Size matters: vegetation patch size and surface temperature relationship in foothills cities of northwestern Argentina

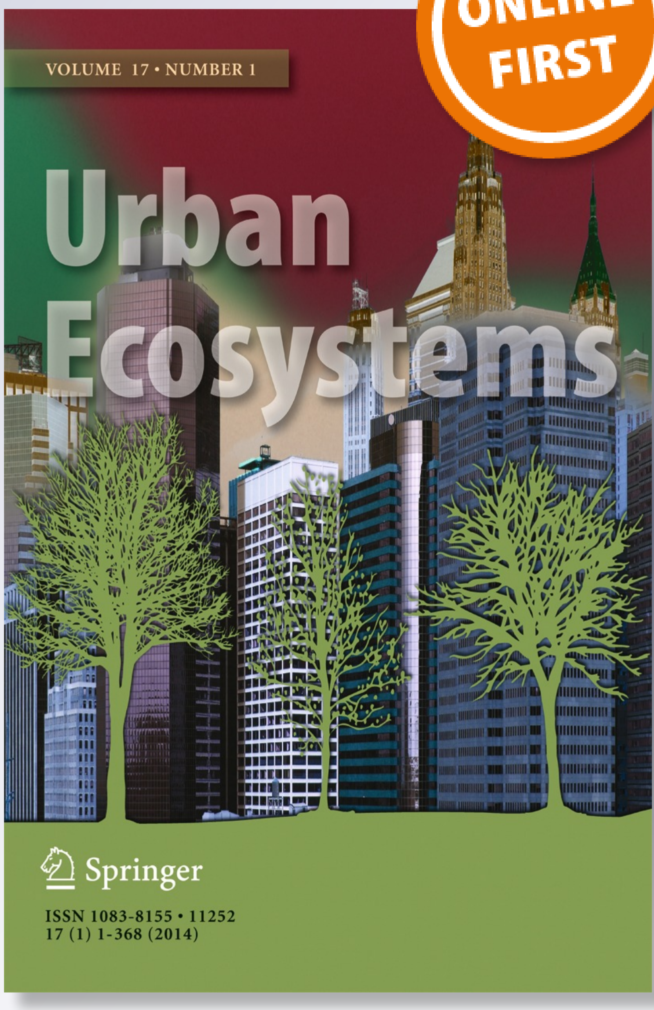
Antonela Gioia, Leonardo Paolini, Agustina Malizia, Rosa Oltra-Carrió & Jose Antonio Sobrino

Urban Ecosystems

ISSN 1083-8155

Urban Ecosyst
DOI 10.1007/s11252-014-0372-1

ONLINE FIRST



Springer

Urban Ecosyst
DOI 10.1007/s11252-014-0372-1

Size matters: vegetation patch size and surface temperature relationship in foothills cities of northwestern Argentina

Antonela Gioia · Leonardo Paolini · Agustina Malizia · Rosa Oltra-Carrió · Jose Antonio Sobrino

Abstract Urbanization is one of the most extreme forms of land alteration. Energy fluxes are severely affected and cities tend to have the Urban Heat Island (UHI) phenomenon, although vegetated areas inside cities could have a positive effect in mitigating UHI effect. Our main objective was to analyze the relationship between vegetation characteristics, patch size and land surface temperature (LST) in three urban areas of northwestern Argentina. We selected 38 green spaces of different size distributed in four cities, all located in the eastern foothills of the subtropical mountain forests. We used Landsat TM satellite images to calculate Normalized Difference Vegetation Index (NDVI) and LST. We assessed the net effect of patch size on LST by computing a Difference Temperature Index. At the regional scale, our results showed that vegetation patch size had a direct effect on reducing the LST of the green space. At a local scale, the analysis of the relationship between vegetation on urban green spaces and LST along a gradient of urbanization showed that green spaces with more vegetation tends to reduce LST. The results showed that largest green spaces were between 1.5 and 2.8 °C cooler than the surrounding built. In order to mitigate the UHI effect in cities, larger green spaces appear to be a possible solution.

Keywords Urban ecology · Urban Heat Island · Green spaces · Normalized difference vegetation index

A. Gioia (✉) · L. Paolini · A. Malizia
Instituto de Ecología Regional (IER), Universidad Nacional de Tucumán (UNT), C.C. 34, CP 4107 Yerba Buena, Tucumán, Argentina
e-mail: antonela.gioia@gmail.com

L. Paolini
e-mail: leopaolini@gmail.com

A. Malizia
e-mail: agustinamalizia@yahoo.com

R. Oltra-Carrió · J. A. Sobrino
Unidad de Cambio Global, Laboratorio de Procesado de Imágenes, Universitat de València, C/Catedràtic Agustín Escardino n°9, 46980 Paterna, Valencia, Spain

R. Oltra-Carrió
e-mail: rosa.oltra@uv.es

J. A. Sobrino
e-mail: sobrino@uv.es

Published online: 11 May 2014

Introduction

Human population is experiencing a shift to urban living (Grimm et al. 2008). Since 2008, more than 50 % of world population (3.2 billion people) lives in urban areas and according to Mills (2007), by 2030 about five billion people will be living in cities. As a result of urbanization, large parcels of land are devegetated and paved (Marzluff and Ewing 2001).

Vegetation replacement by impervious surfaces, change energy fluxes and contributes to the increase of surface temperatures causing a phenomenon known as Urban Heat Island (UHI) (Oke 1997). This phenomenon describes the difference between urban and rural temperatures (Pickett et al. 2001), where cities have higher air temperature than their rural surroundings. Since air temperature is linked to surface temperature (through heat fluxes from the surface to the atmosphere), changes in land cover patterns alters surface temperature and can contribute to enhance or mitigate the UHI formation. Although the relationship between air and surface temperature is complex, the differences between both temperatures decreases with higher proportion of vegetation cover (Niclòs et al. 2010). Several characteristics of urban environments alter energy-budget parameters and may affect the formation of the UHI (Grimm et al. 2008); for example, large-scale use of impervious materials causes precipitation to run off rapidly, which reduces evaporation resulting in more energy available for long-wave emissions (Kuttler 2008), locally altering the sensible heat (energy that is transferred from the land surface to the air) and latent heat flux (energy absorbed during the conversion of water from one state to another, i.e. evapotranspiration) (West et al. 2011).

The UHI characteristics and its relationship with green spaces inside urban areas has been well explored worldwide (Wong and Yu 2005). The extent and quality of urban green spaces has been shown to have influences on climate regulation within cities (Davies et al. 2008). Wong and Yu (2005) studied the cooling effect of green areas of cities in Singapore and found that larger green areas presented lower temperatures (i.e. 4.01 °C less) compared with other land uses such as industrial or business district areas. Similarly, Sukopp (2008) showed that larger green spaces such as parks or zoos can be about 4 °C colder at night than the surrounding areas in Berlin. Potchter et al. (2006) found that an urban park with high and wide-canopied trees had the maximum cooling effect during daytime. Cohen and Potchter (2010) confirmed the positive impact of vegetated open spaces on the micro-climate during the summer, since the cooling effect of a park was higher in this season and could reduce temperature by up to 3.7 °C during daytime in the mediterranean city of Tel Aviv.

On the other hand, vegetation patches whitin the urban landscape, such as urban forests, parks, squares, gardens and other green areas, are an important ecological component in densely urbanized cities (Aminzadeh and Khansefid 2010). At a local scale, urban trees shade the ground and reduce the incidence of solar radiation on paved areas, diminish surface temperature and cooling the air by evapotranspiration (Akbari et al. 2001). Amiri et al. (2009) examined the spatial and temporal dynamics of land surface temperature in relation to vegetation cover, finding that variations in the structure of green spaces could result in slightly different surface thermal conditions.

In northwestern Argentina urbanization mainly occurs in the foothills of subtropical mountain forests (Grau 2010), a biogeographic area which belongs to the southern end of the neotropical montane forests known as *Yungas* (Cabrera and Willink 1980). In recent years there has been a significant increase in the urbanized area of the piedmont (Grau et al. 2008), due to natural population growth and internal migration to cities (Gutierrez Angonese 2010). Despite the accelerated urbanization growth in this region, its effect on urban vegetation and climate change at local scale remains unknown. Generally, these topics are well documented in the United States and some European countries.

The main objective of this study was to assess the relationship between size and land surface temperature (LST) of green spaces in cities of northwestern Argentina. Firstly, at a regional scale, we explored the relationship between vegetation patch size and biophysical variables (such as LST, vegetation index and vegetation cover) in three metropolitan areas of northwestern Argentina. We hypothesized that the vegetation patch size and the quantity of vegetation could modify LST, helping to reduce urban structures heating. Secondly, at a local scale, we assessed the relationship between vegetation structure in urban green spaces and LST along an urban gradient in Gran San Miguel de Tucuman (hereafter referred as GSMT). We hypothesized that green spaces with more vegetation structure (such as bigger crown covers and higher basal area values) would have the lowest LST values.

The combination of regional and local approaches allows for a more comprehensive view of the problem by analyzing the phenomenon at complementary scales. Regional scale (inter cities) gives information about the broad pattern of this relationship and local scale (intra city) represents the scale at which this phenomena is more relevant for urban habitants.

Materials and methods

Study area

We analyzed urban green spaces of different size distributed across three metropolitan areas of northwestern Argentina, located in the eastern foothills of the subtropical mountain forests: GSMT is an urban agglomeration which belongs to Tucuman province; Salta, capital of Salta province; and San Salvador de Jujuy (Jujuy), capital of Jujuy province (Fig. 1). The climate is a subtropical monsoonal (hot-wet summers and cool-dry winters) with an annual mean temperature of 18 °C and more than 1,000 mm of annual precipitation, mainly concentrated in summer (December-March). The natural vegetation correspond to the Yungas phytogeographic province, where periphery area to cities and the lower forest were totally replaced, first for agriculture and then (in part) for urban area. The upper forests located in the mountainous area are, in general, well conservated, where the dominant tree species are Laurel (*Cinnamomum porphyrium*), Tipa (*Tipuanu tipu*), Pacará (*Enterolobium contortisiliquum*), Cebil (*Anadenanthera colubrina*), Lapacho (*Tabebuia impetiginosa*) and Jacaranda (*Jacaranda mimosifolia*) (Pérez Miranda 2003). Some of this tree species represent an important part of the tree cover of the cities (i.e. Lapacho and Jacaranda). GSMT, Salta and Jujuy are the main urban areas of NW Argentina housing more than 1.5 million inhabitants. The three cities also share similar location, climate and growth dynamics, which favors inter-comparisons. GSMT is the largest urban center in NW Argentina (Gutierrez Angonese 2010). It is located in the eastern foothills of the Sierra de San Javier (SSJ) and includes San Miguel de Tucuman city (SMT) and Yerba Buena city (YB). At a local scale, we worked on an east–west gradient of urbanization between SMT and YB.

Data collection and methodology

In order to explore the relationship between vegetation patch size and biophysical variables in three metropolitan areas of NW Argentina (regional scale, first objective),

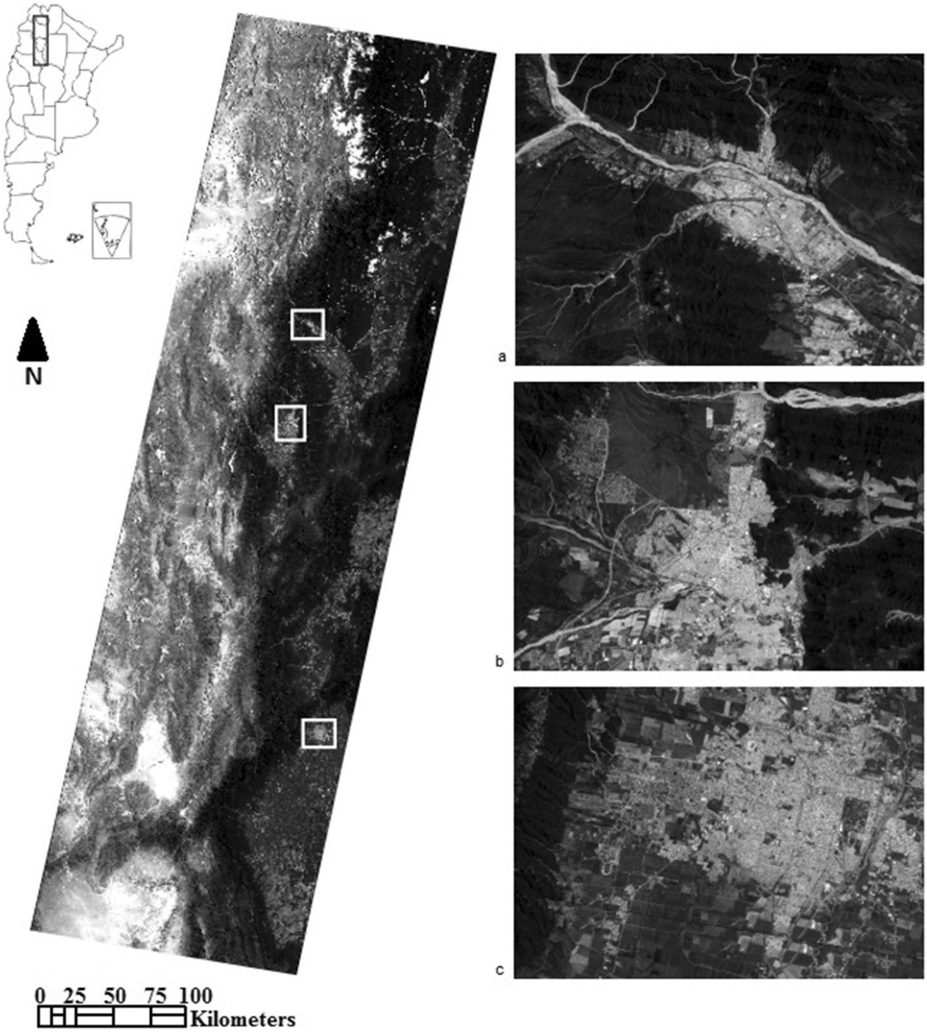


Fig. 1 Landsat TM satellite images of the study area: three metropolitan areas of northwestern Argentina, located in the eastern foothills of mountain ranges, San Salvador de Jujuy (**a**), Salta (**b**), Gran San Miguel de Tucuman (**c**)

we selected 38 green spaces of different sizes: 22 in GSMT, eight in Salta and eight in Jujuy. We calculated the area and four biophysical variables in each green space: percentage of area occupied by grass (from now on called "percentage of grass"), percentage of area occupied by tree cover (from now on called "percentage of tree cover"), Normalized Difference Vegetation Index (NDVI) of green space and Difference Temperature Index (Appendix 1).

Total area, percentage of grass and percentage of tree cover for each green space were obtained through manual digitalization over Google Earth images. Polygons containing green spaces parameters were matched to Landsat 5 TM images in order to compute NDVI (Fig. 2a) and LST (Fig. 2b).

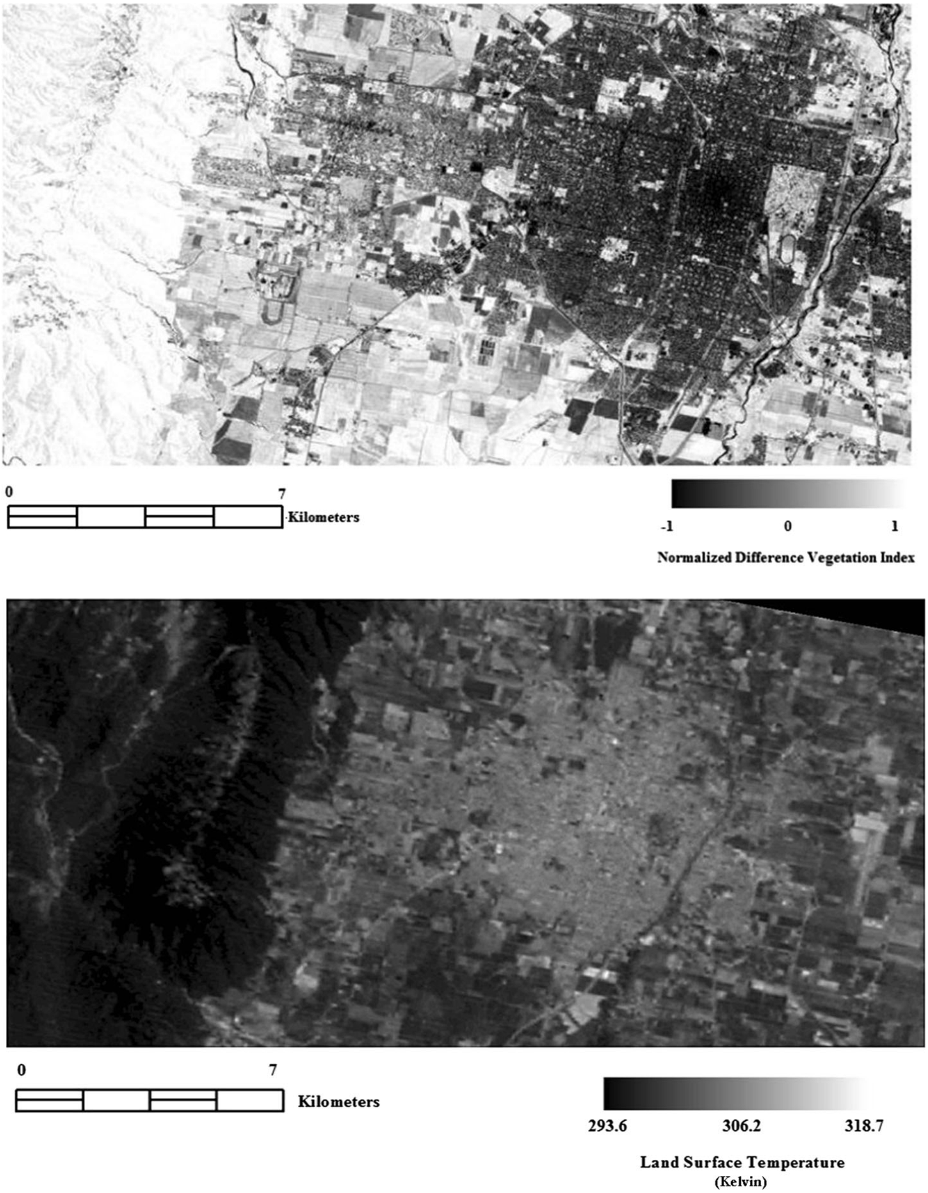


Fig. 2 Images of January 16th, 2010 of Gran San Miguel de Tucuman (this area was selected for explanatory way) obtained from Landsat TM, **a** Normalized Difference Vegetation Index (NDVI) and **b** Land Surface Temperature (LST) in Kelvin. In **a** light tones represent surface with photosynthetically active green vegetation, while dark colors mean higher building density, impervious surface or bare soil. In **b** dark places represent lower temperatures and, in contrast, clearest places are surfaces with higher temperatures

NDVI is a commonly used vegetation index based on the reflectance properties of leaves in red (R) and near-IR (NIR) wavelengths. Green plant leaves (photosynthetically active) typically have low reflectance in the visible regions of the electromagnetic spectrum, due to strong absorption by leaf mesophyll. Meanwhile, in the near infrared region, leaves exhibit high reflectance due to extensive scattering effects in these wavelengths (Tucker and Sellers 1986). NDVI is defined by the following Eq. 1:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}} \tag{1}$$

Its value ranges from −1 to 1 and, in general, provides high values for photosynthetically active green vegetation.

We used land surface temperature (LST) values mainly because LST has a direct relationship with the spatial pattern of land cover surface, and spatially explicit records exist over all the study area (i.e., every pixel has a LST record). Besides, urban surfaces (especially, paved ones) heat more rapidly than the air and therefore the greatest LST are observed during midday versus night-time for air temperature (Imhoff et al. 2009). We derived a LST map of the study area from Landsat TM images of January 16th, 2010. The criteria for choosing this date was because of its availability and because it represents summer time as all tree species have leaves during summer, plus the image shows the highest values of tree shades allowing us to evaluate the maximum possible effect of the vegetation cover on LST.

The methodology used to calculate the LST is that proposed by Jiménez-Muñoz et al. (2009). The single-channel algorithm is described in Eq. 2:

$$LST = \gamma \left[\frac{1}{\varepsilon} \left(\psi_1 L_{sen} + \psi_2 \right) + \psi_3 \right] + \delta \tag{2}$$

Where ε is the emissivity of the surface, calculated by the simplified method of NDVI (Sobrino et al. 2008); L_{sen} is the radiance measured by the sensor, γ and δ are parameters that depend on temperature level sensor, L_{sen} and the wavelength of the channel; Equation ψ_1, Equation ψ_2 and Equation ψ_3 are called atmospheric functions and have been taken as:

$$\psi_1 = \frac{1}{\tau} \quad \psi_2 = -L^{\downarrow} - \frac{L^{\uparrow}}{\tau} \quad \psi_3 = L^{\downarrow} \tag{3}$$

Where τ is the transmissivity of the atmosphere, $L^{\downarrow}$ downward radiance and $L^{\uparrow}$ upward radiance. These three parameters were derived from MODIS products Land Surface Temperature & Emissivity 8-Day L3 Global 1 km (MOD11A2).

In order to assess the relative differences between green spaces LST and its surrounding area in all the urban areas analyzed, we compute a Difference Temperature Index, as described in Eq. 4:

$$\text{Difference Temperature Index} = \frac{\mathrm{LST_{SU}} - \mathrm{LST_{GE}}}{\mathrm{LST_{SU}} + \mathrm{LST_{GE}}} \tag{4}$$

Where LST_{SU} is land surface temperature of the surroundings (360 m buffer) and LST_{GE} is land surface temperature of the green space. Its value ranges from −1 to 1 and becomes extreme when the differences in LST between the green space and its surroundings are maximum. Since our study sites can present variations in the range of values of LST, the normalization process included in the index resolves the problem of comparisons of the differences between each green space and it sourrundings, despite the absolute temperature values from which the index was computed.

Due to the spatial effect that the green space temperature can have over the adjacent pixels, prior to compute the Difference Temperature Index, we conducted a scaling analysis by establishing 120, 240 and 360 m buffers around each green space (1, 2 and 3 entire pixel of distance), regardless of its size. We performed correlations between LST of green spaces and LST of each buffer to evaluate if there is a scale effect of the green space on its surroundings. In addition, we used as a descriptive measure NDVI of each buffer and we performed correlations between NDVI and LST of each buffer. Based in this complementary analysis, we decide to use the 360 m buffer to compute the temperature index, to minimize the effect of green space temperature on the surroundings.

To explore the relationship between vegetation structure of urban green spaces and LST at a local scale (second objective), we studied 22 green spaces along a gradient of urbanization in GSMT. We previously identified three different zones based on the degree of urbanization: SMT center with the highest density of buildings and paved areas; a transition zone between SMT center and YB city characterized by low-height buildings and open areas, and YB city with a less densified profile development, being the city less densely populated and hence with the lowest built surface per unit area.

Field sampling of vegetation structure was conducted between March 2009 and November 2010, in 22 green spaces in GSMT, all < 2.5 ha. For all trees with ≥ 10 cm diameter at breast height (DBH) we measured DBH and tree crown radius, and calculated the following structural parameters: 1) tree cover estimated from crown diameter as [Cover=$\pi.r^2$], 2) basal area [BA=$\pi.(d^2/4)$] estimated from DBH, and 3) tree density, as total number of individuals per area (Appendix 2). In green spaces > 2.5 ha we chose a random area of 1-ha where we measured all trees ≥ 10 cm diameter at DBH as mentioned above.

Data analysis

For the first objective, we performed a multiple linear regression between the Difference Temperature Index (dependent variable) and the independent variables selected (green space area, NDVI and percentage of tree cover) for green spaces in NW Argentina. We chose these independent variables (i.e. not considering percentage of grass) as they did not correlate with each other (Table 1a).

Table 1 Correlation coefficients between the independent variables at: **a.** regional scale and **b.** local scale

a.

	Percentage of tree cover	Percentage of grass	NDVI
Area of green space (ha)	0.0504	−0.2447	0.2638
Percentage of tree cover		**−0.7673***	0.0060
Percentage of grass			0.2776

*p<0.001

b.

	Percentage of grass	BA [m2/ha]	Tree Cover [m2/ha]	Density [ind/ha]
Percentage of tree cover	0.2546	0.1688	0.3766	0.2083
Percentage of grass		−0.4105	−0.3529	−0.1823
BA [m2/ha]			**0.6725****	0.3258
Tree Cover [m2/ha]				**0.4816***

*p<0.05 **p<0.001

For the second objective, we performed a multiple linear regression between the LST of green space (dependent variable) and four independent variables selected: percentage of grass and percentage of tree cover (both biophysical variables calculated from satellite images), basal area and tree density (both field measured variables representing green spaces structure) to evaluate the relative contribution of each independent variable in predicting the dependent LST along 22 green spaces of GSMT (Table 1b).

For both objectives, all assumptions of multiple regression were checked, including spatial autocorrelation (through Durbin-Watson test) and nonlinear variables were log-transformed. We ran forward stepwise multiple regressions to quantify the relative contribution of each independent variable in predicting the dependent variable.

Results

The results of correlations between LST of green spaces and LST of each buffer showed a decrease in the relationship as we increase the distance from the center of the green space (Table 2a). The high correlation between greenspace surface temperature and the surface temperature of the surrounding area suggests a broader cooling effect, so we decided to work with the 360 m buffer data to minimize this effect. Additionally, the results of correlations showed that the negative relationship between NDVI and LST of each buffer became stronger as we increase the distance from the center of the green space (Table 2b). This analysis reinforces the idea that there is an effect of green space on the immediate surroundings that decreases as we move away.

At a regional scale, the results of the multiple regression showed that green space area and percentage of tree cover was related to the Difference Temperature Index (adjusted R^2=0.34, F=10.59, p<0.0002), where partial correlation coefficients were positive for (Log) green space area (r=0.53, p=0.0007) and for percentage of tree cover (r=0.41, p=0.01) (Fig. 3). These results help to explain the relative importance of each variable in decreasing green space temperature (compared to the surrounding area). Vegetation patch size account for the majority of the variation in Difference Temperature Index.

At a local scale, the results of the multiple regression showed that two green space vegetation variables were related with green space LST (adjusted R^2=0.39, F=5.44, p=0.007): (Log) percentage of grass (r=−0.62, p=0.003) and basal area (r=−0.52, p=0.02).

Table 2 Correlation coefficients between: **a.** Land Surface Temperature (LST) of green space and LST of 120, 240 and 360 m buffers, and **b.** Normalized Difference Vegetation Index (NDVI) and LST of 120, 240 and 360 m buffers

a.			
	LST of 120 m buffer	LST of 240 m buffer	LST of 360 m buffer
LST of green space	0.88**	0.77**	0.72**
b.			
	Buffer of 120 m	Buffer of 240 m	Buffer of s360 m
Correlation coefficients between NDVI and LST	−0.43*	-0.50**	-0.59**

*p<0.05 **p<0.001

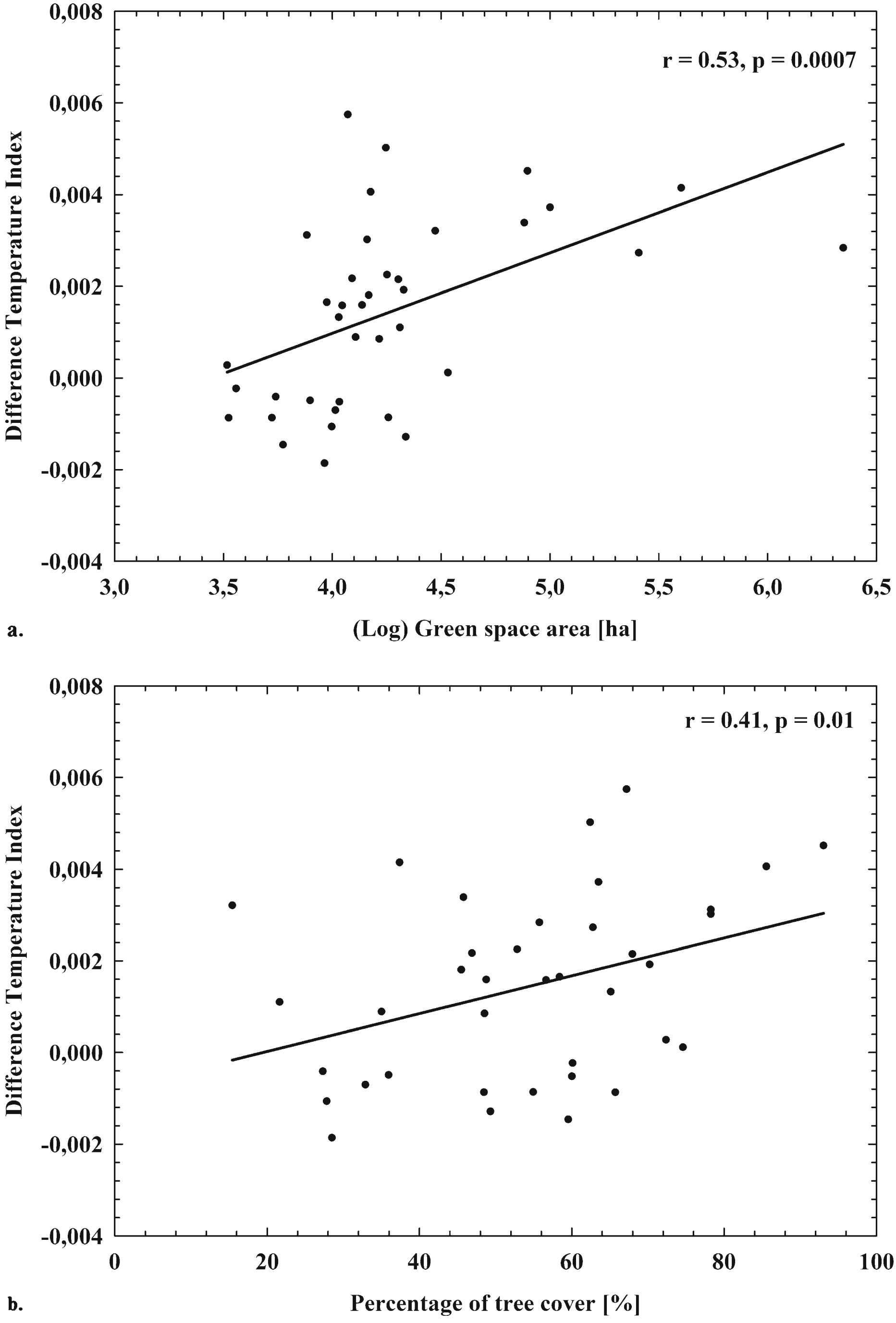


Fig. 3 Scatterplots of multiple regression (regional scale) with partial correlation coefficients of: **a** (Log) Green space area, **b** Percentage of tree cover

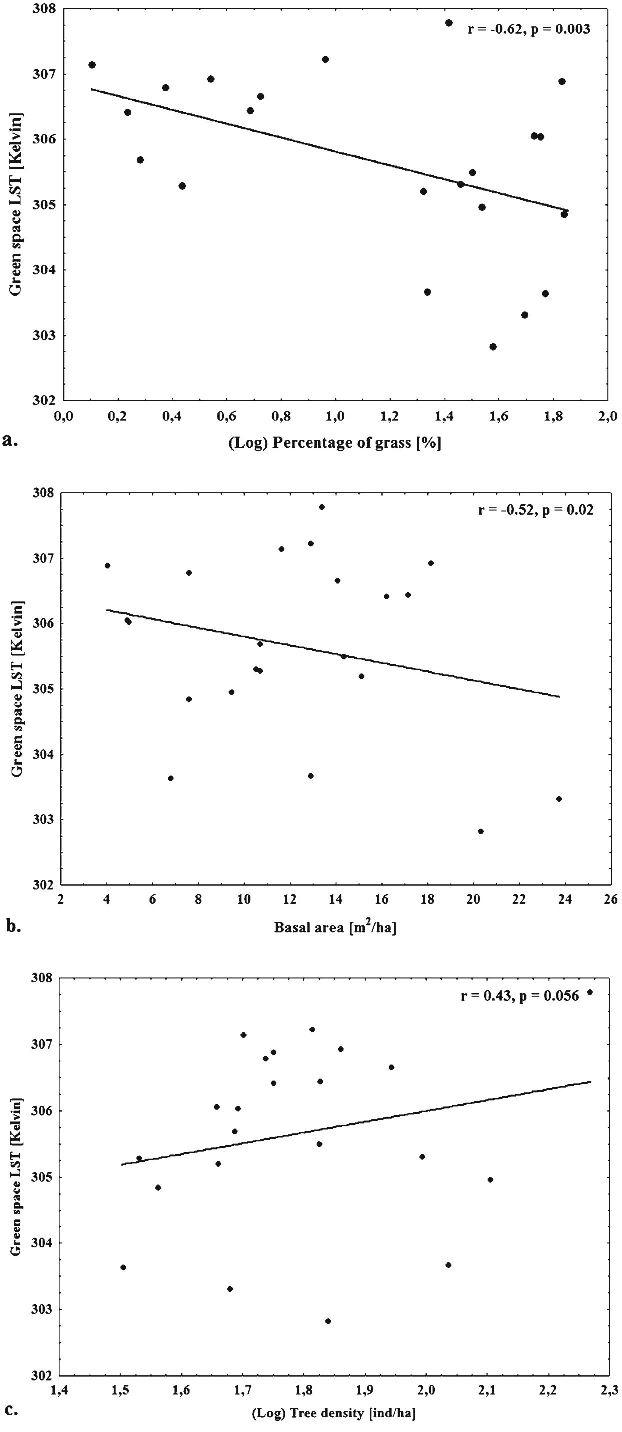


Fig. 4 Scatterplots of multiple regression (local scale) with partial correlation coefficients of: **a** (Log) Percentage of grass, **b** Basal area, **c** (Log) Tree density

Note that (Log) tree density was positively related to LST of green space, although marginally significant (*r*=0.43, *p*=0.056) (Fig. 4). In summary, the higher the percentage of grass and increased basal area, the lower the green spaces LST.

Discussions and conclusion

Our research shows a positive relationship between vegetation patch size and Difference Temperature Index. Therefore, LST difference between green spaces and their surroundings is more pronounced, and the green space are always cooler. In particular, the multiple regression support this results, reveling that a larger area together with higher percentage of tree cover in green spaces are important factors in reducing green space LST. These findings suggest that by increasing urban vegetation (which according to Peretti et al. (2005) reduces insolation, decreases temperature, increases relative humidity and controls wind velocity) the cooling influence on the microclimate could mitigate the UHI effect. This can help to make decisions in urban design and revegetation projects.

At a local scale, along the gradient of urbanization analyzed, although green spaces in less densely urbanized areas (YB city) have more vegetation and more NDVI in relation to built area, the LST difference is lower than in the urbanized zone. This could be due to the high proportion of vegetation cover within and among green spaces, together with the low proportion of built land. In more densely urbanized areas (SMT center) green spaces have lower LST than their surroundings, mainly because of the cooling effect of urban trees, as mentioned above. Furthermore, the impervious surface of the densely built blocks alters heat capacity and radiative properties of the land surface (Streutker 2003) generating higher LST, for which LST difference between green spaces and their surroundings are higher.

Studies in a coastal Mediterranean area showed that the cooling effect of trees is influenced by foliage density, trees height and size and canopy volume (Potchter et al. 2006). Other authors found that plants with higher Leaf Area Index may cause lower ambient temperatures within parks (Wong and Yu 2005). In our study area, we observed that green spaces with more vegetation structure and also higher percentage of grass have an influence on decreasing LST.

Therefore, at different scales, we observed that larger green spaces will be cooler than around, and the proportion of grass as well as the vegetation structure of green spaces are valuable parameters to reduce LST of green spaces.

In conclusion, our results show that vegetation patch size influence LST of the patch itself: the largest green spaces analyzed, such as parks, were between 1.5 and 2.8 °C cooler than the surrounding built areas. These results suggest that, in order to mitigate the UHI effect, it is important to take into account the size of green spaces (e.g. larger than 3 ha) to operate as a cooler area without becoming masked by surrounding buildings. Large green spaces appear to be a possible solution to mitigate the UHI. The methodology applied in this study might be useful to investigate the relationships between green spaces and biophysical variables in other cities that occur in foothills of the subtropics and extrapolate to areas of similar climatic zones.

Acknowledgments This paper was funded by CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas). We would like to thank Ricardo Grau for their valuable comments and constant support, and other members of the IER (Instituto de Ecología Regional) for their helpful comments.

Appendices

Appendix 1

Table 3 Green spaces of the three metropolitan areas of NW Argentina ordered by green space area, with their respective cities, names of green spaces and biophysical variables: Difference Temperature Index, Normalized Difference Vegetation Index (NDVI) of green space, percentage of grass and percentage of tree cover

City	Name of green space	Green space area [ha]	Difference temperature index	NDVI	Percentage of grass	Percentage of tree cover
San Salvador de Jujuy	Solidaridad	0.33	−0.0009	0.058	34.28	65.72
	Y	0.53	−0.0009	0.412	48.22	48.46
	Irigoyen	1.07	0.0013	0.315	16.60	65.13
	Belgrano	1.28	0.0009	0.175	18.09	35.01
	España	2.04	0.0011	0.268	41.90	21.62
	Tusquita Cuyaya	2.17	−0.0013	0.444	47.56	49.31
	Castañeda	2.97	0.0032	0.439	76.48	15.42
	San Martin	10.01	0.0037	0.378	17.30	63.51
Salta	Belgrano	0.59	−0.0015	0.176	20.54	59.54
	Gorriti	0.99	−0.0011	0.280	56.44	27.82
	9 de Julio	1.18	0.0057	0.235	12.95	67.20
	Alvarado	1.50	0.0041	0.406	8.42	85.55
	General Guemes	1.64	0.0009	0.238	24.58	48.53
	Gurruchaga	1.76	0.0050	0.315	21.75	62.42
	20 de Febrero	7.63	0.0034	0.357	33.21	45.77
	San Martin	25.63	0.0027	0.307	20.43	62.77
Gran San Miguel de Tucuman	Las Rosas	0.33	0.0003	0.321	21.16	72.39
	Redonda	0.36	−0.0002	0.363	34.52	60.10
	Apunt	0.55	−0.0004	0.383	69.29	27.30
	Ruben Dario	0.76	0.0031	0.405	21.83	78.27
	Perito Moreno	0.79	−0.0005	0.369	56.78	35.95
	La Paz	0.92	−0.0019	0.323	67.90	28.51
	Eva Peron	0.94	0.0017	0.264	28.91	58.39
	25 de Mayo	1.03	−0.0007	0.182	53.68	32.90
	Irigoyen 1	1.08	−0.0005	0.306	26.09	60.01
	Marcos Paz	1.11	0.0016	0.413	38.12	56.62
	Vieja	1.23	0.0022	0.385	49.67	46.89
	Irigoyen 2	1.37	0.0016	0.242	38.82	48.76
	Alberdi	1.45	0.0030	0.280	8.08	78.27
	Independencia	1.47	0.0018	0.122	3.78	45.48
	Villa Lujan	1.78	0.0023	0.356	22.68	52.83
	Brigadier Heredia	1.81	−0.0009	0.238	42.79	54.94
	Urquiza	2.01	0.0021	0.337	4.86	67.97
	Manuel Belgrano	2.13	0.0019	0.335	1.97	70.23
	San Martin	3.40	0.0001	0.318	9.20	74.60
	Avellaneda	7.89	0.0045	0.379	2.75	93.04
	Guillermina	40.17	0.0041	0.544	59.03	37.39
	9 de Julio	222.78	0.0028	0.416	32.03	55.74

Appendix 2

Table 4 Green spaces of Gran San Miguel de Tucuman with their Land Surface Temperature (LST) values, LST Standard Deviation and three structural variables: tree cover, basal area (BA) and tree density (Density), whose data are estimated from field sampling of 1825 trees

Name of green space	LST [Kelvin]	LST standard deviation	Tree cover [m2/ha]	BA [m2/ha]	Density [ind/ha]
Las Rosas	305.19	0.248	6546.05	15.12	46
Redonda	304.95	0.875	6545.46	9.48	127
Apunt	304.84	0.657	4763.00	7.60	36
Ruben Dario	303.66	0.410	8656.51	12.93	109
Perito Moreno	306.03	0.240	2519.77	4.99	49
La Paz	306.88	0.270	2440.56	4.06	56
Eva Peron	305.30	1.625	4055.68	10.53	99
25 de Mayo	306.05	1.169	2830.57	4.92	46
Irigoyen 1	307.78	0.177	7671.87	13.40	186
Marcos Paz	302.82	0.449	5926.88	20.33	69
Vieja	303.31	0.702	4859.86	23.74	48
Irigoyen 2	307.14	0.512	4686.51	11.65	50
Alberdi	306.92	0.536	6675.08	18.15	73
Independencia	306.65	0.693	4448.05	14.09	88
Villa Lujan	305.68	0.479	4232.97	10.72	49
Brigadier Heredia	306.78	0.684	4064.76	7.61	55
Urquiza	306.43	0.719	6597.11	17.15	67
Manuel Belgrano	306.41	1.107	5247.97	16.24	56
San Martin	307.22	0.502	5045.09	12.93	107
Avellaneda	305.28	1.586	5021.65	10.72	34
Guillermina	303.63	2.161	2618.76	6.80	32
9 de Julio	305.49	1.747	5357.63	14.36	67

References

Akbari H, Pomerantz M, Taha H (2001) Cool surface and shade trees to reduce energy use and improve air quality in urban areas. Sol Energy 70:259–310

Aminzadeh B, Khansefid M (2010) A case study of urban ecological networks and a sustainable city: Tehran's metropolitan area. Urban Ecosyst 13:23–36

Amiri R, Weng Q, Alimohammadi A, Alavipanah SK (2009) Spatial–temporal dynamics of land surface temperature in relation to fractional vegetation cover and land use/cover in the Tabriz urban area, Iran. Remote Sens Environ 113:2606–2617. doi:10.1016/j.rse.2009.07.021

Cabrera AL, Willink A (1980) Biogeografía de América Latina (Biogeography of Latin America). Organization of American States, Washington [in Spanish]

Cohen P, Potchter O (2010) Daily and seasonal air quality characteristics of urban parks in the mediterranean city of Tel Aviv. CLIMAQS Workshop 'Local Air Quality and its Interactions with Vegetation'. Antwerp, Belgium

Davies RG, Barbosa O, Fuller RA, Tratalos J, Burke N, Lewis D, Warren PH, Gaston KJ (2008) City-wide relationships between green spaces, urban land use and topography. Urban Ecosyst 11:269–287. doi:10.1007/s11252-008-0062-y

Grau HR (2010) Ecologia de la interfase natural-urbana. San Javier-Tucumán como modelo de estudio (Ecology of natural-urban interface. San Javier-Tucumán as a study model). In: Grau HR (ed) Ecologia de una interfase natural-urbana. La sierra de San Javier y el Gran San Miguel de Tucumán (Ecology of natural-urban interface The Sierra de San Javier and the Grand San Miguel de Tucuman). Editorial Edunt, Tucumán, pp 11–18, in Spanish

Grau HR, Gutiérrez J, Hernández ME, Jayat P, Gasparri I, Casaveccia C, Flores E (2008) A peri-urban neotropical forest transition and its consequences for environmental services. Ecol Soc 13:35

Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM (2008) Global change and the ecology of cities. Science 319:756–760. doi:10.1126/science.1150195

Gutierrez Angonese J (2010) Dinámica espacio-temporal de crecimiento urbano en el pedemonte oriental de la sierra de San javier (1986–2045) (Spatio-temporal dynamics of urban growth in the foothills east of the Sierra de San Javier (1986–2045)). In: Grau HR (ed) Ecologia de una interfase natural-urbana. La sierra de San Javier y el Gran San Miguel de Tucumán (Ecology of natural-urban interface The Sierra de San Javier and the Grand San Miguel de Tucuman). Editorial Edunt, Tucumán, pp 137–151, in Spanish

Imhoff M, Zhang P, Wolfe RE, Bounoua L (2009) Remote sensing of the urban heat island effect across biomes in the continental USA. Remote Sens Environ 114:504–513

Jiménez-Muñoz JC, Cristóbal J, Sobrino JA, Sòria G, Ninyerola M, Pons X (2009) Revision or the single-channel algorithm for land surface temperature retrieval from Landsat thermal-infrared data. IEE Trans Geosci Remote Sens 47:339–349

Kuttler W (2008) The urban climate—basic and applied aspects. Urban Ecol 3:233–248. doi:10.1007/978-0-387-73412-5_13

Marzluff JM, Ewing K (2001) Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. Restor Ecol 9:280–292

Mills G (2007) Cities as agents of global change. Int J Climatol 27:1849–1857

Niclòs R, Estrela MJ, Valiente JA, Barberà MJ (2010) Análisis de correlaciones entre la temperatura del aire y la temperatura de las superficies vegetadas medida con radiometría térmica (Regression analysis between air temperature and vegetated-surface temperature measured by thermal radiometry). Rev Teledetección 34:36–43 [in Spanish]

Oke TR (1997) Urban climates and global change. In: Perry A, Thompson R (eds) Applied climatology: principles and practices. Routledge, London, pp 273–287

Peretti G, Marino D, Montacchini E (2005) Green areas in open urban spaces. International Conference "Passive and Low Energy Cooling for the Built Environment", Santorini, Greece

Pérez Miranda C (2003) Biodiversidad y recursos silvestres de la provincia de Tucumán (Biodiversity and wildlife resources in Tucumán province). In: Goldstein L, Passio S (eds) Tucumán y los Recursos Naturales: biodiversidad, los recursos Silvestres, los Ambientes Naturales y las Áreas protegidas (Tucumán and Natural Resources: Biodiversity, the Wildlife Resources, Natural Environment and Protected Areas). BIFRONTE, Buenos Aires, pp 81–205 [in Spanish]

Pickett STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat RV, Zipperer WC, Costanza R (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annu Rev Ecol Syst 32:127–157

Potchter O, Cohen P, Bitan A (2006) Climatic behavior of various urban parks during hot and humid summer in the mediterranean city of Tel Aviv, Israel. Int J Climatol 26:1695–1711

Sobrino JA, Jiménez-Muñoz JC, Sòria G, Romaguera M, Guanter L, Moreno J, Plaza A, Martínez P (2008) Land surface emissivity retrieval from different VNIR and TIR sensors. IEEE Trans Geosci Remote Sens 48:316–327

Streutker DR (2003) Satellite-measured growth of the urban heat island of Houston, Texas. Remote Sens Environ 85:282–289

Sukopp H (2008) The city as a subject for ecological research. Urban Ecol 4:281–298

Tucker CJ, Sellers PJ (1986) Satellite remote sensing of primary production. Int J Remote Sens 7:1395–1416

West PC, Narisma GT, Barford CC, Kucharik CJ, Foley JA (2011) An alternative approach for quantifying climate regulation by ecosystems. Front Ecol Environ 9:126–133. doi:10.1890/090015

Wong NH, Yu C (2005) Study of green areas and urban heat island in a tropical city. Habitat Int 29:547–558