewer for helpful observation. We followed this advice and performed a more detailed analysis / case study for two of the five selected cities: Lima and Buenos Aires. In the manuscript we are thus extending both analysis and text so that the manuscript now has the form of a regular research article in forests (as opposed to a short communication). To achieve this, we performed a more in-depth GIS analysis of a subset of our data which not only included Green area (m<sup>2</sup>) divided by total area, but also the following landscape ecology variables: largest Patch size (m<sup>2</sup>), total number of patches of green space, mean patch size of green spaces (m<sup>2</sup>), and Average Nearest Neighbor between patches (m).

I would strongly recommend to extend the introduction section

**ANSWER:** This has been done in the revised manuscript (line. 46-92)

Furthermore, I would like to see a “Case Study Area” section with profound information on the 5 LAC and describing the specific challenges in these 5 LAC cities. Why it is worth to compare them? In terms of results the reader would expect more detailed data analysis, e.g. in terms of the quality of green spaces (parks vs. green lanes), size of green areas (smaller vs. large areas), and differences between LAC in general as well as similar district sizes – all in all analyzing the whole facets of the interrelation between urban green spaces and real estate values in these 5 LAC cities.

**ANSWER:** As detailed in our response to point 1 of reviewer 1 we have now augmented the data analysis and manuscript with the suggested case study. Which as the reviewer suggested it might, provides insight into where and when the amount of green space is important vs. when the ecological attributes of green space is important. We again thank the reviewer for this helpful and insightful recommendation.

I’ve some doubts with regard to the other proposed variables (businesses and crime) as these are poor explained and do not contribute to a broader discussion.

**ANSWER:** Crime rate, business and population densities were included in the cross-city analysis because the evaluation committee for my thesis, which is the basis of the work presented here, suggested/required it, arguing that real estate prices could be affected by these variables also. If the thesis reviewers raise this question we think it likely that other readers may do the same. So, we think it is important to leave these variables in the analysis across cities. We do however agree fully with the reviewer that the analysis across cities shows that these other variables are almost irrelevant and that real estate prices can be used as hedonic price indices to quantify the value of urban green spaces and the ecosystem

services they provide. And so, following the reviewer's advice we have dropped crime rates and business and population density in the *case study analysis* and instead use relative green area and landscape ecology variables (see table 2). Again, as the reviewer suggests this provides deep insight into where and when the amount of green space is important vs. when the ecological attributes of green space is important. Again, we are extremely thankful to the reviewer for their insight and willingness to share it.

Against this background and independently of the authors' decision, the manuscript would require a profound rework, considering and integrating my concerns/comments. As the topic is highly relevant, I would like to encourage the authors to take the time needed for restructuring the manuscript and developing a clear focus as well as data analysis in case of a research article.

**ANSWER:** We addressed second option of reviewer's request by: 1) extending the introduction including ecosystem services and urban green spaces definitions, their relevance in a global and regional context. Explaining the LAC challenges related to green spaces in sustainability criteria and the importance of having a regional trend for policy formulation and comparison (line. 46-92). 2) Developing two study cases: Lima and Buenos Aires. These cities represent the extremes of climatic characteristics, related to precipitation and temperature, for the selected cities. We measured variables: Total Green area (m<sup>2</sup>), Largest Patch (m<sup>2</sup>), Total number of patches, Mean Patch Size (m<sup>2</sup>), Average Nearest Neighbor (m) (table 2) 3) Describing every variable selected and its relevance (line. 191-208) 4) Including an extension of discussion and conclusions based on this new analysis (line. 268-307).

Reviewer #2:

This a fascinating short communication that attempts to scribe a value to ecosystem services to real estate prices in five Latin American mega-cities. I have taken the liberty to provide some critical comments for the authors to consider that I hope will improve the readability and impact of this research for the journal Forests. These are:

p.1, line 16: 'this study seeks to assess' (insert word)

**ANSWER:** Corrected

p.1, line 21: past tense applies?

**ANSWER:** Corrected

p.1 line 26: 'The results further also the need for the additional....' (insert word)

**ANSWER:** Corrected

p.1 line 27: LAC acronym not explained

**ANSWER:** Corrected

p.1 line 33: urbanization is not exactly a recent phenomenon! What defines a 'mega-city'? Many urban areas are now conceptualized as internally heterogeneous, functionally differentiated, and highly interconnected ecosystem mosaics.

**ANSWER:** We agree that urban expansion is not exactly a recent phenomenon and that cities are highly heterogeneous, discussion of this is beyond the scope

of what we aim for or could achieve in this study and so we use the (simple) UN habitat definition, which we now cite in the case study in a modified way to incorporate the reviewer's correct observation (line. 96-99)

p. 1 line 39: Is it the cities themselves that consider, or rather those who implement governance such as city planners? Here you can expand on wider issues to do with social and environmental interfaces – for example, in the UK we have a concept called 'natural capital' which tries to link green infrastructure (GI) and access to greenspace with mental and physical well-being of citizens. The Total Economic Value (TEV) conceptual framework in Europe gives the National Ecosystem Assessment a monetary value. For GI to work it needs to be inter-connected.

**ANSWER:** We corrected the expression for city planners.

p. 1 line 43: other factors? e.g.: urban heat island affect, public health benefits (as explained above).

**ANSWER:** We mentioned more factors (line. 69-78).

p. 2 line 53: LAC acronym not explained. Are all factors that influence real estate prices considered adequately? Hedonic pricing is often linked to quality of life indicators such as in Europe proximity to suitable schools, local employment opportunities etc. In fact there are a whole bunch of multi-linked influencing social, economic, physical/environmental and Governmental drivers at work. The regression model you propose needs a more implicit justification here so that it is clear that the causal factors you have selected are the most important factors for consideration in the urban areas in question.

**ANSWER:** The acronym is now explained. With respect to the factors that influence real estate prices we have now provided more bibliographic justification in the manuscript. The selection of the variables of population density and crime rates was based on the results from other studies where these variables are considered as determinants of real estate prices (Dunse, Thanos, & Bramley, 2013; Garcia & Riera, 2003; Ihlanfeldt & Mayock, 2010; Kryvobokov, 2007; Pope & Pope, 2012; Wassmer & Baass, 2006). The selection of business density was based on Yu, Cho, & Kim's (2012) results, describing a positive impact of shopping centers on real estate prices and above all, a considerable annual property tax revenue. Second, as an indicator of commercial dynamism that can justify employment opportunities, and implicit income index. Also, it is worth to mention, that schools of high quality in LAC megacities are generally private and compiling data on their spatial location would require significant work. We agree however that it would have been an excellent additional variable for the analysis across cities (line. 191-208)

p. 2 line 57: why select these five? There is an assumption here that they are comparable, but they all exist in different countries and therefore are influenced by very different economic, political and fiscal measures.

**ANSWER:** The selection of these five megacities was based on availability of real estate data and social-demographic and economic data in 2013. Also as the majority of the research team is from Lima, a city built in a hyper arid location, we were interested to know how the relation between urban green space and willingness to pay for it changes across megacities where rainfall varies. With

the new case study added to the manuscript following the recommendation of reviewer 1 the rationale behind city selection we think is now clearer (line. 100-103).

p.2 line 61: does your paper provide a ‘first measure of willingness to pay’ as you suggest? There is a growing amount of literature available. Is this also what you will really show? Residents may be blissfully unaware of this in certain contexts.

**ANSWER:** agreed the possibility for spurious correlations exists however the consistency of the pattern across megacities does provide support for the conclusion that the correlations presented are not spurious. To address the reviewer’s correct observation, we have modified text to acknowledge the possibility of spurious correlation (line 275-289).

p.2 line 74: streamlining of data mining needs justification. Will this pick up heterogeneous districts – examination of Fig 1 seems to indicate these samples are not random.

**ANSWER:** After the first filter (rural and close to water districts), the remaining districts per city were written in a different sheet of an Excel file. The number of ten (10) districts was determined in order to be able to establish comparisons because of the differences in the numbers of districts per city. We opted for the random function in Excel, which gives you numbers with long decimals between 0 and 1 and typing it in the next column. When selecting both column and ordering from minor to major, we selected the first ten (10) districts per city and with them perform the measurements and analysis required.

p.2 line 76: label for section 2.2 too brief! What kind of data?!

**ANSWER:** Corrected

p.2 lines 77-84: Do you need this section? Elsewhere in the world this information is freely available.

**ANSWER:** Probably this type of information is freely available in most of the countries around the world. However, the reality in Latin America is quite different. Peru does not publish house price statistics, and generally its statistics are weak. The Ministerio de Economía y Finanzas has basic statistics on production, prices, interest rates, international reserves and the balance of payments. There are financial statistics at the Banco Central de Reserva del Perú but just for some districts. The Instituto Nacional de Estadística e Informática produces data, but not on-line time-series. The Peruvian Chamber of Construction (CAPECO) produces data, but it is not publicly or freely available. No housing price statistics are published in Argentina; Reporte Inmobiliario, a private firm, produces house price statistics but they are not publicly available. General statistics come from the Banco Central de la República Argentina, the Secretary of Economic Policy, the Instituto Nacional de Estadística y Censos and the Dirección Nacional de Cuentas Internacionales. No housing price or rent statistics are published in Mexico. The Instituto Nacional de Estadística y Geografía is weak in this aspect, and appears to concentrate on census data. Most Colombian house price statistics are from Colombia's central bank, Banco de la Republica Colombia. The time-series are quarterly, from 1988 and there are no rentals statistics. Chile publishes house price statistics through the Chilean Chamber of Construction (CChC) but the information is for period and not all is publicly available. Reporte

Inmobiliario also publishes reports on Chilean property market from time to time. So, private firms have a niche market that they can exploit for their own business and for the public, in that sense, information access is restricted. However, we will follow your suggestion and we will place this paragraph in the acknowledgements section

p. 2 lines 92-101: this is better placed in the acknowledgements section.  
**ANSWER:** Corrected.

p.3 line 103: citation for Google Earth should include year of issue. Citing images for use in publications is worth checking – a convention might be software and version, date of original imagery, location name, geographic coordinates, altitude, data set (if applicable), image source(s) and copyright(s), website URL and date accessed – check this. Interestingly some land use data available on GIS for featured countries from: <https://freegisdata.rtwilson.com/>.  
**ANSWER:** Thanks for the GIS information, we appreciate it. About Google Earth images, we made the details (scale, date) more visible and wrote a more specific description of the figure.

p. 3 line 104: why 2.5 km<sup>2</sup>? Can this be justified with reference to the work of others who used a similar approach? Does the 250 polygons mean that data is upscaled from 5 or did you measure data within all of these?  
**ANSWER:** Within the five megacities, Buenos Aires has the smallest district size. After random selection, the smallest district size was 3.5 Km<sup>2</sup>, because of that we decided to establish 2.5 km<sup>2</sup> as total measured area. The measure of green space was done within all 250 polygons.

p. 3 line 110: how was vegetation cover quantified? Link to urban forests here.  
**ANSWER:** From Google Earth images, all vegetation from single trees to urban forests were mapped by using the tool polygon in Google Earth program.

p. 4 Fig 1: clustering of points seems non-random. Are these scaled (to size) polygons? Please note previous comments above. No scale bar on the maps – label each image (a), (b), (c) etc and link to the relevant city. There will be spatial heterogeneity across all the cities (e.g.: some areas would have higher crime rates than others), so the relative contribution of these factors will change.  
**ANSWER:** The Figure 1 shows the central point of each sampled polygons in order to visualize the distribution of all sampled polygons within the selected districts of each city. It could be perceived as non-random distribution; however, there must be considered the two filters used (ruralness and districts located close to beaches; and districts smaller than 3 km<sup>2</sup> and bigger than 100 km<sup>2</sup>) (Figure. 2).

p.4 line 116: OK, interesting. Data transformation of the independent variable (X) will not affect the distribution of Y, so can be made with impunity providing the transformation has the desired affect (ie: normalises data to meet assumptions for homoscedasticity). Transforming the value of Y (in your case, price of real estate) will affect least squares considerations. Log Y data transformations are commonplace. Can you clarify that the transformation method you ascribe to the Y variable is valid? Here again I would ask you to justify why these four



independent variables were selected when others could have been used? A model is only as useful as what is fed into it. Would a multiple stepwise regression not work?

**ANSWER:** The normalization was made for all the variables (Y and X), due to the variability of price ranges from one city to another. Data relativization ensures that this source of variability is taken into account outside the statistical analysis, ensuring that our ability to evaluate the variable of interest across cities is maximized. The practice of normalization (making data relative) is applied across a wide range of disciplines including studies focused on urban issues, e.g. Bettencourt, L., & West, G. (2010). A unified theory of urban living. *Nature*, 467(7318), 912-913.

p.5 line 129: we? Personal term; it is probably my lack of familiarity with XLStat, but I am unfamiliar with the symbol denoted as a column header in the final column of Table 1. What is this? (also mentioned on line 132).

**ANSWER:** The  $\eta^2$  is the percentage of variation of the  $R^2$  explained for each independent variable.  $\eta^2$  is obtained from the SS partial value between the SS total value per 100. The table legend has been expanded to include this information (table 2)

p.5 line 135: comments here might be linked to data transformation approach of Y variable, the way data was subdivided and sampled or that fact that not enough causal factors were included in the model. Remember – here I am playing devil's advocate. There seems to be an insistence that higher prices are linked to more greenspace, but this is kind of predictable. Prices will always generally be higher in residential areas that are less developed and more affluent. Value of Table 1 could be questioned.

**ANSWER:** Agreed. The new analysis/case study we did follow the suggestion of reviewer 1 which we believe increases the value of the analysis we have performed. We also would like to reiterate the fact data availability is extremely limited and complicated in our region and the compilation of the data we provide in the appendix we believe is valuable.

p.5 line 141 and Figure 2 p. 5: could relationships between measured and predicted price values be quantified e.g.: spearman rank? Could the authors explain the validity of plotting actual values versus predicted values, when  $R^2$  value is already calculated? Is there something about undertaking some intra-city comparisons that would explain why there is (perhaps) regional variation here? I know the 10 were randomly selected but this might make your results go further. Could you not also explore trends within individual capital cities, as this might show the spatial heterogeneity you might find in any cityscape.

**ANSWER:** We agree. The reviewers comment aligns closely with comment 1 of reviewer 1. We now do intra-city comparisons (Lima and Buenos Aires) and as the reviewer suggests it adds significantly to the manuscript. Thank you for the helpful suggestion and see our response to comment 1 of reviewer 1

p.6 line 144: use of vs.?

**ANSWER:** Corrected

p.6 line 149: first use of the word neighborhood? According to your regression

model inhabitants and crime had no effect on prices contradicting your statement on lines 151-152.

**ANSWER:** Corrected

p.6 line 152: you say findings but feature only one reference. Have you really determined the value of ecosystem services? What you seem to have done is tried to explain real estate prices using an (incomplete) multiple regression model.

**ANSWER:** We included more references. We assumed that where people prefer to live is reflected in the monetary and non-monetary value that they attribute to their district. Focusing on the value of green space, we can assume that urban green spaces provide bundles of Ecosystem Services (line. 269-280).

p.6 line 157: why can't you do this? If you do, this article becomes far more publishable. The network via connecting nodes is critical for GI – this is worth adding.

**ANSWER:** We can and have done this as per this recommendation and the first suggestion of reviewer 1. Thanks for the hint.

p.6 line 161: surely public health agendas are worth a mention? In the UK it is proven that having access to greenspace can reduce the bill for the National Health Service. Doctors are even prescribing green prescriptions for combating mental health problems.

**ANSWER:** We included health aspect in discussion (line. 298-299).

p.6 line 162: by assuming homogeneity between and within cities, you could have provided an answer for this. Most of what features in the next paragraph is largely conjecture and not borne from the work you have undertaken.

**ANSWER:** We are not assuming homogeneity between cities, what we assumed based on the document published by ECLAC named “REGIONAL PANORAMA Latin America Megacities and Sustainability” is that LAC megacities present common problems and challenges related to sustainability, even when the intensity of specific aspects changes from one city to another (line. 302-303)

One would assume that to be published in a journal called Forests, there would need to be more mention of urban forestry and trees – there is little mention of this in the actual paper.

**ANSWER:** We extended and focused more on this topic in the case studies of Lima and Buenos Aires.

Reviewer #3:

I feel that the context of the study with existing theoretical, practical and philosophical work in the area of ecosystem services valuation is a little obscure and could benefit from more explicit description. Why is it a useful addition and what are the limitations of the approach?

**ANSWER:** We agreed. We mention in case study results, that it might be useful to consider more research to better understand when and where ecological attributes of green space affect prices so we can confidently use hedonic price indices for holistic valuations of green space (line. 300-307)

It would be useful to have more of a thread throughout the manuscript re: the

importance of urban green space / global context, and the kinds of decision-makers that it / this work would be most relevant to. This is covered in the discussion but isn't clearly set out in the introduction.

**ANSWER:** Thank you. We extended the introduction section in order to add more useful information (line. 46-92).

It might be good to break the discussion down more clearly in to (for example) technical considerations, considerations for different decision-makers, broader relevance of the work and future research. At present each statement seems rather isolated and lines 181-184 in particular are important but comes across a little tokenistic when included only as a final thought.

**ANSWER:** Thank you. We followed your recommendation to improve the flow and readability of the discussion (line. 269-307).

18-19: mapping vs / plus quantification or qualification?

**ANSWER:** Corrected.

20-21: why was this particular set of other variables chosen? This isn't really made completely clear in the body of the manuscript later either

**ANSWER:** This comment aligns closely with comment p2-line 53 of Reviewer 2, please see our response to comment p2-line 53 of reviewer 2.

22: which value are you showing here, with what accuracy etc.?

**ANSWER:** The value was explained and the accuracy was added.

26: Yes - it is one element in the full picture of the way in which environment and society are enriched by urban green spaces. It would be worth briefly setting out the philosophical context of this approach - not here, but early in the manuscript

**ANSWER:** Thank you, we agreed. Now, we have presented a broader picture of the benefits that society receives with the incorporation of urban green spaces in the introduction and mentioned this in the discussion (line. 69-78)

27: 'LAC cities' - define this acronym at least once in the text and try to be consistent throughout with use of the full text / acronym

**ANSWER:** The acronym is now explained.

Keywords: it would be useful to include some keywords that refer to the method and approach used, e.g. hedonic pricing

**ANSWER:** Hedonic price indices was added as a keyword.

34: 'Latin America and the Caribbean (LAC)'

**ANSWER:** Corrected

36: As above

**ANSWER:** Corrected

38: What kinds of infrastructure are you referring to here? It is a pretty broad term referring to a range of physical and non-physical elements. I presume you mean things like civil engineering interventions: water, energy and transport infrastructure and housing?

**ANSWER:** We referred to physical civil infrastructure, because Latin American and the Caribbean has a considerable deficit of infrastructure. Closing the region's infrastructure deficit requires US \$ 250 billion annually over the next five years, equivalent to 5% of GDP(BID,2016). This has now been defined clearly in the manuscript (line 108-154).

43-46: Yes... but how and why? While it is beyond the scope of the manuscript, it might be useful to consider (or hint at the consideration of) the implications and limitations that hedonic pricing methods have for indicating a holistic value of green space. What kind of political decisions do you have in mind here? Local planning decisions or more general, high level decisions around environmental policies?

**ANSWER:** We extended and expanded this point in the discussion (line. 300-307)

47: What about private infrastructure developments? How significant are these in comparison to the public sector in these spaces?

**ANSWER:** Private infrastructure developments related to urban green space are scarce, and they usually take place in private-public alliances. The best examples of this are in Belo Horizonte, Brasil and more often in Chile. However, they are not widespread in all the region because of several factors (politics, governance, capacity, profitability, etc)

51-53: I am sure that this is true, but in which ways are you considering this an open question: Because it hasn't been done before in LAC? Or at all? Because other studies in other cities are non-transferrable / there are particular differences that you expect to be the case in LAC?

**ANSWER:** We considered it as an open question related to a regional context, because policy design for Latin American megacities requires an identification of common urban trends in the region. This we have emphasized now in the revised manuscript (line 108-154)

54-55: Why were these particular variables chosen? It would be good to briefly outline why.

**ANSWER:** We have now provided more bibliographic justification in the manuscript as we mentioned above (see response to comment p2 line 53 of reviewer 2).

57: Formatting: m<sup>2</sup>

**ANSWER:** Corrected

59: Variable selection - as above

**ANSWER:** Explained (line. 191-208)

61: Invest in having green space... does the word 'preserving' give too much future weighting to the method?

**ANSWER:** Agreed, we corrected.

63: Variable selection - as above

**ANSWER:** Explained

67: In what way was the real estate data used to select the cities? This is unclear. Is this just a question of data availability, or was there a considered 'selection process'?

**ANSWER:** The reviewers comment aligns closely with comment p2: lines 77-84 of reviewer 2. As we explained, real estate data in Latin American region is very difficult to obtain. From the eight megacities, we were able to obtain information for only five. We consider that one of the greatest achievements of the research presented here is to make this information available.

72: How did you judge level of 'rural'-ness, or proximity to water bodies? Distance, scales etc.

**ANSWER:** The city administration defines rural zones within the city according to data obtained in census. However, due to pragmatic limitations, we considered "rural and close to sea shore districts" districts in which present 50% of the district was rural or adjacent to a beach.

74-75: How was the random selection undertaken?

**ANSWER:** After the first filter (rural and close to water districts), the remaining districts per city were written in a different sheet of an Excel file. The number of ten (10) districts was determined in order to be able to establish comparisons because of the differences in the numbers of districts per city. We opted for the random function in Excel, which gives you numbers with long decimals between 0 and 1 and typing it in the next column. When selecting both column and ordering from minor to major, we selected the first ten (10) districts per city and with them perform the analysis.

78: Presumably because they only have jurisdiction over a certain number of areas is which they are marketing property? I do not know this system well, and presume that other readers may benefit from a brief explanation of how the real estate system operates in these cities

**ANSWER:** We provided a brief explanation in acknowledgment section.

83-84: Actually, really useful to know!

**ANSWER:** Thank you. We are sure this will help others to identify partnerships.

104: Why were these quantities chosen?

**ANSWER:** Within the five megacities, Buenos Aires has the smallest district size. After random selection, the smallest district size was 3.5 Km<sup>2</sup>, because of that we decided to establish 2.5 km<sup>2</sup> as total measured area because it fit within this area.

108: 500m 'above ground level'? Unclear on the meaning of this reference point - this is referring to where the remote images were taken? So all of your randomly selected points were also constrained by a requirement to be (at?) 500m within your methodology?

**ANSWER:** The 500 m above ground level (m.a.g.l.) is the altitude where the measure took place, due to the differences between cities' altitudes. For example, Lima's average altitude is 154 m.a.s.l. and Mexico city's altitude is 2.250 m.a.s.l. In that sense, the urban green space measure was done at 654 m for Lima and 2750 m for Mexico City to ensure standardization of measurements.

111: Is this a validated methodology? Has it been used in other notable studies?

**ANSWER:** The use of Google Earth is valid (Mering, Baro, & Upegui, 2010; Clark & Aide, 201; Dorais & Cardille, 2011; Duhl, Guenther, & Helmig, 2012; Wardaya & Ridha, 2014).

130: Refers to 'Table 2'?

**ANSWER:** Corrected

133-135: So this just refers to all of the possible factors that were not fed in to the model? - including, presumably, a lot of factors that are irrespective of the environmental context

**ANSWER:** Yes, in the case studies now included deeper insights are provided.

152-154: Further references would be useful here. As noted previously: " it might be useful to consider (or hint at the consideration of) the implications and limitations that hedonic pricing methods have for indicating a holistic value of green space." It gives valuable insight through a particular lens: the perspective of standard, contemporary economic approaches for valuing commodities

**ANSWER:** Agreed. We mentioned in discussion section in order to point out the limitations of the methods (line. 261-267)

156: As comment for 133-135

**ANSWER:** We extended the analysis in order to provide better insights.

158-160: This is a useful list, but seems rather specific when some general aspects such as 'biodiversity' on the environmental side, and 'amenity value, or specifics like value for recreation' are not included

**ANSWER:** Agreed. We mentioned some additional factors like biodiversity and culture/recreational values.

162-165: A valid point. Are these the kind of decision-makers that you have in mind for this work in general? Just to be clear - is this a statement about natural resource managers having a better understanding of the most important factors (and potentially 'tradeoffs') between different kinds of ecosystem services depending on the way in which they are valued?

**ANSWER:** Yes. We measured urban green spaces as a bundle of ecosystem services from which society benefits, although the relevance of an ecosystem services in a given city depends on the environmental and socio-economic characteristics of each city.

170: WRT 'urban land consolidation' - presumably this is the case in existing urban 'boundaries', but not necessarily in the peripheral areas?

**ANSWER:** we agree the imbalances and asymmetries of development in the Latin American and the Caribbean region are expressed territorially in the human settlements that exist in it, where the increase and concentration of wealth in contrast to the increase and diffusion of poverty are the main examples that illustrate the urban land consolidation phenomenon in the region, this complex issue is at least now mentioned in the revised manuscript (line 108-154)

174-176: Another group of decision-makers. This statement re: the importance of green spaces feels like it could have been made earlier in the introduction for greater impact

**ANSWER:** Thank you. We follow your recommendation and extended the idea in the introduction (line. 4-108)

177-178: Your message is a bit mixed here, between urban green space priorities and calls for better data and open access. (How, where would this data be generated and stored? Any examples?)

**ANSWER:** Agreed. We divided the two ideas into separate parts and explained in a more detailed way (line. 269-307)

190: Formatting: m<sup>2</sup>

**ANSWER:** Corrected

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Giovanni Sanesi  
Guest Editor  
*Special Issue - Forests*  
November, 9th, 2017  
Dear Giovanni Sanesi:

We are very grateful for the opportunity to resubmit a revised and improved version of our manuscript identified with ID forests-235954 and to have the manuscript considered for the Special Issue "What Role Can Ecological Factors Play in Supporting Ecosystem Services in Urban and Peri-Urban Forests?". Also, we would like to express our thanks to the reviewers for the positive feedback and helpful comments for improving the manuscript.

We have modified the manuscript in line with the helpful comments from the reviewers and addressed main concerns about manuscript structure to guide the readers to better understand the context dependence of ecosystem service provision from urban green space and a potentially productive strategy for future research to better comprehend how and when spatial patterns of LAC urban green spaces matter for ecosystem service provision.

We believe the manuscript have resulted in an improved revised study benefited from these insightful revision suggestions.

Below are point by point explanations of how we have modified the manuscript in response to the reviewer comments.

Thank you for your consideration

Sincerely,

Ursula

Undergraduate Thesis Candidate

Universidad Científica del Sur, Lima, Perú

Comments for the Author:

Reviewer #1:

Most elements have been addressed from the original critical review, and the revisions have improved the academic value of this paper.

**ANSWER:** We are very grateful with the reviewer's comment.

Reviewer #2:

Thank you very much for the improved manuscript and I'm happy to read an extended manuscript. Most of the reviewer's comments were integrated into the resubmitted version that lead to a better understanding of the topic. However, I have some concerns /comments on the paper that hopefully will be useful to the author/s in improving this manuscript:



Introduction section: A general overview of the topic is presented; a definition of urban green space is given and the research topic and challenges are generally addressed. But what the reader is missing is the central research question / hypothesis of the paper. The last paragraph provides some insides. However, no research question is provided that guides through the manuscript.

**ANSWER:** We thank the reviewer for helpful recommendations in order to improve the academic quality of our manuscript.

Our hypothesis referred to where people prefer to live is reflected in the monetary and non-monetary value that they attribute to their district. On this basis, if there is a relationship between green space and real estate prices, it will lead to ensure the provision of ecosystem services through specific economic tools. Focusing on the value of green space, we can assume that urban green spaces provide bundles of ecosystem services. Our both research questions described in the last paragraph of the introduction section pretend to guide the readers to the first step of a permanent urban research agenda.

Additionally, some minor remarks on this section:

Line 46-49: Those sentences refer to Latin America or in general to the world? This should be clarified.

**ANSWER:** We clarified the information by specifying the word “world” where needs to be.

Line 49: You refer to “dense settlements (cities) by 2000.” This source is quite old considering that urbanization is a very fast process. It would be great if a more current source would be cited.

**ANSWER:** It was corrected, and an updated reference was cited.

Line 60: What do you mean with “undeveloped areas”? Please provide a more precise definition or wording.

**ANSWER:** We follow reviewer recommendation and reword to Vacant Lots to be more precise

Line 76: I would kindly recommend to consider the following publication that refers especially to the potential of urban green spaces and social interaction in Santiago de Chile: Krellenberg, K., Welz, J., Reyes-Päcke, S. 2014: Urban green areas and their potential for social interaction – A case study of a socio-economically mixed neighbourhood in Santiago de Chile. Habitat International, Volume 44, Pages 11-21, ISSN 0197-3975, <https://doi.org/10.1016/j.habitatint.2014.04.004>.

**ANSWER:** We thank the recommendation and cite the study Krellenberg, et al (2014).

Line 79-81: These two sentences do not contribute to the overall discussion on challenges for urban planners in LAC cities as these are to general/obvious. What is the real challenge behind? The reader would expect a more profound discussion on the challenges that LAC cities faces today. I would kindly recommend being more precise and try to formulate interesting hypothesis.

**ANSWER:** We follow reviewer’s recommendation and precise the urban challenges in LAC context, as follow:

“One of the main challenges that LAC urban planners face in order to achieve

welfare for millions of urban residents in LAC megacities is related to large, /uncontrolled and informal urban development that places pressure on the provision of basic services, increases a city's vulnerability and has a number of negative environmental consequences. This informal growth also tends to occur independently and apart from formal urban expansion which leads to the consolidation of spatial segregation socioeconomically”

Line 88-92: Are these your research question? What is the main aim of the paper? How is it structured ... this would guide the reader through the manuscript.

**ANSWER:** The aim of the study is to provide a first insight into the estimation of the value of ecosystem service provision from urban green space across LAC megacities using hedonic price indices; and the identification of how the ecological attributes of urban green space might impact the capacity of urban green spaces to provide ecosystem services. As well, we mention that it might be useful to consider more research to better understand when and where ecological attributes of green space affect prices so we can confidently use hedonic price indices for holistic valuations of green space because it is beyond our scope.

We agreed about manuscript structure and make subdivision through all document to provide a better understanding.

Methods: Although the authors indicated that a specific focus on Lima and Buenos Aires is given the manuscript still focuses on a comparative analysis. Therefore, it is absolutely necessary to present a profound description why these specific 5 LAC cities were selected. Why 5 and not 7? Which kind of criteria sustains your selection? Thus, what are the central aspects/topics of comparison in order to highlight similarities and differences of the research studies? Line 108 and further on some broad information is given on the 5 LAC cities, however it is still not clear why these 5 cities were selected for a statistical analysis. Are these cities very similar to each other or are they very different? Why is it worth to compare them?

**ANSWER:** The main reason about the selection of five cities instead of eight was the possibility to obtain real estate prices at district level. The three megacities excluded are located in Brazil, and the access to real estate prices there is more complex.

Additionally, I would recommend removing Figure 1 as this does not provide any important information. Instead of Figure 1, a table should be presented that gives the most important information on the 5 cities and that better explains the criteria for comparison. Furthermore, be careful in presenting the 5 cities. At least a consistent structure should be pursued. For example, annual population growth is only presented for Bogotá and Buenos Aires; and only in Bogotá a percentage of housing deficit is presented. Thus, be precise in presenting the cities, use similar criteria (maybe those of section 2.3?) and those that are very important for your analysis and research question. Furthermore, please extend your bibliographic references for this section. Many of your statements are not supported by literature.

**ANSWER:** We addressed reviewer's recommendation by removing Figure 1 and presenting a Table 1 with the five cities information in the same structure and same indicators for better comparison. Also, we extended the references for this section. (lines. 111-147).

In section 2.2 (Land Cover Data) you refer only to Lima and Buenos Aires. Why Lima and Buenos Aires were selected? For the reader it is very important to know why and it is quite important to explain your decision. Why do you need the other 3 cities?

**ANSWER:** We agree that the justification is not exactly precise. The reason of city selection is now explained (lines.192-195), and literally says:

“Buenos Aires and Lima were chosen for the case study because within the group of five cities considered in this analysis these cities represent the extremes of climatic conditions captured in the analysis. Mean Annual Precipitation (MAP) for example in Lima is 16.4mm, whereas in Buenos Aires the figure is 1040mm”

Discussion and conclusion: This section aims to respond the research question, thus it should stretch the bow to the introduction. Unfortunately this is not explicitly done here. The discussion is very simple, e.g. line 282 states that “classifications of urban green spaces can lead to a deeper understanding” --- What do you mean with deeper understanding? How far your analysis can contribute to this kind of deeper understanding? Furthermore, in line 284 and further on you give an explanation for the different results in Lima and Buenos Aires and highlight the climatic conditions. This kind of specific criteria was not discussed in the case study area section and this seems very surprising here.

**ANSWER:** We improved the discussion section by providing further information of Buenos Aires and Lima context to better understand the impact of green spaces attributes and the value people’s preference about these spaces on real estate prices. In addition, we introduced climatic conditions and differences in the specification of case study section.

Line 296-298 is a kind of definition that could be moved to the introduction section. It should not be part of the discussion section, unless it is to be questioned here.

**ANSWER:** The sentences were moved to the introduction section. (lines. 84-86)

Line 303 seems very obvious – “relationship between green spaces and real estate prices is context-specific” – It would be interesting to know what kind of context make the difference?

**ANSWER:** We have now augmented the information of Buenos Aires and Lima, in order to provide a better contextualization of the relationship between green space provision/attributes and real estate prices. (lines. 279-287)

Finally, within the discussion I would acclaim a differentiation (e.g. in terms of sub-sections) of a theoretically part (what does the results mean for theoretical framework), methodological reflection (e.g. data availability, further statistical analysis) and relevance of the results for further urban planning strategies.

**ANSWER:** This has been done in the revised manuscript in all section to keep a coherent way for better understanding. We again thank the reviewer for this helpful recommendation.

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Giovanni Sanesi  
Guest Editor  
*Special Issue - Forests*  
November, 18th, 2017

Dear Giovanni Sanesi:

We are extremely grateful for your consideration accepting our manuscript identified with ID forests-235954 for the Special Issue "What Role Can Ecological Factors Play in Supporting Ecosystem Services in Urban and Peri-Urban Forests?".

We have addressed all your comments and constructive feedbacks.

Thank you for your consideration

Sincerely,

Ursula  
Undergraduate Thesis Candidate  
Universidad Científica del Sur, Lima, Perú

Comments for the Author:

I ask the authors to select the right term between 'Latin American and Caribbean megacities' and 'Latin American megacities'

**ANSWER:** We selected Latin American to stay coherent in terms along the study.

I also ask whether the term 'green spaces' refers only to public spaces or the total availability of green spaces. In my opinion this aspect is unclear and the authors have to explain how they were able to select only public spaces, if any.

**ANSWER:** Thank you for the hint. We have added an explicit statement at the end of section 2.2 *Green space quantification across the 5 megacities* precisising that we referred to the availability of green spaces including private and public green spaces. (Line 168)

I would like to add further elements to the debate on ecosystem services that green areas can provide to citizens in this geographic context.

**ANSWER:** We have added a paragraph in discussion section pointing out the relevance of ecosystem services depending to the specific characteristics of a city. (Line 290)

The bibliography also contains several typing errors.

**ANSWER:** We corrected typing errors in bibliography following Forests reference format and style.

#### IV. VERSION EN ESPAÑOL

Artículo

# Sobre el Uso de Índices de Precios Hedónicos para Comprender la Provisión de Servicios Ecosistémicos de las Áreas Verdes Urbanas en Cinco Megaciudades de América Latina

## 1. Introducción

Entre los años 1700 y 2000, el 55% de la cubierta terrestre libre de hielo fue transformada por las actividades humanas dejando menos del 45% de la biosfera terrestre, natural o seminatural [1]. Asimismo, los seres humanos hemos cambiado no solo la forma de utilizar nuestro entorno sino también nuestra distribución dentro de él. La población mundial ha pasado de vivir principalmente en tierras semi naturales en 1700 [2], a vivir substancialmente en densos asentamientos, o ciudades, en el 2016 [3]. En la actualidad, las ciudades albergan más de la mitad de la población mundial [4], y se expanden en promedio el doble de la tasa de crecimiento poblacional [5-7].

En América Latina (AL), tres cuartas partes de la población ya vive en ciudades [8], convirtiéndola en una de las regiones más urbanizadas en el mundo. Mas aun, las ciudades y megaciudades de AL desempeñan un papel muy importante en la economía de la región [9]. No obstante, las ciudades de AL también se caracterizan por una profunda segregación socio-espacial, altos niveles de delincuencia, desigualdad de ingresos y pobreza [10]. La alta densidad poblacional y la alta concentración de actividades humanas en las megaciudades de AL han conllevado un número de impactos ambientales negativos [11], así como varios retos en términos de satisfacer la demanda por nueva infraestructura, la cual se logra generalmente a un alto costo socio-ambiental [12].

Muchos planificadores urbanos y políticos consideran las áreas verdes urbanas y los lotes disponibles como zonas potenciales para ser convertidas en infraestructura [13,14], sin tomar en cuenta el hecho que las ciudades dependen de los servicios ecosistémicos que las áreas verdes urbanas proveen para sostener el bienestar humano [15,16]. Las áreas verdes urbanas, definidas como espacios exteriores con vegetación natural o espacios humanamente modificados [17] incluyen parques y bosques urbanos, vías verdes, senderos, jardines comunitarios, árboles en la calle, cementerios y otros [18], aparecen como parches inmersos en la matriz urbana, donde su conectividad y continuidad esta muchas veces en peligro por otras prioridades de adjudicación de tierras [19]. Por estas razones, las ciudades de América Latina se caracterizan por un crítico déficit de áreas verdes urbanas [8], las cuales perjudican la calidad de vida de sus habitantes [20].

Las áreas verdes urbanas proveen beneficios ambientales y sociales; al mismo tiempo, ayudan a aminorar muchos problemas urbanos al proveer numerosos servicios ecosistémicos. Los servicios ecosistémicos son las contribuciones directas e indirectas al bienestar humano, en este caso, de ecosistemas urbanos y sus componentes [15], y su provisión está relacionada con un incremento en la calidad de vida [21] y en la resiliencia urbana [22]. Las áreas verdes urbanas pueden mejorar la calidad del aire a través de la filtración de contaminantes, regular el flujo de agua y la temperatura urbana, reducir el efecto de isla de calor generado por el concreto y la combustión de motores como también reducir la contaminación acústica [23,24]. Las áreas verdes urbanas también mejoran la salud mental y física de los ciudadanos, y facilitan la interacción social de los residentes urbanos [18,25-27].

Sin embargo, estos servicios ecosistémicos no poseen un precio de mercado; por lo tanto, no pueden ser comercializados en un mercado existente [28], provocando una inadecuada consideración de las áreas verdes en las políticas públicas de planificación urbana.

Uno de los principales desafíos que los planificadores urbanos enfrentan para alcanzar el

bienestar de millones de residentes en las megaciudades de AL, está relacionado con el masivo crecimiento urbano, descontrolado e informal; el cual ejerce presión en la provisión de servicios básicos, aumentando la vulnerabilidad de las ciudades y otras consecuencias ambientales negativas [29–31]. Este crecimiento informal tiende a ocurrir independientemente y por separado de la expansión urbana formal, conduciendo a la consolidación de la segregación espacial socioeconómica [32]. Las áreas verdes son importantes en las zonas urbanas debido a que contribuyen a su integridad ecológica, proveen servicios ecosistémicos, y mejoran la habitabilidad en las ciudades [18,24,25]; lo cual requiere ser considerado en las actividades de planificación urbana [33,34]. Si el valor económico de las áreas verdes pudiese demostrarse a través de una prima en los precios inmobiliarios, la importancia de los servicios ecosistémicos provistos por las áreas verdes se vería reforzada en el proceso de la toma de decisiones políticas [35]. Ello es realmente importante porque la financiación de la infraestructura y los servicios públicos depende en gran medida de los arreglos institucionales gubernamentales [36].

Un enfoque para cuantificar el valor de los servicios ecosistémicos es mediante el uso de índices de precios hedónicos [37]. Los índices de precios hedónicos se basan en correlaciones entre los precios de mercados existentes (ejem., el mercado inmobiliario) y servicios ecosistémicos específicos (ejem., la calidad del aire) o paquetes de servicios ecosistémicos, como por ejemplo las áreas verdes urbanas [18,25]. Una pregunta abierta para la región de AL es si los índices de precios hedónicos pueden ser utilizados para estimar el valor de la provisión de servicios ecosistémicos a partir de las áreas verdes en estas megaciudades. Otra pregunta abierta para las ciudades de AL sería cómo los atributos ecológicos de las áreas verde urbanas pueden impactar la capacidad de estas áreas en la provisión de servicios ecosistémicos.

En esta investigación, se proporciona algunos alcances en los dos temas mencionados para las ciudades de AL. Específicamente se prueban las siguientes hipótesis: (1) los índices de precios hedónicos pueden proveer estimaciones confiables del valor de los paquetes de servicios ecosistémicos generados por las áreas verdes urbanas a través de las megaciudades de AL, y (2) la información obtenida de los índices de precios hedónicos puede ser específica al contexto y variar a través de las ciudades.

## 2. Métodos

### 2.1. Características de las ciudades empleadas en la comparación de índices de precios hedónicos a través de las ciudades

Esta investigación está enfocada en las megaciudades de AL (opuesto a las ciudades, utilizadas generalmente) debido a la alta concentración de población latinoamericana en megaciudades en comparación con otras regiones del mundo [38]. De acuerdo con UN Habitat (2012), existen ocho megaciudades en AL: Buenos Aires, Ciudad de México, Rio de Janeiro and São Paulo (con más de 10 millones de habitantes) y Belo Horizonte, Bogotá, Lima y Santiago (con poblaciones aproximadas a los 10 millones) [8]. De estas ocho ciudades, fue posible obtener los precios inmobiliarios a nivel de distritos para las siguientes cinco megaciudades: Bogotá en Colombia, Buenos Aires en Argentina, Lima en Perú, Ciudad de México en México y Santiago en Chile (Anexo A).

A pesar que estas cinco megaciudades presentan desafíos comunes en el desarrollo urbano, la intensidad de los aspectos específicos relacionados a la sostenibilidad y la resiliencia varían de una ciudad a otra [10] (Tabla 1).

Bogotá está ubicada en el centro de Colombia, en el flanco este de los andes, a 2625 msnm [39]. La extensión de la ciudad es de 1637 km<sup>2</sup> [40] y está dividida políticamente en 20 localidades [26]. Bogotá tiene una tasa de crecimiento poblacional anual de 1.3%, con un promedio de densidad poblacional de 4,876 habitantes/km<sup>2</sup> [41]. Posee una estructura relativamente compacta con alta consolidación de densidad poblacional, y con una gran concentración de desarrollo informal en áreas periféricas [42]. El crecimiento de los asentamientos informales y los pronunciados niveles de desigualdad de ingresos son los desafíos más importantes en Bogotá. La

estimación de áreas verdes por habitante es de 10 m<sup>2</sup> [43].

Buenos Aires se encuentra ubicada en la región centro-oriental del país, en la orilla occidental del río de la Plata, en la llanura pampeana, a 25 m sobre el nivel del mar [44]. La extensión de la ciudad es 204 km<sup>2</sup> [45]. Buenos Aires está oficialmente dividido en 48 barrios; sin embargo, la administración política y administrativa de la ciudad se distribuye a través de quince comunas que, en la mayoría de los casos, cubren más de un barrio de Buenos Aires [44]. Tiene una tasa de crecimiento poblacional anual de 1,5%, con una densidad poblacional media de 14,970 habitantes/km<sup>2</sup> [45]. Buenos Aires presenta una pronunciada diferenciación socio-espacial con un fuerte crecimiento suburbano y periurbano [29]. El crecimiento urbano informal y precario, la pobreza, la desigualdad y el crimen son los desafíos más urgentes en Buenos Aires [10]. La estimación de las áreas verdes por habitante es de 6 m<sup>2</sup> [44].

Lima se encuentra en la costa central del país, a orillas del Océano Pacífico, limitada por el desierto costero y la construcción formal de la ciudad, la cual se ha desarrollado mayormente en tierras agrícolas de las llanuras inundables de tres ríos: Chillón, Rímac y Lurín. Lima está a 154 m sobre el nivel del mar [46]. La ciudad tiene una extensión de 2812 km<sup>2</sup> y está dividida en 43 distritos [47]. La tasa de crecimiento poblacional anual es de 1,6% [48] y su densidad poblacional media es de 3,328 habitantes/km<sup>2</sup> [49]. Lima es una aglomeración metropolitana altamente segregada con profundos contrastes entre los sectores de altos ingresos y de bajos ingresos [50]. En Lima hay una gran cantidad de crecimiento urbano informal y una demanda insatisfecha de servicios básicos como agua potable, transporte y vivienda [10]. La ciudad cuenta con 3 m<sup>2</sup> de áreas verdes por habitante [51].

Ciudad de México se encuentra en el Valle de México a 2240 m sobre el nivel del mar [52]. La ciudad posee una extensión de 1485 km<sup>2</sup> y está dividida en 16 delegaciones [53]. La tasa de crecimiento poblacional anual de la Ciudad de México es de 0.3%, con una densidad poblacional de 5,967 habitantes/km<sup>2</sup> [54]. La creciente inseguridad, la fragmentación socio-espacial y las condiciones de vivienda precarias son los desafíos sociales más importantes en la Ciudad de México [10]. La Ciudad de México tiene 13 m<sup>2</sup> de áreas verdes por habitante [55].

Santiago se encuentra en el valle de Santiago, rodeado por los Andes, a 520 m sobre el nivel del mar [56]. La ciudad tiene una extensión de 640 km<sup>2</sup> y está políticamente dividida en 32 comunas [57]. Tiene una tasa de crecimiento poblacional anual del 1.0% y una densidad poblacional media de 2,304 habitantes/km<sup>2</sup> [58]. Las políticas de vivienda de Santiago han reducido los problemas de vivienda informal; sin embargo, estas políticas han llevado a una profunda segregación social [10,59]. Santiago posee 4 m<sup>2</sup> de áreas verdes por habitante.

**Tabla 1.** Megaciudades de América Latina seleccionadas y su respectiva información relevante

	Bogotá	Buenos Aires	Lima	Ciudad de México	Santiago
País	Colombia	Argentina	Perú	México	Chile
Altitud media (msnm)	2625	25	154	2240	520
Extensión (km <sup>2</sup> )	1637	204	2812	1485	640
División administrativa	20 localidades	48 barrios	43 distritos	16 delegaciones	32 comunas
Área verde (m <sup>2</sup> /hab)	10	6	3	13	4
Precipitación media anual (mm)	818	1040	16	749	390
Temperatura media anual (°C)	13.5	16.8	18.8	15.7	14.4
Tasa de crecimiento poblacional (%)	1.3	1.5	1.6	0.3	1.0
Desafíos más relevantes	Crecimiento de asentamientos informales	Inseguridad	Falta de servicios básicos	Inseguridad	Segregación socio-espacial

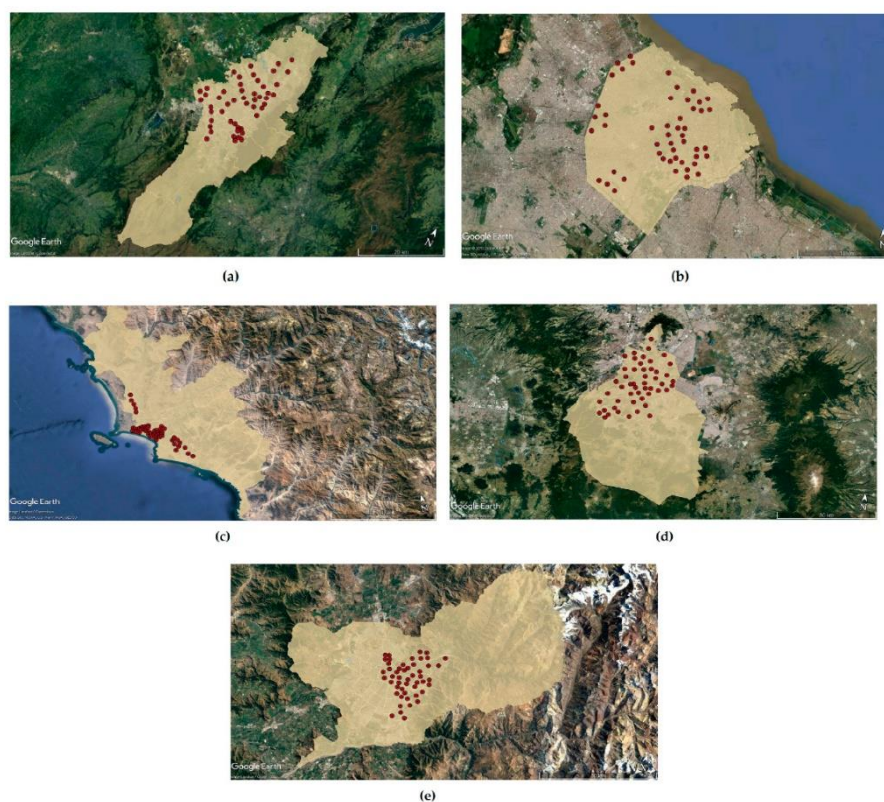


2.2. Cuantificación de las áreas verdes a través de las 5 megaciudades

Las megaciudades de AL ocupan diferentes cantidades de espacio físico, así como su construcción se ha dado sobre diferentes tipos de cubiertas terrestres. Por lo tanto, se consideraron tres características para definir los distritos incluidos en este estudio: (1) porcentaje de la población rural; (2) ubicación; y (3) tamaño.

Se excluyeron los distritos que tenían más del 50% de población rural y/o que eran predominantemente rurales o adyacentes a la orilla del mar. Dentro y entre las cinco megaciudades, los tamaños de los distritos son diferentes. San Telmo en Buenos Aires es el distrito más pequeño con un área de 1.2 km<sup>2</sup>; y Tlalpan en la Ciudad de México es el distrito más grande con 312 km<sup>2</sup>. Se excluyeron los distritos menores a 3 km<sup>2</sup> y/o mayores a 100 km<sup>2</sup>. Para crear una muestra comparativa, diez distritos por ciudad fueron seleccionados al azar de los distritos que eran más grandes que 3 km<sup>2</sup> y más pequeños que 100 km<sup>2</sup>.

Google Earth Pro (versión 7.3) se utilizó para obtener los datos de cobertura terrestre con imágenes del 2013. El área total muestreada por distrito fue de 2.5 km<sup>2</sup>, dividida en cinco polígonos seleccionados al azar de 0.5 km<sup>2</sup>, los cuales representaron la mayor parte del área en la mayoría de los distritos muestreados. En resumen, este estudio consideró cinco polígonos por distrito equivalente a 50 polígonos por ciudad, con un número total de 250 polígonos (Figura 1). Las mediciones del área verde se establecieron a una altitud de 500 m sobre el nivel del suelo. Las áreas verdes urbanas se definieron como áreas cubiertas con cualquier tipo de vegetación según lo descrito por Wolch et al. (2014) [18]. Por lo tanto, todos los tipos de cubierta vegetal se muestrearon dentro de todos los polígonos, desde árboles individuales hasta bosques urbanos para medir la disponibilidad total de las áreas verdes, incluyendo los espacios públicos y privados.



**Figura 1.** 250 polígonos muestreados distribuidos a través de las cinco megaciudades (a) Bogotá; (b) Buenos Aires; (c) Lima; (d) Ciudad de México, (e) Santiago. Imagen Landsat/Copernicus descargada de Google Earth.

### 2.3. Estimación de variables socio-económicas a través de las cinco megaciudades

Densidad Poblacional: Esta variable fue estimada como el número de habitantes por km<sup>2</sup> de cada distrito en año 2013 (Anexo B). Esta variable fue incluida en el análisis entre ciudades debido a que García & Riera (2003) han demostrado que las personas están dispuestas a pagar para vivir en barrios menos densamente poblados [60]. Otros estudios también han expresado que las personas prefieren barrios con baja densidad poblacional y baja densidad de unidades de vivienda [61,62].

Densidad empresarial: Esta variable es el resultado de dividir el número total de negocios por el área total del distrito en el 2013 (Anexo B). Esta variable muestra la relación probable entre un área más económicamente activa y la disposición a pagar para vivir en dicha área. De acuerdo con Des Rosiers et al. (2000) y Yu et al. (2012), existe una relación positiva entre los precios inmobiliarios y la proximidad a los centros comerciales, lo que sugiere que el atractivo de las instalaciones comerciales repercute en las decisiones de los hogares, lo que se traduce en una mayor demanda y, por lo tanto, precios y rentas más altas [63,64].

Tasa de criminalidad: Esta variable se calcula como el número de delitos registrados por km<sup>2</sup> en cada distrito en el año 2013 (Anexo B). Los hallazgos previos sugieren que existe una importante relación entre las tasas de criminalidad y los valores de las propiedades. Ihlanfeldt y Mayock (2010) sugieren que los compradores de vivienda están dispuestos a pagar primas no triviales por viviendas ubicadas en barrios con menores incidencias de asaltos agravados, robos y delitos [65]. De hecho, la reducción de la tasa de criminalidad tiene un beneficio inmediato en los precios de los bienes raíces, pero también, los beneficios pueden derivarse por períodos de 4 a 6 años [66].

### 2.4. Caso de estudio: Efecto de las variables de ecología del paisaje en los índices de precios hedónicos

Buenos Aires y Lima fueron elegidos como casos de estudio para un análisis más profundo en el que evaluamos cómo las variables de ecología del paisaje (tamaño medio de parche, conectividad de parches, etc.) afectan los precios inmobiliarios, en un esfuerzo por obtener una comprensión más profunda de cómo y cuándo los atributos ecológicos de las áreas verdes pueden afectar el potencial de la provisión de servicios ecosistémicos de las áreas verdes urbanas. En este conjunto de datos, Buenos Aires y Lima representan los extremos de las condiciones climáticas, con una precipitación anual media más baja en Lima (16 mm) y la más alta en Buenos Aires (1040 mm).

Las imágenes de satélite de Buenos Aires y Lima de marzo del 2013 se descargaron de Google Earth Pro (Versión 7.3, Google Inc., Mountain View, CA, EE. UU.) y se procesaron en ArcGIS 10.3 (ESRI, Redlands, CA, EE. UU.). Primero se georreferenciaron las imágenes y se proyectaron en forma geográfica. Luego se extrajeron las áreas de interés de los cinco polígonos seleccionados al azar de 0.5 km<sup>2</sup> por distrito. Utilizamos Segment Mean Shift de la caja de herramientas de Spatial Analyst para segmentar las imágenes en objetos de al menos 10 píxeles. A continuación, seleccionamos manualmente los objetos que correspondían a nuestra definición de áreas verdes urbanas o "parche verde" dentro de las áreas de interés. El área de cada parche se calculó utilizando la función de cálculo geométrico en la tabla de atributos de ArcGIS. La distancia promedio del vecino más cercano entre los parches verdes se calculó utilizando la Distancia euclidiana en la caja de herramientas Estadísticas espaciales.

### 2.5. Análisis estadístico

Para homogenizar los datos y simplificar la interpretación del análisis de índices de precios hedónicos a través de las ciudades, las variables independientes y dependientes fueron normalizadas previo al análisis estadístico tomando la siguiente fórmula:

$$X^*_i = X_i / X_{\max}$$

donde  $X_i$  es cada variable dependiente después de la normalización.  $X_i$  es la variable previa a la normalización y  $X_{max}$  es el máximo valor obtenido para cada variable en su respectiva ciudad.

Para el estudio de caso (Lima and Buenos Aires) no se realizó una normalización de los datos antes del análisis ya que las diferentes escalas no son un problema dentro de las ciudades individuales.

Los datos transformados y no transformados se analizaron mediante regresión lineal múltiple utilizando XLStat (Versión 2014.5, Addin Soft, París, Francia).

### 3. Resultados

#### 3.1. Comparación de los índices de precios hedónicos a través de las megaciudades

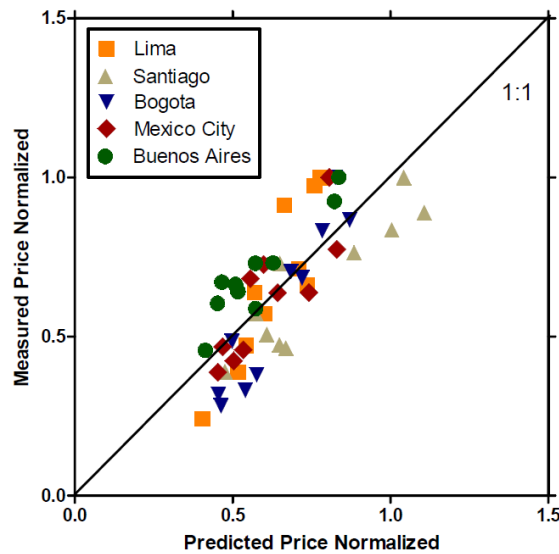
A partir de una regresión múltiple con cuatro variables independientes, obtuvimos un modelo con precisión admisible ( $R^2=0,62$ , Tabla 2A, Figura 2). Los valores  $\eta^2$  indican que el área verde urbana fue la variable predictiva más importante explicando el 52% de la variabilidad de los precios inmobiliarios en las megaciudades consideradas en este análisis. La densidad de negocios también tuvo una modesta influencia en los precios inmobiliarios con un valor de  $\eta^2$  de 10, mientras que la tasa de criminalidad y la densidad poblacional tuvieron impactos no relevantes (Tabla 2). Sin embargo, también hubo un error considerable con una variabilidad inexplicada que representa el 39% de la suma de cuadrados; por lo tanto, no se obtuvo una comprensión completa de los factores que determinan los precios inmobiliarios en el análisis a través de las ciudades.

**Tabla 2.** (A) Estadísticas resumidas para los modelos de regresión múltiple en los que (A) los precios inmobiliarios se correlacionaron con cuatro variables: área verde, densidad poblacional, densidad empresarial y tasa de criminalidad, (B) área verde y atributos de parche verde vs. precios inmobiliarios en Lima, y (C) área verde y atributos de parche verde vs. precios inmobiliarios en Buenos Aires. Variables: Av/at = área verde/área total, TGS = área verde total, TNP = Número total de parches, MPS = Tamaño medio del parche, LPS = Parche más grande, ANN = distancia al vecino más cercano, PopDen = Densidad poblacional, BusDen = Densidad empresarial, CrimDen = Tasa de criminalidad.

Source	df	SS	MS	F	Pr > F	$\eta^2$
(A) Analysis hedonic price indices across cities						
AV/AT*	1	1.14	1.14	60.16	<0.0001	51.5
Pop Den*	1	0.00	0.00	0.03	0.87	0.0
Bus Den*	1	0.22	0.22	11.5	0.002	9.8
Crim Den*	1	0.00	0.00	0.24	0.63	0.2
Error	45	0.85				38.5
Corrected Total	49	2.21				100
(B) Analysis of green space and patch attributes vs. real estate prices in Lima						
TGS	1	2,663,521.6	2,663,521.6	42.9	0.0	83.8
LPS	1	223,703.7	223,703.7	3.6	0.1	7.0
TNP	1	18,053.0	18,053.0	0.3	0.6	0.6
MPS	1	21,708.4	21,708.4	0.3	0.6	0.7
ANN	1	2851.4	2851.4	0.0	0.8	0.1
Error	4	248,443.6	62,110.9			7.8
Corrected Total	9	3,178,281.6				100.0
(C) Analysis of green space and patch attributes vs. real estate prices in Buenos Aires						
TGS	1	213,044.0	213,044.0	1.7	0.3	12.5
LPS	1	393,208.9	393,208.9	3.1	0.2	23.0
TNP	1	88,816.9	88,816.9	0.7	0.5	5.2
MPS	1	131,095.6	131,095.6	1.0	0.4	7.7
ANN	1	375,692.7	375,692.7	3.0	0.2	22.0
Error	4	508,002.4	127,000.6			29.7
Corrected Total	9	1,709,860.5				100

df, grados de libertad; SS, suma de cuadrados; MS, cuadrados medios; F, F-test; Pr, probabilidad,  $\eta^2$  porcentaje de variación del  $R^2$  explicado por cada variable independiente,  $\eta^2$  es obtenido de la suma de cuadrados parcial entre la suma de cuadrados total por 100. \* Variables después de

transformación (normalización) utilizadas en la regresión múltiple para el primer análisis. Normalización:  $X_i^* = X_i/X_{max}$ .  $X_i$ : variable antes de la normalización  $X_{max}$ : máximo valor obtenido para la variable para cada ciudad.



**Figura 2.** Relación entre los precios medidos y los precios estimados a nivel de distrito. Valores estimados obtenidos por regresión múltiple: Precio Estimado Normalizado (NOR) =  $0.35 + 0.71 * av / at \text{ NOR} - 0.053 * \text{Densidad de Población NOR} + 0.34 * \text{Densidad de Negocios NOR} - 0.061 * \text{Tasa criminalidad NOR}$ . Ver la Tabla 2 para más detalles. La línea diagonal indica la relación 1:1. Los datos normalizados utilizados en este análisis se adhieren estrechamente a la línea 1: 1 (lo que indica una correspondencia estrecha entre los valores medidos y estimados, demostrando la solidez del modelo de regresión múltiple).

### 3.2. Caso de Estudio: Efecto de las variables de ecología del paisaje en los índices de precios hedónicos

Los resultados de los estudios de caso (Lima y Buenos Aires) proporcionaron un fuerte indicio de que la efectividad de los índices de precios hedónicos para restringir el valor de los servicios ecosistémicos proporcionados por el espacio verde urbano puede ser específico al contexto.

Los datos de Lima mostraron una fuerte relación entre el área verde total y los precios inmobiliarios, explicando el 83.8% de la variabilidad de los precios inmobiliarios (Tabla 2B). El impacto positivo y significativo del área verde total (TGS) confirmó además que la cantidad de área verde urbana es muy valorada por los residentes de Lima. El tamaño de parche más grande (LPS) del área verde en Lima tuvo un impacto menor en los precios inmobiliarios ( $\eta^2 = 7$ ), mientras que el tamaño medio de parche (MPS), el número total de parches (TNP) y el vecino promedio más cercano (ANN) o conectividad entre parches fueron irrelevantes.

En contraste, para Buenos Aires, las variables más relevantes respecto a la variación en los precios inmobiliarios fueron el tamaño de parche más grande (LPS) con un valor  $\eta^2$  de 23 (Tabla 2C), seguido por distancia al vecino más cercano (ANN) o conectividad con un  $\eta^2$  valor de 22. El área verde total (TGS) tuvo un impacto modesto que explica el 12.5% de la variabilidad en los precios inmobiliarios. El tamaño promedio del parche (MPS) del espacio verde urbano en Buenos Aires también tuvo un pequeño impacto, explicando el 7.7% de la variabilidad en los precios inmobiliarios. En Buenos Aires, hubo un error considerable con una variabilidad inexplicada que representa el 29.7%. En cambio, el término de error para Lima fue 7.8%.

## 4. Discusión y Conclusiones

### 4.1. Consideraciones generales

Los resultados de este estudio refuerzan los hallazgos previos que muestran que el área verde urbana es un determinante importante de los precios inmobiliarios [35,67-69], y que los índices de precios hedónicos pueden proporcionar una estimación robusta del valor de los servicios ecosistémicos proporcionados por las áreas verdes urbanas a través de las ciudades de AL. Sin embargo, la variabilidad inexplicada en el modelo de regresión múltiple para el análisis a través de las ciudades (38.5%) también fue significativa y podría estar relacionada con una variedad de factores que no fueron tomados en cuenta en este estudio. Algunas variables sociales, como las percepciones del estado económico [26], la dinámica de los ingresos [70], la calidad escolar [71] y / o los valores culturales y espirituales como el sentido del lugar y la cohesión social [24,72] pueden proporcionar información adicional sobre los factores subyacentes que impactan los precios inmobiliarios.

Además, el uso de variables de ecología del paisaje en el estudio de caso de Lima y Buenos Aires demuestra que, a pesar de las similitudes regionales, la relación entre el área verde y los precios inmobiliarios depende del contexto, y que los atributos ecológicos del área verde pueden afectar el potencial para la provisión de servicios ecosistémicos. Estas preferencias podrían estar relacionadas con varios factores, como la tendencia de crecimiento de la ciudad, la política del gobierno o, como sospechamos, el entorno físico. Parece lógico que la cantidad de área verde sea más apreciada en una ciudad hiper árida como Lima que en una ciudad como Buenos Aires, donde las precipitaciones son suficientes para mantener el crecimiento del bosque. Esto creemos que puede explicar por qué vemos una valoración más matizada de los espacios verdes en Buenos Aires centrada en los patrones espaciales del área verde, específicamente relacionados con el tamaño de las áreas verdes y la conectividad. Sin embargo, las diferencias en la calidad de la planificación de la ciudad también pueden ser importantes en esta comparación específica entre Buenos Aires y Lima [50,73] y un análisis más amplio que incluya datos de más ciudades podría proporcionar una mayor comprensión.

Además, la relevancia de los servicios ecosistémicos difiere según las características ambientales y socioeconómicas específicas de una ciudad [24]. Por ejemplo, las áreas verdes urbanas pueden amortiguar eventos climáticos extremos como inundaciones, que pueden ser importantes para ciudades como Buenos Aires, pero para ciudades como Lima con poca o ninguna lluvia, este servicio ecosistémico no es relevante. La regulación de la calidad del aire es fundamental para todas las megaciudades, pero posiblemente sea esencial en ciudades como Santiago y la Ciudad de México, donde la topografía favorece la concentración de contaminantes en aerosol. Los bosques urbanos estabilizan las laderas, previniendo el daño de los peligros naturales, lo cual es crucial para Bogotá, pero no relevante para Buenos Aires, que se encuentra en una llanura costera. Para asegurar la planificación orientada a la resiliencia, se necesita una clasificación específica al contexto de los servicios ecosistémicos en las áreas urbanas de AL [74]; ya que será importante considerar el papel de las características culturales específicas de las relaciones entre personas-naturaleza para aumentar la calidad de vida de residente de AL [26].

### 4.2. Reflexiones metodológicas

Los planificadores urbanos requieren datos espaciales actualizados y precisos a escala de ciudad para comprender la dinámica y los procesos urbanos [75]. En América Latina, los datos sólidos a escala local y de ciudad son difíciles de obtener debido al limitado interés e inversión en la investigación preliminar; así como el poco esfuerzo para garantizar el acceso abierto de los datos relevantes.

Nuestros resultados demuestran el importante papel que los índices de precios hedónicos pueden desempeñar para ayudarnos a comprender cómo el área verde genera servicios ecosistémicos en diferentes situaciones (por ejem., Buenos Aires vs. Lima). Se requiere investigación adicional para comprender mejor cuándo y por qué los atributos ecológicos de las

áreas verdes afectan los precios inmobiliarios y así optimizar la forma en que invertimos y administramos las áreas verdes en las ciudades de América Latina, garantizando que las áreas verdes urbanas generen la máxima cantidad de servicios ecosistémicos posibles. Sin embargo, nuestra capacidad para lograr esto dependerá en gran medida de la disponibilidad de los datos y un marco común para las comparaciones, como lo hemos intentado aquí en las megaciudades de América Latina. Mejorar la calidad y cantidad de la adquisición y disponibilidad de datos podría mejorar significativamente los procesos de planificación urbana para ciudades latinoamericanas, lo que estaría directamente en línea con los Objetivos de Desarrollo Sostenible de las Naciones Unidas que apuntan a mejorar la buena salud y el bienestar y apoyar el desarrollo de ciudades y comunidades sostenibles (<http://www.un.org/sustainabledevelopment/sustainabledevelopment-goals/>, consultado el 3 de noviembre de 2017).

#### *4.3. Relevancia de los resultados para las estrategias de planificación urbana*

Las altas tasas de urbanización en América Latina continúan presentando amenazas directas a la preservación de las áreas verdes urbanas [76]. La limitada capacidad administrativa en las ciudades de AL para planificar y controlar el crecimiento urbano viene causando la conversión de las áreas verdes urbanas en viviendas e infraestructura. Además, la creación de nuevos espacios verdes urbanos se está volviendo cada vez más problemática debido a los altos niveles de consolidación de tierras urbanas [77] y la superposición de la demanda de tierras para fines múltiples (por ejem., espacio verde urbano vs. infraestructura) [78].

Por otro lado, la planificación del espacio verde no solo está guiada por las teorías urbanas, sino también por los valores que las personas asignan a los espacios verdes [79]. Nuestros resultados demuestran que las personas que viven en las megaciudades de AL valoran significativamente el área verde, expresando sus preferencias a través del mercado inmobiliario. Sin embargo, como el estudio de caso muestra, hay un amplio margen para realizar nuevas investigaciones que nos permitan comprender mejor cómo y por qué los atributos ecológicos de los espacios verdes urbanos pueden ayudar a asegurar, mantener o incluso mejorar una gama de diferentes servicios ecosistémicos [80]. Ser capaz de hacer más con menos, en términos de la provisión de servicios ecosistémicos por el área verde urbana, es especialmente importante para los residentes urbanos más pobres en las ciudades de AL, los cuales generalmente viven en las periferias metropolitanas con déficits críticos del espacio verde urbano.

## VI. ABREVIATURAS

	%	percentage
°C		centigrade scale / Celsius scale
<b>AMSL</b>		above mean sea level
<b>ANN</b>		average nearest neighbor
<b>AV/AT</b>		green space/total area
<b>BUSDEN</b>		Business Density
<b>CRIMDEN</b>		Crime Rate
<b>DF</b>		degrees of freedom
	<b>F</b>	F, F-test
<b>INHABITANTS/KM<sup>2</sup></b>		inhabitants per square kilometers
	<b>KM<sup>2</sup></b>	square kilometers
	<b>LA</b>	Latin America
	<b>LPS</b>	Largest patch size
<b>M<sup>2</sup>/INHABIT</b>		square meters per inhabitant
	<b>MM</b>	millimeter
	<b>MPS</b>	Mean patch size
	<b>MS</b>	mean squares
	<b>POPDEN</b>	Population Density
	<b>PR</b>	probability
<b>R<sup>2</sup></b>		Coefficient of determination
	<b>SS</b>	sum of squares
	<b>TGS</b>	Total green space
	<b>TNP</b>	Total number of patches

**VII. ANEXOS**



**ANEXO 1: CERTIFICADO DE PUBLICACION POR REVISTA FORESTS**



**CERTIFICATE of PUBLICATION**

Certificate of publication for the article titled:

On the Use of Hedonic Price Indices to Understand Ecosystem Service Provision from Urban Green Space in Five Latin American Megacities

Authored by:

Ursula Loret de Mola; Brenton Ladd; Sandra Duarte; Nils Borcard; Ruy Anaya La Rosa; Brian Zutta

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## ANEXO 2: CORREO ELECTRONICO – NOTIFICACION DE ACEPTACION DE PUBLICACION

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