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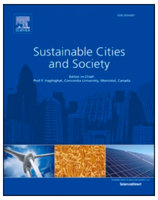

Park cool island and built environment. A ten-year evaluation in Parque Central, Mendoza-Argentina

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ABSTRACT

Urban greening is a strategy for mitigating urban heat island. However, vegetation demands, water and energy, high scarce resources in cities on dry land. Hence, it is necessary to rethink the relationship between green spaces and its surrounding built environment. This worḱs objective is to evaluate the impact of Mendozás Parque Central (Argentina) on the air temperatures of its built environment, taking as a measure the park cool island intensity in the 2007–2017 period. Parque Central has a strategic value for the urban development of a residential area with a low to medium construction density. Methodologically, four monitoring campaigns were carried out during the summer periods of 2007–2008; 2010–2011; 2011–2012 and 2016–2017. In each campaign, temperature and relative humidity sensors were installed in the area. Satellite images from Landsat 7 were analyzed and four spectral indices were determined. The results indicate that during the 2016–2017 summer the forest and meadow structures were cooler than in the 2007–2008 season. Over 10 seasons, the Normalized Difference Vegetation Index has increased more than 8 times, while the maximum park cool island intensities have increased 2.31 times. This non-proportionality can be explained by the densification of the built environment, among other factors.

1. Introduction

Currently, arid environments cover more than 30% of the world's land area, a proportion which will rise with climate change in the next century (ARUP, 2018). Cities in arid environments suffer the effects of urban heat island (UHI), with negative impacts on the environment, people and economies. Heat islands increase the use of water and energy consumption in cities as they rise indoor and outdoor temperatures boosting demand for air conditioning to achieve comfort (Chen, Matsuoka & Liang, 2018; Mohammad, Goswami & Bonafoni, 2019). In addition, they produce an increase in air pollution and have a serious impact on public health and quality of life (Kim and Macdonald, 2015). Thus, cities within arid zones face two main challenges: temperature increase and water scarcity (ARUP, 2018).

Greening is an efficient strategy for the adaptation and mitigation of the UHI and urban warming phenomena (Gómez-Navarro, Pataki, Pardyjak & Bowling, 2021). The application of vegetation in urban areas alters the parameters that make up the microclimate (Yan et al., 2018). Vegetation affects cities fundamentally through three effects: shadow production, evapotranspiration, and the alteration of wind patterns (Oke, Crowther, McNaughton, Monteith & Gardiner, 1989). Green spaces are incorporated in urban areas through various typologies among which urban parks can be considered one of the most important. Urban parks form the so-called Park Cool Island (PCI). It is the difference between park's out-side and inside temperature, which is more down to scale and could explain how park's characteristics may influence the cooling effects (Yang et al., 2017). Various measurements revealed that green areas are generally colder than their surrounding built-up areas (Licón Portillo et al., 2017, Vaz Monteiro et al., 2016). The cooling effect depends largely on the parḱs size and distance, with a temperature difference ranging from 1 °C to 7 °C (Correa, Martinez, Lesino, De Rosa & Cantón, 2006; Krüger & Givoni, 2007; Ruiz, Cantón, Correa & Lesino, 2011).

Motazedian, Coutts, & Tapper, 2020 analyzed the climatic interactions between a relatively small (1.5 ha), inner-city park and its surrounding urban environment in Melbourne, Australia, during the hot Austral summer of 2013–2014. The park's maximum cooling mean reached 1.0 °C during daytime heating peak (3 pm), with a magnitude

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difference between the park and its surroundings varying from 0.5 to 3 °C. However, during the night, park cooling was less variable and dominantly influenced by the characteristics of the site such as Sky View Factor (SVF), vegetation distribution and irrigation.

Some researchers have studied correlations between cooling indicators and physical attributes. Park and Cho (2016) explored the effects of the physical characteristics of green spaces on cooling intensity. LANDSAT 8 images were used to examine 30 green spaces in Ulsan, Korea. They found that the Normalized Difference Vegetation Index (NDVI) —which helps to differentiate vegetation from other types of land cover and determines its overall state— had a positive but non-linear association with cooling intensity. García-Haro, Arellano and Roca (2019) proposed a remote sensing approach to the quantification of cooling effects of the urban parks of Barcelona and the role of their design and location. Particularly, the bivariate correlation attributes pointed to a predominant influence of the characteristics of the interior of the park and not of its surroundings. The mean NDVI values of the parks registered a significant positive correlation with the cooling indicators. Pramanik and Punia (2019) evaluated the cooling effects of different types of urban greenery at local and park level in Delhi, India. Results show that park cooling is negatively related to the amount of built-up area.

Many times, the incorporation of new parks in a city is a strategy to rehabilitate urban voids. This allows new public space and important facilities to be projected. In recent times, new approaches have emerged in terms of efficient management and dimensional relationships. Urban greening planning has an environmental component, for example Yu, Guo, Jørgensen and Vejre (2017) defined the urban cooling island (UCI) efficiency (in terms of the size of greenspaces) as a curve between each greenspace's area and its maximum land surface temperature difference (ΔLST). The UCI efficiency curve shows that the ΔLST will rise with the increase of greenspace size, achieving stability in each range afterwards.

To summarize, within the framework of cooling effect studies, Yu et al. (2020) supposed that determining the threshold-size of green space is the most important step. Seeking out and quantifying the influencing factors (e.g., latitude and longitude, urban form and building density, zonal and temporal variation, landscape components, and configuration) of green space is a critical and difficult step. This is why; threshold-size-based research has currently received less attention, limiting the ability to make specific recommendations for actionable planning and management – using the smallest park for the best cooling effect.

Urban parks have a complex surface structure determined by the characteristics of their landscape design: type of vegetation used and its distribution within the space, proportion and distribution of pervious and impervious surfaces, existence of water bodies, etc. The interactions among the elements that make up the urban parks generate an environment with specific microclimatic characteristics. According to García-Haro and Arellano (2018) the extension of the PCI is defined by the morphology and density of the urban context of the park, as well as by the vegetation and number of permeable surfaces in the surroundings. In addition, the park design defines the intensity of the PCI and the ability to reduce air temperature by convection.

In this setting, the thermal benefits of urban parks have been extensively evaluated. It is necessary to assess its ecosystem services in terms of regulations of urban temperatures over time and in relation to the densification of their built environment.

Thus, the objective of this work is to evaluate the impact of an urban park in the city of Mendoza, Argentina —Parque Central — on the air temperatures of its built environment in the surrounding area of the park, taking as a measure the intensity of park cool island. In addition, we analyzed the evolution of its cooling effect over time (ten years) in relation to the evolution of the park and the surrounding urban areas characterized by means of spectral indices. In the future, it is intended to contribute to understanding the relationship between the efficiency of green infrastructure and urban planning as a strategy for mitigation and adaptation to climate change. Besides, it is expected to detect design parameters and building density threshold of the surroundings that guarantee the beneficial effects of urban parks as microclimate regulators over time.

2. Materials and methods

2.1. Study area

Mendoza city is located in Central Western Argentina. It has an arid continental climate with low relative humidity and high heliophany: BW, according to the Köppen-Geiger classification (Kottek, Grieser, Beck, Rudolf & Rubel, 2006). The local climate is characterized by cold winters (average July temperature: 7.3 °C) and hot summers (January average temperature: 24.9 °C), with important daily and seasonal temperatures amplitude; and the average annual rainfall is 220 mm. The urban conglomerate presents critical environmental problems associated with the increase in urban temperature and intensity of UHI of 10 °C (Correa et al., 2006). The urban model is defined as "open type" where the metropolitan area is represented by 87% of sectors with low building density (< 2 m3/m2) (Sosa, Correa & Cantón, 2018).

Mendoza's Parque Central is the fourth green space on the surface of the city (approximately 14 hectares). It is located in the northwest area of the province capital (32° 52′ 37.08″ S and 68° 50′ 28.03″ W), in a residential area with low to medium construction density (2–4 m^3/m^2). It has a strategic value for urban development, given the numerous uses and artistic, sport, social and cultural activities provided (recreation, art exhibition spaces, cinema, theater, conferences, conventions, among other academic and business events). See Fig. 1.

Recently designed (year 2006), the project responds to the recovery of an urban void placed in the old land of the General San Martín Railway Station. It has a rationalist design and takes the railway geometry of the site. It presents a development with strong N-S linear direction. Regarding its vegetation and botanical richness, it has consolidated the pre-existing small woods. Tree groups —with most perennial species- include adult trees of *Schinus molle, Grevillea robusta, Tipuana tipu, Casuarina cunninghamiana, Morus alba* and *Catalpa bignonioides*. Some isolated and adult trees of Eucalyptus camaldulensis are also identified inside the park.

Initially, 1200 tree specimens and 16,000 shrubs were planted. The species incorporated in 2006 did not adapt to the environmental conditions of the growth site. At present (2019), the most tolerant have been consolidated, integrating forested or aligned groups with the development of a dense vegetation cover (canopy) that provides important shading. These forest groups respond to the following species: *Jacaranda mimosifolia, Brachichiton* spp., *Chorisia speciosa, Tipuana tipu, Salix babilonica* and *Albizia julibrisin*. Poplar curtains (*Populus nigra cv. chilensis*) were also incorporated. The initially planted aromatic species sector did not prosper and was colonized by native species. This sector was redesigned with trees and shrubs of arid areas, of the *Prosopis* ssp., *Geofroea decorticans, Cercidium praecox, Larrea* spp., and *Zucagnia punctata* species, among others.

The built surroundings of the park are mainly composed of R5 and R6 residential zones typologies according to the Municipal Building Code. These residential zones are defined as the areas of low-medium density, destined predominantly to the location of the dwelling in order to guarantee and preserve good living conditions, admitting in the case of development axes, uses related to the residential area (Fig. 2).

Residential Zone 5 (R5): isolated building zone in free perimeter towers with low ground occupation, with front and side yards and large landscaped sectors. The number of levels will be the one that corresponds to the range of surfaces of the plot. See in Table 1 the urban parameters.

Residential Zone 6 (R6): continuous building area (basement), or isolated building (free perimeter). The number of levels will be the one that corresponds to the range of surfaces of the plot, the building being

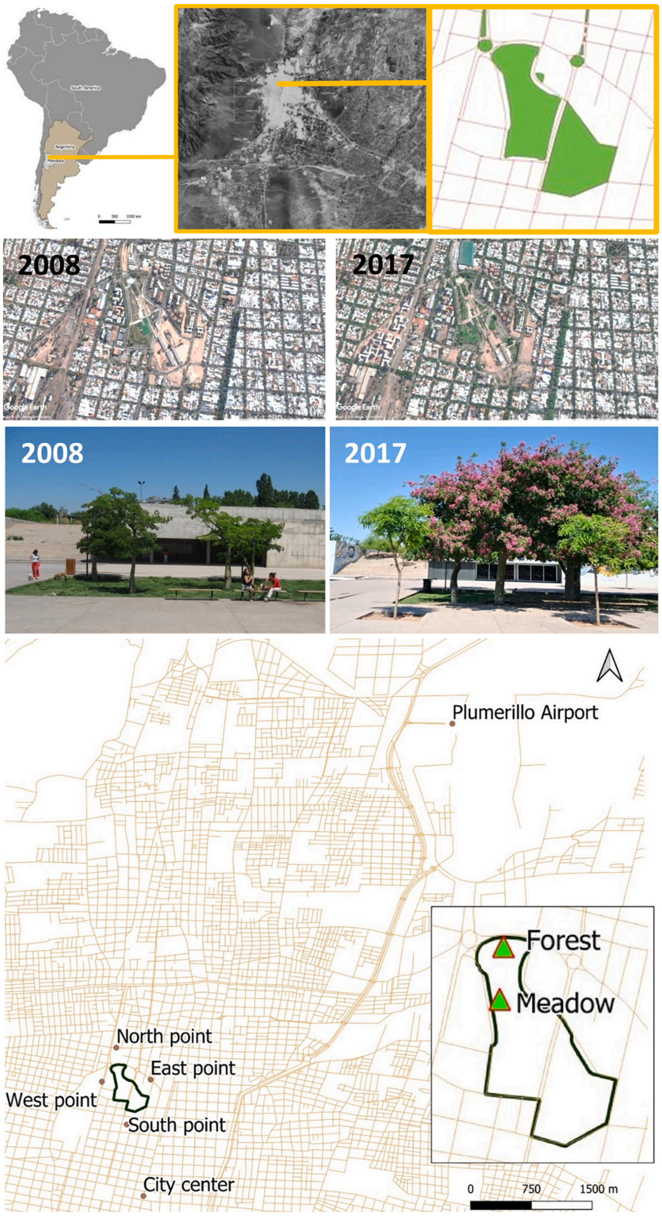


Fig. 1. Location, description, and views of Parque Central, Mendoza, Argentina.

able to have mandatory or voluntary front yard. See in Table 1 the urban parameters.

It is important to consider that the values that appear in Table 1 are the maximum allowed. However, the study city is characterized by not having an orderly growth so there is a diversity of heights.

2.2. Monitoring campaigns

Four monitoring campaigns were developed during the summer periods of 2007–2008; 2010–2011; 2011–2012 and 2016–2017. In each campaign, temperature and relative humidity sensors of type HOBO H8–003–02 and UX100–003 (HOBO®; Onset; Cape Cod, MA) were installed, recording every 15 min. See Table 2. Two of them were located within the park in well differentiated structures: meadow and forest. In addition, four sensors were installed around the park (North, East, South and West) at a distance of between 100 and 250 m from the edge. Finally, a sensor was located in the center of the city. The sensors have been placed at a height of 2.5 m from the street (Oke, 2004), inside perforated white PVC boxes, to avoid irradiation and ensure adequate air circulation.

In the 2007–2008 campaign, data were recorded for 14 days, from 03/12/2008 to 03/27/2008. During the 2010–2011 campaign, 42 days were also registered from 02/12/2011 to 03/25/2011. The 2011–2012 campaign was developed from 12/27/2011 to 01/20/2012 (25 days). Finally, the 2016–2017 campaign took place from 12/21/2016 until 01/02/2017 (13 days).

Based on data from the reference Station of the Meteorological Service located at Mendoza Airport (Plumerillo), the typical days of four summer seasons are selected: 03/20/2008; 03/18/2011; 01/12/2012 and 12/23/2016. These days correspond to clear sky and low frequency and wind speed. The meteorological background condition during this day was characteristic and representative of the measurement period. Table 3 shows the minimum, mean and maximum temperature and relative humidity for each day.

Analysis of variance (ANOVA) and Tukey tests were carried out for data from Airport Station. Air temperature does not show significantly differences among seasons.

2.3. Digital satellite image processing

Landsat 7 satellite images from 10/1/2008 and 1/18/2017 were analyzed in order to study the green areas, together with the evolution of their surroundings, and to evaluate their impact over the microclimate. The selected images have a cloud cover of less than 20% for the entire scene and the area of interest is uncovered. Four satellite indices were determined: Normalized Difference Vegetation Index (NVDI); Soil Adjusted Vegetation Index (SAVI); Normalized Difference Water Index (NDWI); and Normalized Difference Built-up Index (NDBI). The QGIS software was used to process satellite images, which circulate freely on the web. The images were projected onto POSGAR 2007–Argentina 2. Calibration and atmospheric correction of all bands was done automatically using the DOS1 method.

The indices were calculated using the formulas indicated in Table 4. Then, for a better visualization, a color scale was applied.

The Normalized Differenced Vegetation Index (NDVI) is the most commonly used index of vegetation (Mallick, 2021). The NDVI determines the vegetation quantity and quality. Their values range from −1 to 1, corresponding values close to −1, dry or diseased vegetation and, and those close to 1, healthy vegetation. The vegetation cover is considered a key indicator of land status. The NDVI is calculated based on the remotely sensed reflection over their sum of visible (red) and near-infrared vegetation surfaces and provides information on photosynthetically active vegetation's density, condition and health (Hellden & Tottrup, 2008). A divergence from the standard indicates either land degradation or improvement, accounting for climate, land use, terrain, soils, and NDVI has increasingly been used to evaluate a variety of ecosystem services (Mallick, 2021).

The Soil Adjusted Vegetation Index (SAVI) is used to correct NDVI for the influence of soil brightness in areas where vegetative cover is low. It shows vegetation values adjusted by the soil and allows a better determination of low vegetation in urbanized areas with values ranging from 0 to 1, with low SAVI values indicating less vegetation. Vani and Mandla (2017) show that in the semiarid area where soil background is more exposed, the SAVI vegetation index is more suitable over the popular NDVI especially in medium spatial resolution.

The Normalized Difference Water Index (NDWI) is the most appropriate index for water body mapping and soils of high humidity saturation. Water bodies have strong absorbability and low radiation in the range from visible to infrared wavelengths. The index uses the green and near infrared (NIR) bands of the remote sensing images based on this phenomenon. The NDWI can enhance the water information effectively in most of the cases. It is sensitive to built-up land and often results in over-estimated water bodies (Taloor, Manhas & Kothyari, 2020. The NDWI can be used as a unit of measurement to determine water stress in

R5 residential zone

R6 residential zone

Fig. 2. Urban zoning. Source: Google, 2019.

vegetation and soil moisture saturation or to perform direct delimitations of water bodies. The range of NDWI values is between −1 and 1. The values near 1 describe water and vegetation surfaces with water content, and the values near −1 indicate land areas without moisture.

Finally, the Normalized Difference Built-up Index (NDBI) is useful to map urban built-up areas (Zha, Gao & Ni, 2003). It allows the estimation of areas with built or developing surfaces with respect to areas with vegetation or without it. It normalizes the effects of lighting differences between urban areas, as well as atmospheric effects. NDBI represents the concentration of the urban built-up area. NDBI is important as an analytical tool for characterizing land development, urbanization, and land surface parameters (Chen, Yao, Sun & Chen, 2014). The values are between −1 and 1, where the negative pixels represent areas with vegetation, intermediate values correspond to bare areas, growing crops or areas under construction, and high positive values indicate built-up land cover or infrastructure. The value of NDBI is a one is the highest of buildings, and the −1 represents no content of built up (Kemarau & Eboy, 2020). For each surrounding monitoring point on land (north, south, east and west) a buffer was elaborated with their influence area

Table 1
Urban parameters of residential zones R5 and R6 accord to terrain surface. Source: www.ciudaddemendoza.gob.ar.

Zone	*Surface* (m^2)	*Soil Occupation Factor*		*Total Occupation Factor*		*MaximumHeight (m)*
		min	max	min	max	
R5	> 1251	0.00	0.40	0.00	3.60	48
	501 - 1250	0.00	0.45	0.00	2.40	33
	< 500	0.00	0.60	0.00	1.80	26
R6	> 1001	0.35	0.50	1.00	2.50	30
	401 - 1000	0.40	0.55	1.10	2.40	26
	<400	0.45	0.65	1.30	2.30	22

Table 2
Specifications of used sensors. Source: https://www.onsetcomp.com/.

	HOBO H8–003–02		UX100–003	
	Temperature	**Relative humidity**	**Temperature**	**Relative humidity**
Operating range	−20 °C to +70 °C	25% to 95%	−20° to 70 °C	15% to 95%
Accuracy	1.2 °C at 20 °C	±5%	±0.21 °C from 0° to 50 °C	±3.5% from 25% to 85% at 25 °C
Resolution	0.8 °C at 20 °C	not provided by manufacturer	0.024 °C at 25 °C	0.07% at 25 °C and 30% RH

Table 4
Index calculation formulas.

Index L7	**Reference**
NDVI: B4-B3 / B4+B3	Rouse, Haas, Schell, Deering & Harlan, 1974
SAVI: (B4-B3)(1sl)/ B4+B3+l	Heute, 1988
NDWI: B2-B5 / B2+B5	McFeeters, 1996
NDBI: (B5-B4)/(B5+B4)	Zha et al., 2003

Table 3
Characterization of the measurement days during each monitoring campaign.

	2007–2008		**2010–2011**		**2011–2012**		**2016–2017**	
	Temp. °C	**RH%**	**Temp. °C**	**RH%**	**Temp. °C**	**RH%**	**Temp. °C**	**RH%**
MINIMUM	16.9	42.7	16.9	40.6	22.0	26.8	18.9	19.9
MEAN	22.1	64.7	22.0	61.3	28.4	43.1	26.0	36.7
MAXIMUM	27.3	87.1	27.8	84.0	34.5	64.8	32.7	59.5
STANDARD DEVIATION	1.3	7.8	3.3	8.0	2.5	10.5	3.9	9.5

(100 m radius). These buffers were used as masks for clipping the NDBI raster layer for 2008 and 2017. Once the influence areas of the sensors were individualized, the basic statistics were performed for each one. This procedure was performed with the "Raster Layer Statistics'' tool available in QGIS software.

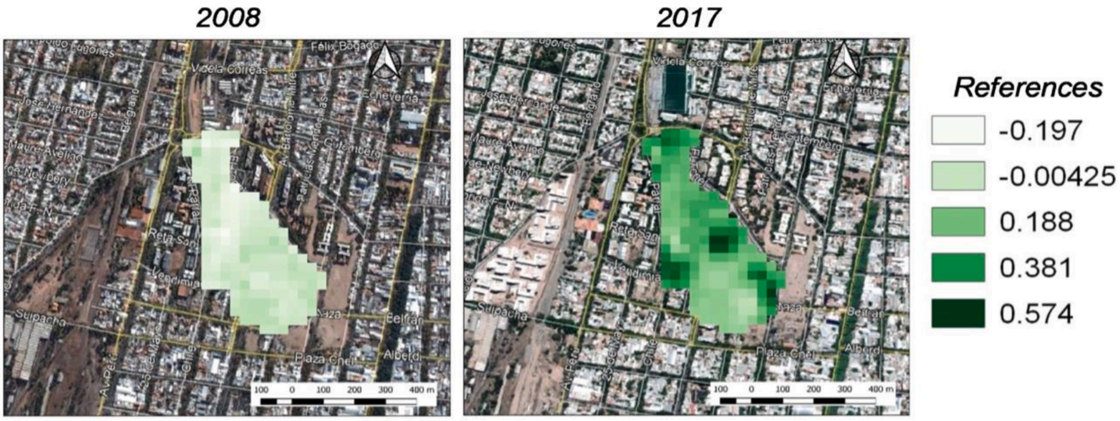
2.4. Definition of indicators

In addition to the spectral indices, different indicators have been taken for the analysis of the results. First, hourly averages of air temperatures are calculated for each measurement point.

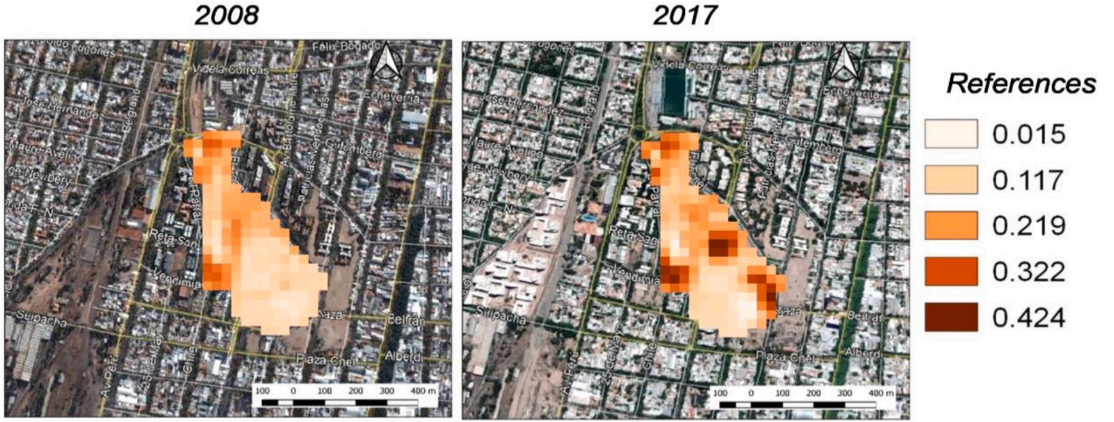
Then, the differences in air temperature between the surroundings and each of the park structures (meadow and forest) are calculated. The objective of this calculation is the comparison between both structures at the time of maximum temperature occurrence in the city in correlation with the highest thermal discomfort (Correa, Ruiz, Cantón & Lesino, 2012), and at the time of minimum temperature occurrence in the city (which is when greater intensity of UHI is observed).

Thirdly, the variation proportion 2016–2017 with respect to 2007–2008 for three magnitudes in each cardinal point was calculated: maximum NDBI; maximum difference in air temperature between the surroundings and meadow; and maximum difference in air temperature between the surroundings and forest.

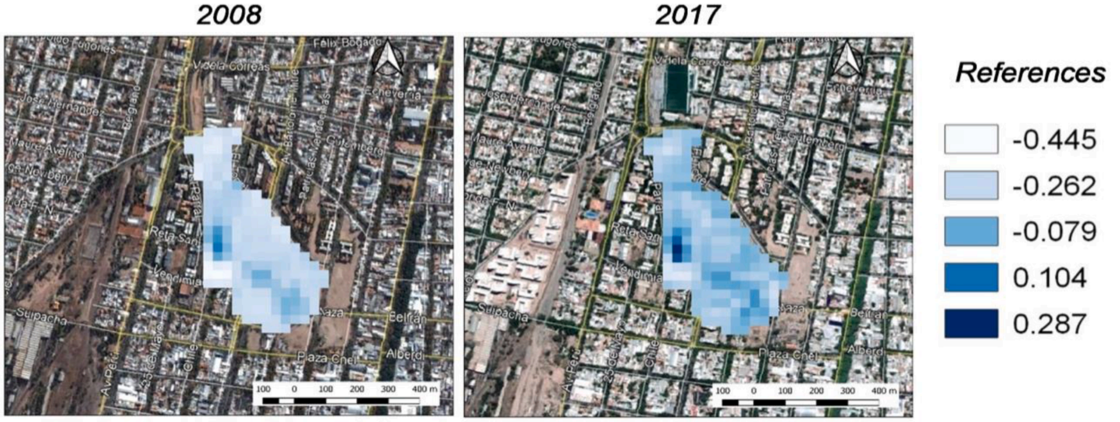
Finally, the definition of hourly PCI was adopted from Motazedian, Coutts, & Tapper, 2020 and García-Haro and Arellano (2018). It is the difference in air temperature between the surrounding urban areas and



(a) NDVI index



(b) SAVI index



(c) NDWI index

Fig. 3. NDVI, SAVI and NDWI indices for the Parque Central-Mendoza, Argentina. Years 2008 and 2017, respectively.

the park (Eqn 1).

$$PCI = Tu - Tp \quad (1)$$

where, Tu is the hourly average temperature of urban surroundings (North, West, South and East), and Tp is the hourly average temperature inside the park (meadow and forest). PCI implies a positive intensity and is measured in °C.

3. Results and discussion

For clarity, the results and discussion are divided into four sections: assessment and explanation of the index maps obtained from satellite imagery processing; thermal behavior evolution of meadow and forest structures; thermal effect of the park during maximum and minimum temperature occurrence in the city, and park cool island intensity.

It should be noted that the 2010–2011 and 2011–2012 seasons can be considered intermediate situations between the 2007–2008 season in which the Parque Central was quite new and the 2016–2017 season in which the Parque Central is already consolidated. In addition, we do not have the data for the meadow in 2011. For these reasons and the sake of brevity, 2010–2011 and 2011–2012 have not been taken into account in all the analysis carried out.

3.1. Spectral indices

As mentioned in the Methodology, to evaluate the evolution of the characteristics of the vegetation and its built environment, a series of widely used indices of satellite images have been calculated.

Fig. 3a shows the distribution range of the NDVI for Parque Central. In 2008, the NDVI covered values from −0.20 to 0.07 (average of −0.05); while in 2017, almost a decade later, values between 0.021 and 0.57 (average of 0.26) were ranged. There is a consolidation of the vegetation within the park which shows improvements in time, specifically for the SE sector of the park. It is also observed that the index maximum values are coincident with the location of the forested sectors. The maximum value of the index has grown more than 8 times throughout the 10 studied summer seasons.

The comparative analysis of the temporal distribution within the park shows a similar behavior between SAVI and NDVI which is consistent with the consolidation of forest sectors in the SE sector of the park (Fig. 3b).

Although there is a slight improvement in 2017 when compared to 2008, the NDWI values highlight that the moisture content of the park is very low. The situation reflects the analysis and the image is congruent with arid areas. In addition, Fig. 3c shows how, in coincidence with the sectors where the forest predominates, areas with low NDWI are detected. This shows that the forest species that thrive or consolidate are those which have less water consumption or are resistant and adapted to drought, with low evapotranspiration rates. The area corresponding to the artificial lake is identified in dark blue, and the areas with the highest moisture content are found in the meadow structures.

The evaluation of NDBI evolution in the sensors' influence areas was performed in order to assess how the changes on the built up area modify the thermal response of the surroundings (Fig. 4).

Table 5 shows that along ten years the quantity of built-up areas has increased in all directions around the park. The maximum values of NDBI have increased in a range of 1.52 to 1.95 times. The sector that presented the largest increment was the East.

3.2. Thermal behavior evolution of meadow and forest structures

The data obtained with the sensors located in the meadow and in the forest are analyzed and compared with the reference stations (Plumerillo Airport and city center). The Airport Station is a reference for typical days and the sensor within the city center works as a reference for the urban heat island in Mendoza.

In general terms, the forest structure is cooler than the airport during sunny hours and warmer during night hours. On the other hand, the meadow structure is warmer than the airport during the day and colder or equal during the night. Regarding the city center, the park cooling effect is observed in both structures during night hours. During the day, the meadow is hotter than the city center. It should be noted that there is no data available for the 2007–2008 summer period in the city center as well as for the meadow during the 2010–2011 period (see Fig. 5).

3.3. Thermal effect during occurrence of maximum and minimum temperature

With the objective of analyzing the effect of the park on two times of the day with different demands, temperature differences between the surroundings and the park were calculated for the evaluated summer seasons at the time of maximum and minimum temperature occurrence

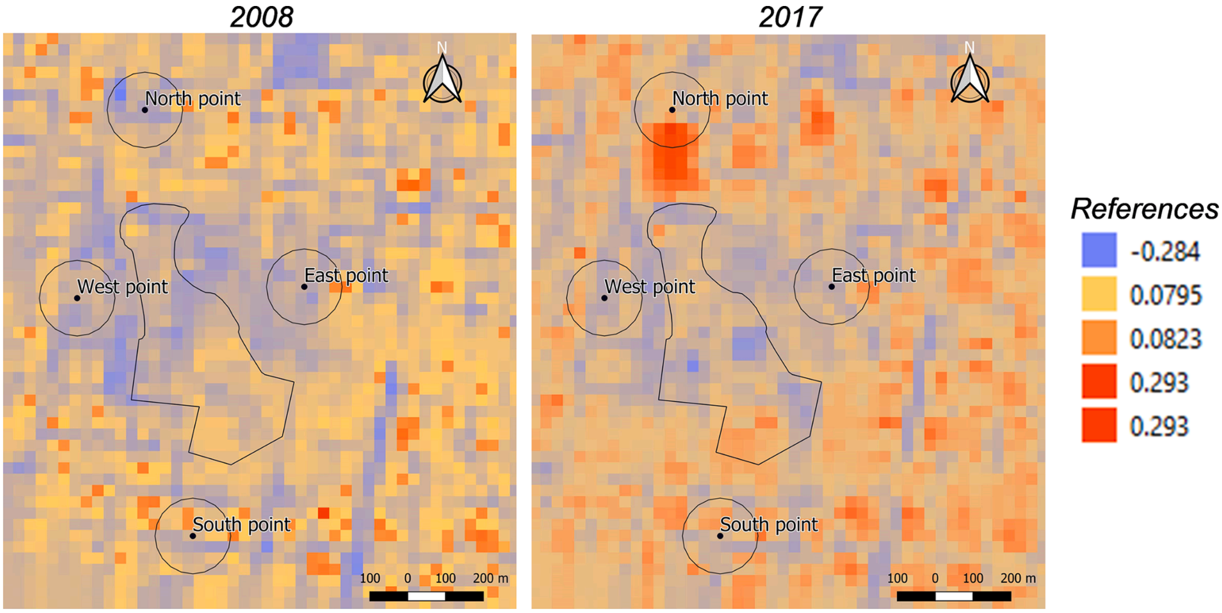
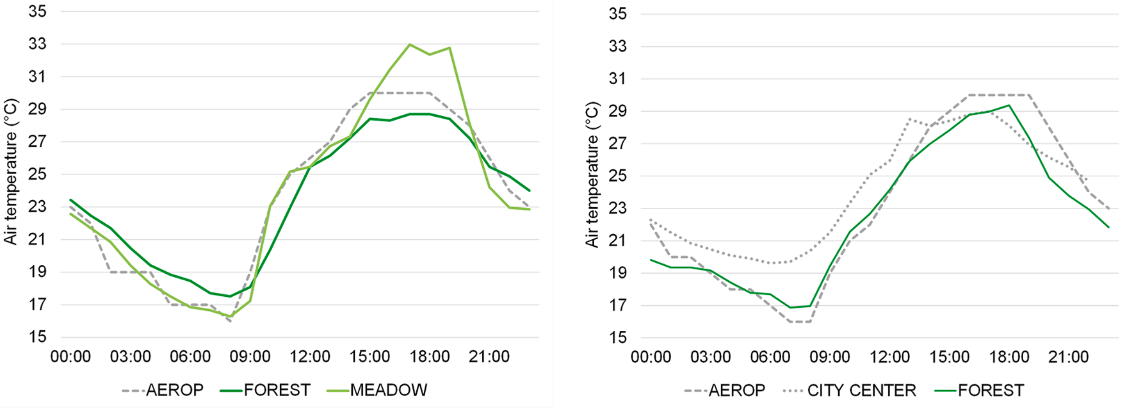


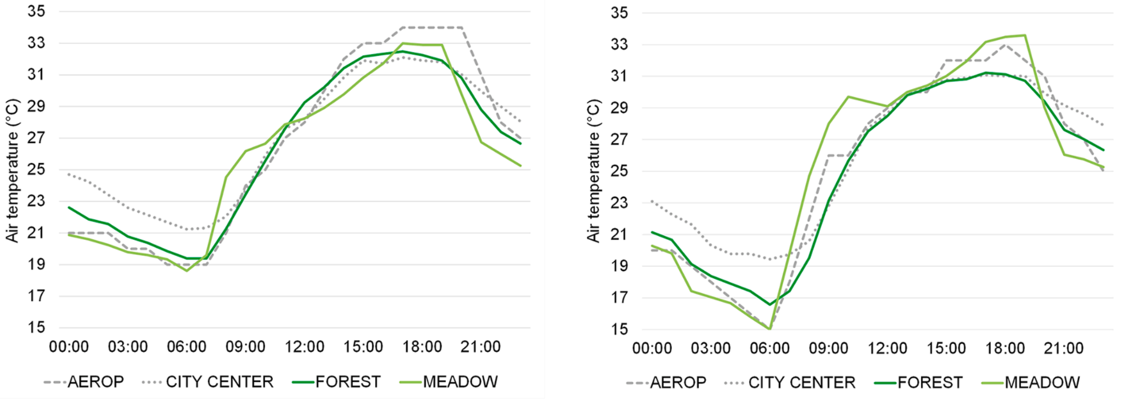
Fig. 4. NDBI index for the surroundings of Parque Central-Mendoza, Years 2008 and 2017, respectively.

Table 5
NDBI values for each area of influence.

	NORTH POINT		SOUTH POINT		EAST POINT		WEST POINT	
	2008	**2017**	**2008**	**2017**	**2008**	**2017**	**2008**	**2017**
Minimum	−0,25	−0,25	−0,18	−0,21	−0,22	−0,26	−0,18	−0,30
Average	−0,01	−0,01	−0,01	−0,01	−0,02	−0,04	−0,01	−0,02
Maximum	0,16	0,26	0,15	0,23	0,19	0,37	0,16	0,27



(a) 2007-2008 *(b) 2010-2011*



(c) 2011-2012 *(d) 2016-2017*

Fig. 5. Thermal behavior of each park structure, Plumerillo Airport and the city center in each evaluated season.

in the city. During the occurrence of maximum temperatures, the ability of the park to reduce the level of thermal distress is interesting. On the other hand, the time at which the minimum temperature occurs is important from the urban heat island and energy consumption point of view.

The time of the maximum temperature coincides at 5 pm during the four summers. In contrast, the minimum temperature occurs at 8 am in 2007–2008, at 7 am in 2010–2011, and at 6 am in the 2011–2012 and 2016–2017 seasons. This difference in the occurrence of the minimum temperature could be due to the days selected in each measurement campaign. It is not a problem when comparing these campaigns since the temperature differences are analyzed.

During the 2007–2008 summer, the park was around 0.6 °C cooler than the surroundings at 5 pm (maximum temperature), while at 8 am (minimum temperature), the difference between the park and the surroundings is 1.3 °C. For the 2016–2017 summer period, the air temperature difference at the time of occurrence of minimum temperature is 1.1 °C, but at 5 pm, the park is 0.3 °C warmer than surroundings (see Fig. 6).

To deepen on these results, Fig. 7 is presented which details the air temperature differences between each point in the surroundings and the forest and meadow sectors, respectively. In summer 2007–2008, at 5 pm (maximum temperature), the forest was around 3.9 °C cooler than the East point, 3.6 °C cooler than the South point and 2.9 °C cooler than the North point. At 8 am (minimum temperature), the differences between the forest and the surroundings of the park are between 0.1 and 1.1 °C (Fig. 7a). On the other hand, in the summer of 2010–2011, the forest is 4.7 °C cooler than the West point at the time of maximum temperature (5 pm). At the minimum temperature time (7 am), the forest is up to 0.8 °C hotter than the surroundings. In the 2011–2012 season, no differences greater than 1 °C are observed between the forest and the surroundings at the maximum or minimum time. In the 2016–2017 season, the forest is 1.6 °C cooler than the South point at 5 pm and 0.8 °C cooler than the West point at the minimum time (6 am) (see Fig. 7a). In general, it can be appreciated that the shadow benefits derived from the forest structures into the park have a wider impact over the surrounding temperatures when the built-up density is lower. Meanwhile, when the density of built up in the surrounding is increased, the benefit of forest over surroundings' temperatures decreases. This occurs although the forest structure has been consolidated according to the increase in the NDVI.

Fig. 7b shows temperature differences between the surroundings and the meadow structure for the 2007–2008 and 2016–2017 seasons, at the maximum and minimum temperature time. In the 2007–2008 summer,

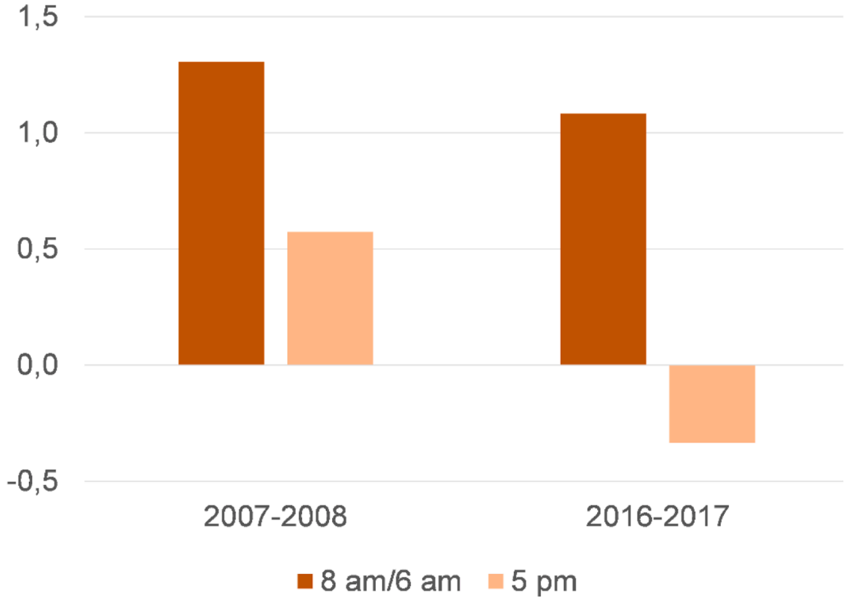
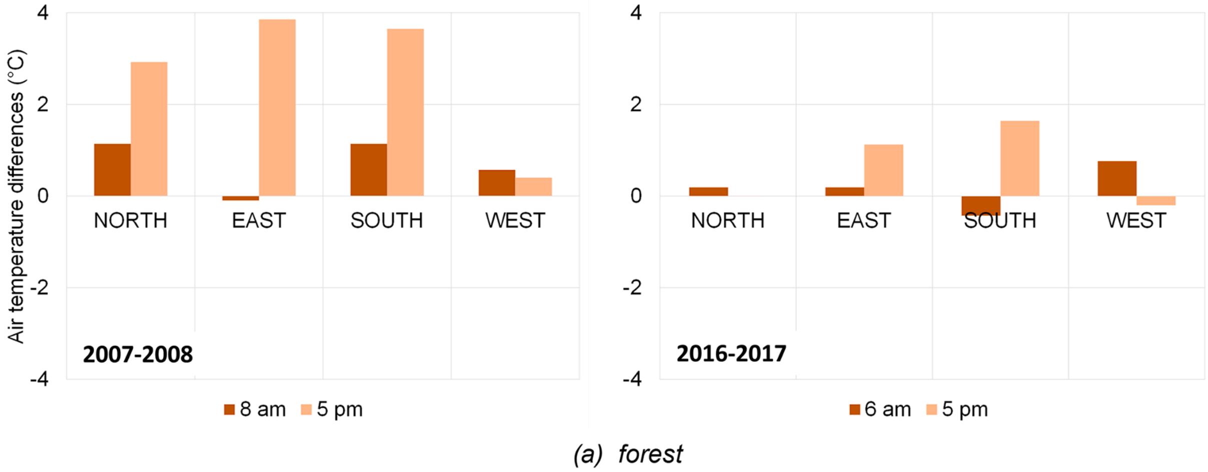
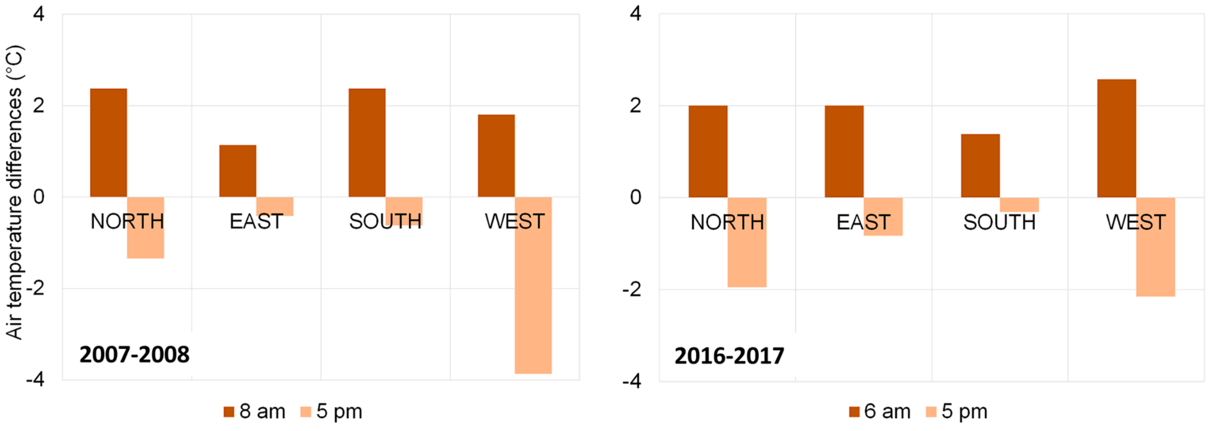


Fig. 6. Temperature differences between the surroundings and the park for the 2007–2008 and 2016–2017 seasons, at the maximum and the minimum temperature time.



(a) forest



(b) meadow

Fig. 7. Temperature differences between the surroundings and each structure for the 2007–2008 and 2016–2017 seasons, at the maximum and the minimum temperature time.

at 5 pm (maximum temperature), the meadow is 3.9 °C hotter than the West point and at minimum temperature time (8 am), the meadow is 2.4 °C cooler than the North and South points. In 2011–2012, the North point presents the greatest differences: the meadow is 1.4 °C warmer at the maximum time and 1.1 °C cooler at the minimum (6 am). During 2016–2017, however, the West point presents the greatest differences: the meadow is 2.2 °C warmer at the maximum time and 2.6 °C cooler at the minimum.

Mendoza's results indicate that the forest mean cooling reached 2.7 °C (varying from 0.4 - 3.9 °C) during daytime heating peak in 2007–2008 and 0.6 °C in 2016–2017. In coincidence with Motazedian, Coutts, & Tapper, 2020, meadow cooling is less variable and has been maintained over time because of the increase in thermal inertia around the park (see NDBI, Fig. 4).

In Mendoza's Parque Central, NDVI increases over the years (from an average of −0.05 in 2007–2008 to an average of 0.26 in 2016–2017), but the maximum temperature differences decrease from 2007 to 2008 to 2016–2017, during maximum temperature occurrence. This reduction shows the impact of urban growth throughout the period (10 years). As the building mass increases, the thermal inertia of the environment increases as well and temperature differences with the cold structures within the park —the forests— decrease in the hours of sun. In Parque Central, Mendoza, the increase in NDVI denotes the consolidation of biomass. Based on García-Haro et al. (2019) results, the cooling effect of the park would be expected to increase. However, this has not been the case, demonstrating that the thermal benefits of the park have been governed by the densification of its surroundings. In the same way, these results coincide with Pramanik and Punia (2019).

In this sense, Fig. 8 shows the variation proportion 2016–2017 with respect to 2007–2008 for three magnitudes in each cardinal point: maximum NDBI; maximum difference in air temperature between the surroundings and meadow; and maximum difference in air temperature between the surroundings and forest. It is observed that the cooling effect of the forest is more susceptible to the increase of NDBI than that of the meadow. It is also observed that in the South point the variation of the maximum NDBI has been the lowest whereas the cooling effect caused by the park is the greatest. On the contrary, the East point shows the highest increase in maximum NDBI and the lowest cooling effects.

3.4. Park cool island intensity

Fig. 9 shows the PCI intensity along the day for summers 2007–2008 and 2016–2017. During the 2007–2008 season, the maximum PCI is 1.3 °C, being relatively stable throughout the day (between 0 and 1 °C). During the 2016–2017 summer, the maximum values of PCI occur during noon: the park is up to 3.0 °C colder than the urban surroundings.

Previous studies in different climates show a low variety of PCI intensities. Table 4 shows related researches, the most used geospatial techniques. The PCI intensity in the Parque Central of Mendoza in the 2016–2017 season is similar to other investigations (Table 6).

Although the cooling effects of greenspace are well known, the understanding on the roles of landscape inside and outside parks in PCI features is still not deeply explored. Qiu and Jia (2020) evaluated PCI and explored their relationships with landscape patterns using correlation analysis and a stepwise regression model in Beijing, China. Their results showed that PCI extension was largely regulated by the landscape outside the parks, while the intensity was controlled to a less degree by the landscape patterns. Even though the extension of PCI has not been directly analyzed in this study, the increase in the intensity of the PCI (more than double) over time, in less proportion than the increase in the maximum NDVI (more than 8 times), can be read as an indicator of the reduction of PCI extension. The NDVI and SAVI indices between 2007 and 2008 and 2016–2017 demonstrate the consolidation of vegetated areas within the park. This has allowed the meadow structure to behave more efficiently than the forest structure despite the increased anthropic pressure from the surroundings evidenced by the NDBI.

This temporal comparison has allowed a combined evaluation of the effect of the park itself and the effect of the urban growth of the surroundings. The result of the combination shows that the effects of the park are conditioned to what happens in the surroundings. The uncontrolled evolution of the surroundings has more weight than the consolidation of the park over nighttime thermal benefits.

Instead, in Mendoza's Parque Central, NDVI increases over the years (from an average of −0.05 in 2007–2008 to an average of 0.26 in 2016–2017), but the maximum temperature differences decrease from 2007 to 2008 to 2016–2017, during maximum temperature occurrence. This reduction shows the impact of urban growth throughout the period

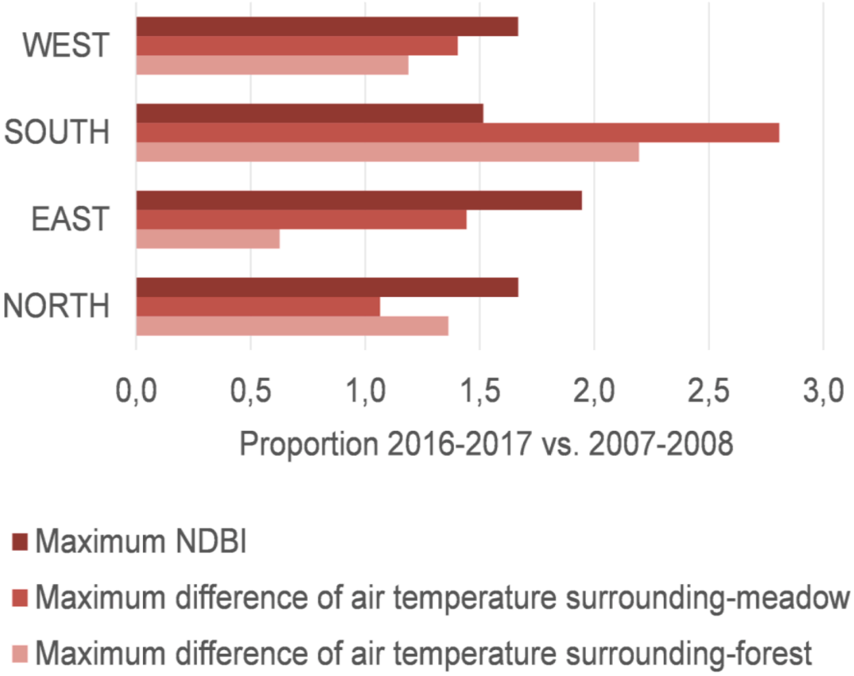


Fig. 8. Proportion 2016–2017 vs 2007–2008 for three magnitudes.

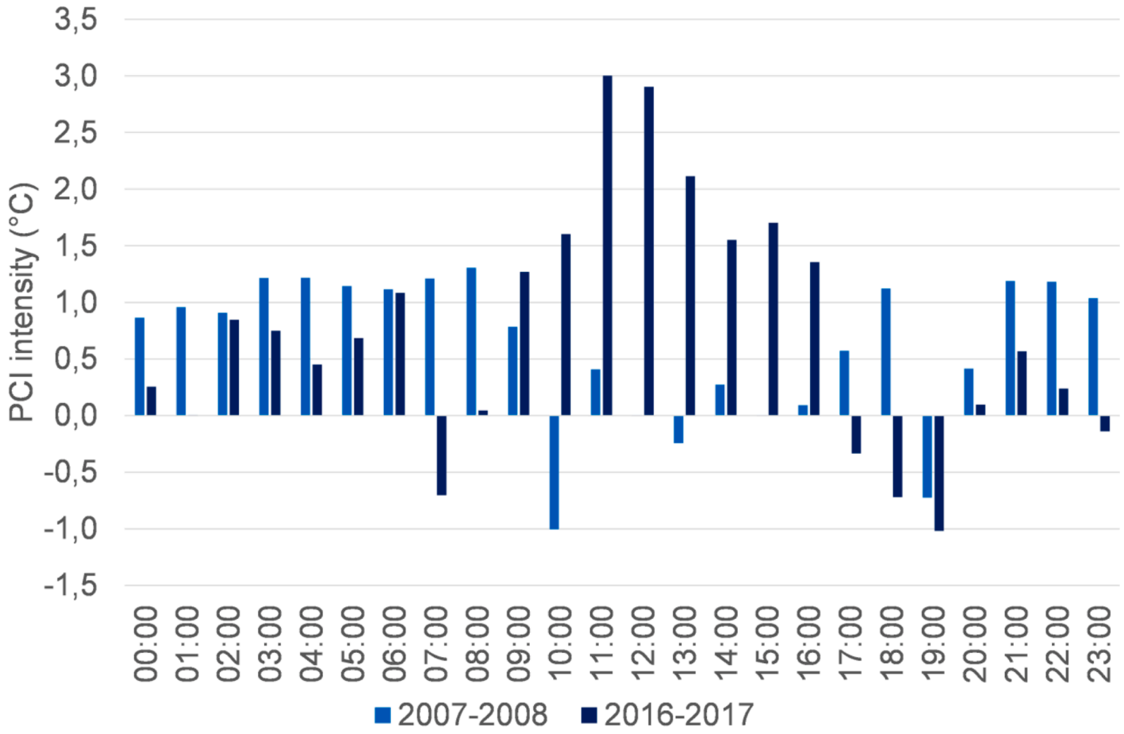


Fig. 9. PCI intensity along the day for 2007–2008 and 2016–2017.

Table 6
Comparison among some related researches.

City	Climate	PCI intensity	Research
Ulsan, Korea	Cfa (Humid Subtropical Climate)	< 3 °C	Park and Cho (2016)
Chongqing, China	Cfa (Humid Subtropical Climate)	~ 2 °C	Lu et al. (2017)
Abuja, Nigeria	Aw (Tropical savanna climate with dry-winter characteristics)	~ 2 °C	Chibuike, Ibukun, Abbas and Kunda (2018)
Barcelona, Spain	Csa (Mediterranean hot summer climates)	< 2.5 °C	García-Haro et al. (2019)
Mendoza, Argentina	BW (Arid climate)	< 1.3 °C	2007–2008
Mendoza, Argentina	BW (Arid climate)	< 3.0 °C	2016–2017

(10 years). As the building mass increases, the thermal inertia of the environment increases as well and temperature differences with the cold structures within the park —the forests— decrease in the hours of sun. In Parque Central, Mendoza, the increase in NDVI denotes the consolidation of biomass. Based on García-Haro et al. (2019) results, the cooling effect of the park would be expected to increase. However, this has not been the case, demonstrating that the thermal benefits of the park have been governed by the densification of its surroundings. In the same way, these results coincide with Pramanik and Punia (2019).

Therefore, the use of urban voids is important to generate new green spaces. But we must not lose sight of the fact that these new green spaces attract urban development in the surroundings, so it will be necessary to pay attention to the urban carrying capacity (UCC) so as not to lose the thermal benefits of green space. In this sense, it is interesting to rescue the concept of the threshold-size of green space from Yu et al. (2020) and extend it to the threshold of the green space-built space relationship.

4. Conclusions

This research highlights the challenges of reconciling the thermal benefits of an urban park placed in an arid zone with the built environment growth.

The beneficial effect of the park is strongly regulated by the two structures: meadow and forest. Their incidence is clearly differentiated throughout the day.

During the time of maximum temperatures in the city, the forest structure is cooler than the surroundings, with maximum differences ranging from 3.6 °C in 2007–2008 to 1.6 °C in 2016–2017. The decrease in the difference shows the impact of urban growth in the last 10 years which, by increasing the building mass, increases the surrounding thermal inertia, and decreases the temperature differences with the cool structures within the park —forests— during sun hours.

In contrast, during the time for the minimum temperatures of the city, the meadow structure is cooler with differences that reach up to 2.5 °C in 2008 and 2.6 °C in 2016. In this sense, the differences in cooling have been maintained over time, as a consequence of the increase in thermal inertia around the park.

However, the analysis of the maximum PCI values shows increases in the maximum PCI recorded between the forest structure in the park and its surroundings (6.4 °C in 2008 vs. 8.8 °C in 2016). This represents a 37% increase in its cooling effect. The maximum PCI recorded between the meadow structure and its surroundings also shows increasing values over time, (4.2 °C in 2008 vs. 6.8 °C in 2016), representing an increase of 62% in its cooling effect.

If the NDVI and SAVI index values reported in the analysis of the satellite images of this area between 2008 and 2017 are taken into account, it can be inferred that the forest area consolidation and the park evolution have allowed a more efficient behavior of the meadow structure, despite the temporary increase in anthropic pressure on the park, evidenced by the NDBI.

Over 10 seasons, the park's maximum NDVI has increased more than 8 times, while the maximum PCI intensities have increased 2.31

times. In other words, the high increase in vegetation is not directly proportional to the cooling effect of this urban park.

The cooling profile of the park has changed. In absolute terms, NDVI and PCI grew but the evolution of the surroundings (measured as NDBI) has modified the role of the park as a thermal regulator. The thermal benefit of the park has moved from the night to the afternoon hours.

These results allow us to have a notion about the interaction between the park and the urban surroundings. At this point, it is convenient to clarify that there are also other factors, besides climate conditions, such as the heat generated by anthropogenic sources - vehicular traffic, industrial processes, or the use of air conditioning- that can affect intensity and profile of PCI. For this reason, in the future it is necessary to carry out simulations to detect the densification thresholds of the urban environment to sustain the regulation of the temperature by the parks.

In relation to park design, it is advisable to prioritize the forest sector, but it is important to select tree species adapted to the climate. In arid cities, it is necessary to choose species with low-water-requirement and high growth speed so that the park consolidates more quickly.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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