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Article

Estimation of the Relationship between Urban Park Characteristics and Park Cool Island Intensity by Remote Sensing Data and Field Measurement

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Abstract: The cooling effects of urban parks, which form "Park Cool Island" (PCI), can help decrease land surface temperature (LST) and mitigate urban heat island (UHI) effects. PCI intensity largely depends on the characteristics of urban parks. The relationship between PCI intensity and urban park characteristics such as urban park size has been well documented. However, it is still unclear how urban forest structures in parks affect PCI intensity and particularly whether the relationship changes across seasons. In this study, PCI intensity for 33 parks in Changchun, China was obtained from Landsat-5 Thematic Mapper (TM) data and then correlated with urban park characteristics such as the size derived from "Systeme Probatoire d'Observation dela Tarre" (SPOT) satellite data and the forest structures of parks derived from the field-based survey to uncover the relationship between urban park characteristics and PCI intensity. Our results suggested that (1) The PCI intensity varied across seasons and the cooling effect of parks in summer was higher than that in autumn. (2) The increase of urban park size was still an effective measure to mitigate UHI. However, urban park size was non-linearly correlated to PCI intensity. (3) Not only by increasing urban park size, but also by optimizing urban park shape and forest structures in parks can increase PCI intensity. (4) The relationship between PCI intensity and urban park characteristics changed across seasons and seasons should be considered when exploring the relationship between them. These findings can deepen the understanding of PCI formation and provide useful information for urban planners about how to design urban parks to maximize their PCI intensity and mitigate UHI effects.

Keywords: urban heat island (UHI); urban park; park cool island (PCI); TM image; SPOT image

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1. Introduction

Urban heat islands refer to the phenomenon that urban air/surface temperatures are higher than non-urban area air/surface temperatures, which is considered to be one of the major environmental problems of the 21st century [1,2].The higher temperatures as a result of urban heat islands increase cooling energy consumption [3], raise pollution levels [4,5] and even may affect the habitability of cities and lead to mortality [6–8]. Therefore, how to mitigate UHI has become a major research focus today. It is well known to us that urban vegetation can decrease the temperatures in cities through shading and evaporative cooling [9–11]. Urban parks have been considered as an important part of urban vegetation, which are cooler than their surrounding built-up areas and can form a "Park Cool Island" (PCI) [12–15]. So, the establishment of urban parks can be an effective measure to improve the urban thermal environment and mitigate UHI effects. Therefore, it is necessary for urban planners to understand how to design urban parks to maximize their PCI intensity and mitigate UHI effects.

In the past two decades, there were a lot of studies focusing on the influences of urban park characteristics on PCI intensity. These studies have found that there is a significant positive correlation between PCI intensity and urban park size [16–19]. Larger parks had stronger PCI effects than smaller parks. These studies mostly focused on the relationship between PCI intensity and the characteristics of urban parks such as their size. However, the cooling effect of urban parks may be also related to other characteristics of parks, such as the urban forest structures in parks [17]. The relationship between PCI intensity and urban forest structures in parks has rarely been studied and is not yet fully understood.

Urban forest structure, considered as the three-dimensional spatial arrangement of forests in urban areas (canopy density, stem density, tree size and health, species composition, *etc.*), is an important variable that influences urban forest ecosystem functions that affect urban inhabitants across the city [20,21]. The exchanges of evapotranspiration and energy that occur in the most important ecological processes between the forest ecosystems and the atmosphere strongly depend on forest structures. So, urban forest structures in urban parks may potentially influence PCI intensity. As is known to us, it is hard to increase the amount of urban parks due to limited land resources for urban greening and many political reasons [22,23]. Therefore, interest in how to improve cooling potential through park design has increased in recent years. Fortunately, some researchers have begun to pay attention to the effects of urban forest structures on PCI intensity. The qualitative relationship between urban forest structures and PCI intensity has been investigated by exploring the effects of urban park types or forest combinations on PCI intensity [16,17,24,25]. These studies indicated that urban park types or forest combinations were closely related with PCI intensity and may play an important role in decreasing LST. However, there has been little quantification of the relationship between urban forest structures and PCI intensity, and statistical models should be established.

In addition, the cooling effects of urban forests varied significantly across different seasons [26,27]. However, few studies have reported whether the relationship between PCI intensity and urban park characteristics changes across different seasons. Therefore, further research on the relationship between PCI intensity and urban park characteristics is eagerly needed to deepen the understanding of PCI formation, particularly changes in the relationship between PCI intensity and urban park characteristics at different seasons.

Based on the field-based survey, SPOT and Landsat TM imagery from Changchun City, China, this study aims to investigate the effects of urban park characteristics on PCI intensity. The purposes of this research are to: (1) Identify the PCI intensity of urban parks inside the fourth ring-road of Changchun at different seasons; (2) Explore the quantitative relationships between PCI intensity and urban park characteristics and investigate whether urban forest structures significantly affect PCI intensity; (3) Investigate whether the relationship between PCI intensity and urban park characteristics changes across different seasons. The ultimate goal of this study is intended to provide useful information for urban planners and designers about how to design urban parks to maximize their PCI intensity and mitigate urban heat islands.

2. Methods

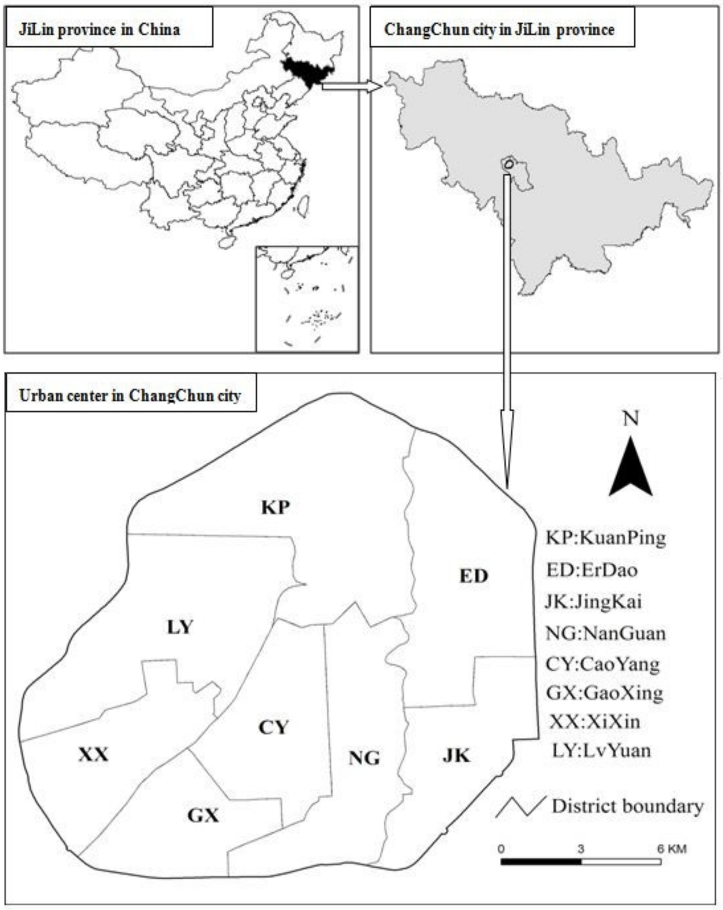
2.1. Study Sites

The study was carried out in the city of Changchun (125°09′E–125°48′E, 43°46′N–43°58′N). It is the capital of Jilin province and an important social-economic center of northeastern China located in the hinterland of the Northeast Plain with 45 percent of its area covered by urban vegetation.

The area of the urban center in Changchun City is 284.65 km^2. The climate classification of Changchun is a continental climate of the North Temperate Zone with the obvious variation of four seasons. The average total yearly rainfall is 567 mm and the annual average temperature of a cold winter in the region is −14 °C. The annual average temperature of a hot summer in the region is 24 °C. According to meteorological records of 1951–2011, temperatures have increased in Changchun with air temperatures rising 1.86 °C during the 60 years from 1951–2011, particularly in the hot summer season due to global warming. In recent years, the urban thermal environment has deteriorated due to the UHI phenomena in Changchun caused by rapid urbanization and accelerating global warming [28].

Changchun is therefore an interesting area for research of the relationship between PCI intensity and urban park characteristics (Figure 1).

Figure 1. The study area: areas within the fourth-ring road of Changchun, China.



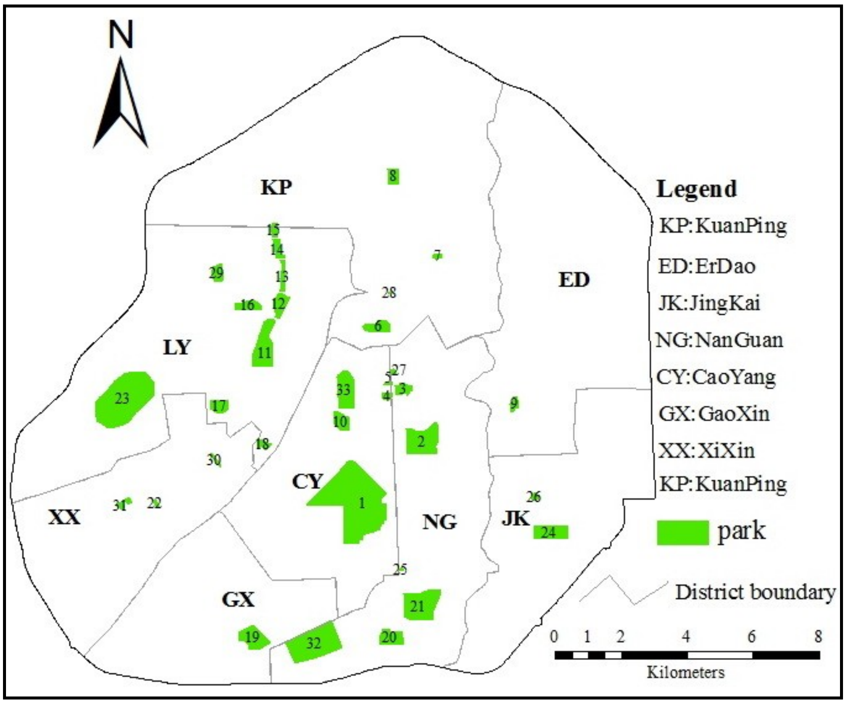
2.2. Data Preparation

2.2.1. Urban Park Characteristics

2.2.1.1. Urban Park Size and Shape

We used SPOT data, which was taken at around 10:25 a.m. local time on September 14, 2010 with a spatial resolution of 2.5 m, to map urban parks in the study area. The SPOT data was first geo-referenced to UTM coordinate system and then visually interpreted to derive urban parks in arcGIS9.3. An accuracy estimate was conducted based on 30 check points with field-based reference data acquired by fieldwork during summer in 2011. The total accuracy of the derived map was 90.12%. Figure 2 shows the map of 33 forested urban parks in our study area. Urban park area, perimeter and perimeter/area were selected to describe urban park size and shape. The former two indices denote the size of the urban park. The ratio of perimeter/area describes the complexity and the edge effect of the urban park. The larger the ratio of the perimeter/area, the more complex the urban park shape will be. Urban park area and perimeter were calculated by the software of ArcGIS. Based on the two values, the ratio of perimeter/area was also calculated in ArcGIS.

Figure 2. The selected parks of the study area in Changchun.



2.2.1.2. Urban Forest Structures in Parks

In this study, field measurements were established and conducted in parks during July and August 2012 by using a stratified random sampling design [29]. One hundred and fifty-eight plots were investigated in our study and the plot number of each urban park was determined according to the area of each park and its within-type variance of urban forest structures, including species diversity and the DBH distribution of trees according to our pre-investigation. The number of sampled plots for each park is shown in Table 2. Each of the 158 sampling quadrats was defined as a 30 m × 30 m square (0.09 ha). Finally, the measurements of urban forest structures were conducted at all sampling quadrats. Within each site, all trees were measured and a total of 4536 tree individuals were measured for all sampling sites. Several indices of urban forest structures were selected in our study, including stem density (SD), diameter at breast height (DBH), tree height (H), leaf area index (LAI), canopy density (CD) and base area (BA). For each sampling quadrat, urban forest structures were calculated as follows:

Stem density (SD): It is defined as the number of trees (N) per unit area (Equation 1).

Diameter at breast height (DBH): The DBH was measured directly by optical instruments. Their value in a sampling quadrat is the average of DBH values for all sampled trees (Equation.2).

Tree height (H): The H was also measured directly by optical instruments. Their value in a sampling quadrat is the average of H values for all sampled trees (Equation 3).

Base area (BA): Basal area is defined as the ratio of the cross-sectional area of all trees in a sampling quadrat to the ground area they occupy. It was calculated from DBH and the value of base area is the total BA values of all sampled trees per unit area in a sampling quadrat (Equation 4).

Canopy density (CD): CD was measured directly with a fish-eye camera, which is defined as the ratio of the fractional area (projected vertically) of urban forest canopy in a sampling quadrat to the ground area it occupies.

Leaf area index (LAI): LAI was also measured directly with a fish-eye camera and TRAC, which is defined as the ratio of the leaf areas in a sampling quadrat to the ground area they occupy.

$$\text{SD (n/ha)} = N/0.09 \tag{1}$$

$$\text{DBH (cm)} = \frac{\sum_{i}^{N} DBH_i}{N} \tag{2}$$

$$\text{H (m)} = \frac{\sum_{i}^{N} H_i}{N} \tag{3}$$

$$\text{BA (m}^2\text{/ha)} = \frac{\left[\sum_{i}^{N} \pi (DBH_i / 2)^2\right]}{0.09} \tag{4}$$

Where N is number of trees in a sampling quadrat for all equations.

After urban forest structures for each sampling quadrat were obtained, the average of urban forest structures for all sampling quadrats in a park is the value considered for later statistical analyses.

2.2.2. Park Cool Island (PCI) Intensity

Urban land surface temperature was calculated based on a Landsat-5 Thematic Mapper (TM) thermal band with a spatial resolution of 120 m and a wavelength of 11.45–12.50 µm, which was taken on June 5, 2011 (summer) and September 22, 2010 (autumn) under clear sky conditions, having good quality with less than 5% of scenes covered by cloud. Table 1 shows the meteorological records in Changchun on the dates of TM data acquisition. The raw TM image was geo-referenced based on SPOT using the one-order polynomial method**.** Many methods have been developed to retrieve LST from Landsat-5 Thematic Mapper (TM) in ENVI 4.6. In this study, the mono-window method by Qin *et al. et al.* was applied to compute land surface temperatures from the thermal band of Landsat data [30]. Then, an image layer of urban land surface temperature was generated (Figure 3). Based on an image layer of urban land surface temperature, PCI intensity was calculated as follows.

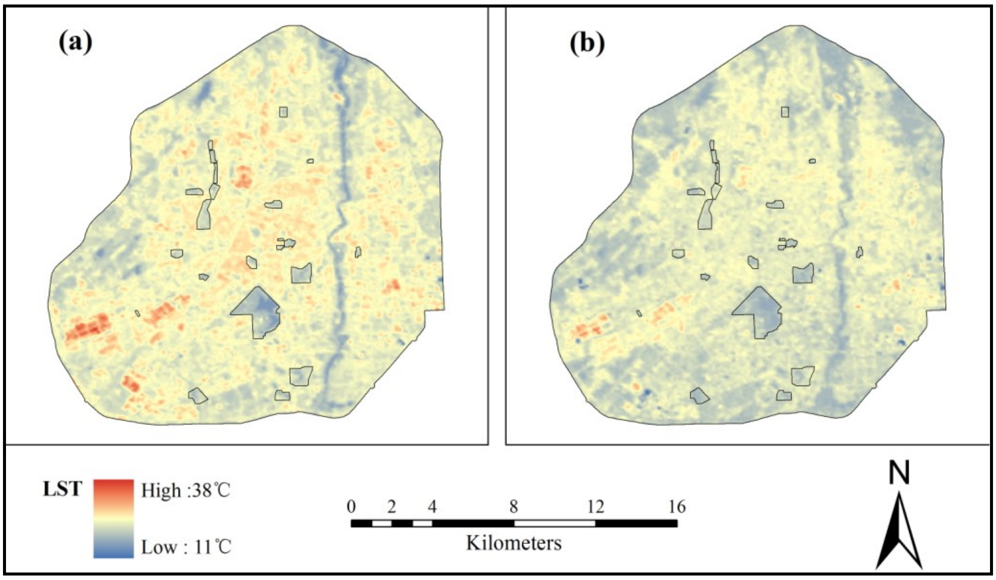
$$\mathbf{T_{PCI}} = T_U - T_P$$

Where T_U is the average temperature of urban surroundings within a 500 m buffer zone from the park (excluding other parks and water) [19,31]; T_P is the average temperature inside the park.

Table 1. Meteorological records on the dates of the Landsat-5 Thematic Mapper (TM) imagery acquisition in Changchun.

Season	Summer	Autumn
Data of TM acquisition	June 5, 2011	September 22, 2010
Time of TM acquisition	10:12 a.m.	10:11 a.m.
Min air temperature(°C)	21.6	4.6
Max air temperature(°C)	31.2	21.6
Mean air temperature(°C)	26.4	14.3

Figure 3. The land surface temperature (LST) map of the study area in Changchun: (**a**) June 5, 2011 (summer), and (**b**) September 22, 2010 (autumn).



2.3. Statistical Analyses

In order to analyze the relationship between PCI and urban park characteristics and the changes of relationship across seasons, the research on the relationship between PCI and urban park characteristics in summer and autumn was conducted respectively. The ordinary least squares multiple linear regression model and correlation coefficient were used to determine the effect of urban park characteristics on PCI at different seasons. In linear regression models analysis of the relationship between PCI and urban park characteristics, the PCI was used as the dependent variable, and urban park characteristics were used as independent variables. Finally, the standardized coefficients (Std. coefficient) of multivariate regressions between PCI and urban park characteristics at different seasons was calculated to analyze the changes of the relationship between PCI and urban park characteristics and 18 linear regression models between PCI and urban park characteristics were also established further to uncover the quantitative relationship between them. All of the statistical analyses were carried out with the help of SPSS.

3. Results

3.1. Descriptive Statistics of PCI and Urban Park Size

Table 2 lists descriptive statistics for PCI intensity and urban park size. Both urban park area and perimeter among the parks had relatively large ranges, with a mean value of 41.33 ha and 2294.91 m and a standard deviation of 68.28 ha and 1795.64 m, respectively. PCI intensity also varied greatly among parks with a mean value of 4.52 °C and 3.77 °C and a standard deviation of 1.86 °C and 1.66 °C, respectively in summer and autumn. Both in summer and autumn, the parks with a large area or perimeter tended to have high PCI intensity. The maximum PCI intensity values (8.96 °C and 7.17 °C) were all observed in the largest park with an area of 324.64 ha for summer and autumn, respectively. While low PCI intensity was usually observed in parks with a small area and perimeter.

Besides, it was observed that the PCI effect existed in each park and all parks were on average cooler than their surroundings, which confirmed the term "Park Cool Island". However, the cooling effect of urban parks in summer was very different from that in autumn. In summer, the parks were on average 4.52 °C cooler than their surroundings. However, the parks were on average 3.77 °C cooler in autumn. So, urban parks had a stronger cooling effect in summer than in autumn.

Table 2. Descriptive statistics of the size, PCI intensity and number of plots for each urban park.

Park	Area(ha)	Perimeter(m)	PCI(°C)		Plot
			Summer	Autumn	
1	324.64	8737.28	8.96	7.17	13
2	75.86	3852.54	6.39	5.85	9
3	15.98	1806.08	5.73	4.80	4
4	7.02	1115.03	3.92	3.76	3
5	3.08	781.84	2.59	2.67	2
6	23.90	2259.43	5.43	4.30	6
7	4.37	871.87	4.48	4.94	4
8	14.92	1549.77	5.00	3.70	5
9	11.74	1625.92	4.81	4.63	3
10	23.57	1980.82	4.43	4.67	6
11	69.06	3928.14	4.81	3.48	9
12	25.09	2086.32	4.94	2.28	3
13	13.20	2396.81	4.68	3.99	3
14	13.45	1873.13	5.37	3.98	4
15	9.07	1261.56	4.43	4.02	6
16	23.17	2194.94	6.01	5.09	8
17	18.50	1739.95	4.55	2.91	4
18	8.88	1334.59	6.71	4.95	6
19	44.32	2821.94	6.10	6.26	7
20	29.87	2302.04	5.82	5.31	5

Table 2. *Cont.*

Park	Area(ha)	Perimeter(m)	PCI(°C)		Plot
			Summer	Autumn	
21	87.23	3783.27	5.80	3.64	7
22	3.38	811.09	3.60	1.40	2
23	210.00	6001.00	7.90	6.84	8
24	43.97	2921.70	3.29	3.41	4
25	4.34	743.88	2.24	3.15	1
26	1.90	494.45	1.24	1.02	1
27	3.89	704.25	2.37	1.64	2
28	1.47	432.73	0.51	1.36	1
29	15.30	1607.08	3.68	2.76	5
30	4.52	1229.70	1.65	1.58	3
31	10.70	1345.53	4.27	3.63	4
32	159.93	5924.30	5.56	4.86	7
33	57.60	3212.77	1.93	0.34	3

3.2. Effects of Urban Park Size on PCI Intensity

Table 3 demonstrates the Pearson correlation coefficients between PCI intensity and urban park size. The results showed that urban park size (area and perimeter) had a significant positive relationship with PCI and significantly increased PCI in summer and autumn. However, the Pearson correlation coefficients between urban park size and PCI were higher in summer than in autumn. It suggested that the relationship between urban park size and PCI was weaker in autumn than in summer.

Further qualitative regression models had been established to uncover the relationship between PCI intensity and urban park size. Figure 4 shows the established models between PCI intensity and urban park size. The results showed that urban park area and perimeter had a positive non-linear relationship with PCI intensity, indicating that PCI intensity increased non-linearly with the increase of urban park area and perimeter. The non-linear model with urban park area and perimeter as independent variables could explain 54.66%–56.22% of PCI intensity variance respectively in summer and 37.22%–38.12% of PCI intensity variance respectively in autumn for the 33 urban parks. Besides, the results also showed that PCI intensity increased more in summer than in autumn with an increase of urban park size by one unit. It means that the cooling effect of urban parks in relation to urban park size is more evident in summer than in autumn.

Urban park size is the main factor for decreasing LST. However, urban park area and perimeter can explain only 54.66%–56.22% of PCI intensity variances in summer and only 37.22%–38.12% of PCI intensity variances in autumn. It suggests that the complex relationship between urban park characteristics and PCI intensity cannot be represented only by urban park size.

3.3. Effects of Urban Park Shape and Forest Structures in Parks on PCI Intensity

Table 3 demonstrates the Pearson correlation coefficients between PCI intensity and urban park shape. Urban park shape (perimeter/area) had a significant negative relationship with PCI intensity, and urban park shape had a significant effect for decreased PCI intensity both in summer and autumn. It demonstrated that with increasing complexity in the shape, the cooling effect of urban parks decreased. The Pearson correlation coefficients between urban park shape and PCI in summer were also higher than that in autumn, which suggested the relationship in autumn between them also became weaker than that in summer.

Table 3. Pearson correlation coefficients between PCI and park size in different seasons ($n = 33$, $p < 0.01$).

Park	Summer	Autumn
Area (ha)	0.626**	0.549**
Perimeter (m)	0.685**	0.587**
Perimeter/Area (m/ha)	−0.715**	−0.584**

** Correlation is significant at the 0.01 level (two-tailed).

Further qualitative regression models have been established to uncover the relationship between PCI intensity and urban park shape (Figure 4). The results showed that urban park shape (perimeter/area) had a negative linear relationship with PCI intensity, indicating that PCI intensity decreased linearly with the increase of urban park shape (perimeter/area). 50.97% of PCI intensity variance in summer and 34.15% of PCI intensity variance in autumn could be explained by the linear model with urban park shape as independent variables. PCI intensity also increased more in summer than in autumn with an increase in the urban park shape index by one unit, which means that the cooling effect of urban parks in relation to urban park shape is also more evident in summer than in autumn. Thereby, urban park shape can play a more important role in mitigating urban heat islands in summer than in autumn.

Figure 4. Regression analysis of PCI intensity and urban park size and shape in summer (**a–c**) and in autumn (**d–f**) (n = 33, $P < 0.01$).

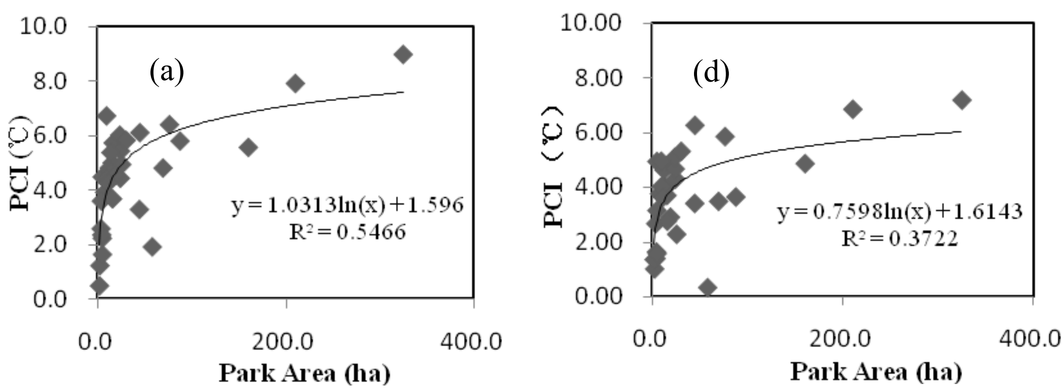


Figure 4. *Cont.*

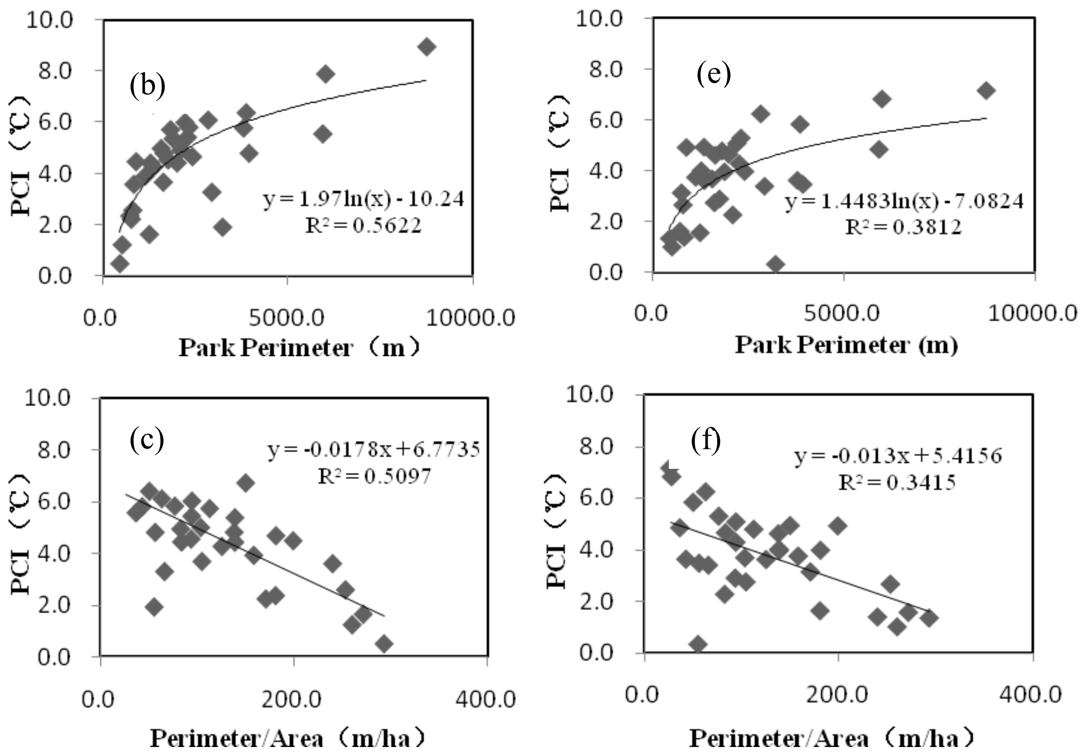


Table 4 gives the correlation between PCI intensity and urban forest structures in parks. The results showed all of the variables of urban forest structure (canopy density, LAI, basal area, height, diameter and stem density) had a relatively strong relationship with PCI intensity in the bivariate correlation analysis both in summer and autumn, which suggested that urban forest structure in parks also had a great impact on PCI intensity except urban park size and shape. In addition to urban park size and shape, urban forest structures in parks can also significantly affect PCI intensity. However, the standardized coefficients (Std. coefficient) of multivariate regressions varied among the selected urban forest structures. The order of the Pearson correlation coefficients between PCI intensity and urban forest structures was canopy density > LAI > basal area > tree height > diameter > stem density both in summer and autumn. Besides, the standardized coefficients of multivariate regressions in autumn were also remarkably different from that in summer. The Pearson correlation coefficients in autumn were lower than that in summer, which suggested that the relationship between PCI intensity and urban forest structures in parks was stronger in summer than in autumn.

Table 4. Pearson correlation coefficients between PCI and vegetation structure in different seasons (n = 33, p < 0.01).

Forest structure	Summer	Autumn
Stem density (n/ha)	0.563**	0.201
Diameter (cm)	0.584**	0.532*
Tree Height (m)	0.666**	0.440
Basal Area (m^2/ha)	0.707**	0.574**
Leaf area index	0.722**	0.658**
Canopy density (%)	0.806**	0.747**

* Correlation is significant at the 0.05 level(two-tailed); ** Correlation is significant at the 0.01 level(two-tailed).

Additional qualitative linear regression models have been established to uncover the relationship between PCI intensity and urban forest structures in parks (Table 5). The results showed that all urban forest structures selected in our study had a positive linear relationship with PCI intensity both in summer and autumn, indicating that PCI intensity increased with the increase of urban forest structures in parks (canopy density, LAI, basal area, height, diameter and stem density). However, the gradient of each linear model for urban forest structures was lower in autumn than in summer. It suggested that PCI intensity increased more in summer than in autumn by one unit. Taking canopy density as an example, the temperature decreased 0.52 °C and 0.48 °C, respectively, in summer and autumn, with increases within the canopy density of 10%. Urban forest structures in parks can play a more important role in mitigating urban heat islands in summer than in autumn and seasons should be considered when exploring the relationship between PCI and urban forest structures in parks.

Table 5. Regression analysis of urban vegetation structure of park and PCI at different seasons (n = 33, P < 0.01).

Forest structure	**Summer**		**Autumn**	
	Regression Model	R^2	**Regression Model**	R^2
Stem density (n/ha)	$y = 0.1012x + 2.7347$	0.3163	$y = 0.0375x + 3.3474$	0.0408
Diameter (cm)	$y = 0.1332x + 3.1482$	0.3419	$y = 0.1250x + 2.331$	0.2826
Tree height (m)	$y = 0.3554x + 2.5021$	0.4432	$y = 0.0023x + 2.4892$	0.1717
Basal area (m^2/ha)	$y = 0.1028x + 3.4094$	0.5011	$y = 0.0871x + 2.7413$	0.3371
Leaf area index	$y = 0.2397x + 3.1915$	0.5225	$y = 0.2254x + 2.369$	0.4330
Canopy density (%)	$y = 5.1905x + 1.9268$	0.6507	$y = 4.7961x + 1.3199$	0.5578

4. Discussion

Our results demonstrated that not only urban park size but also urban park shape and urban forest structures in parks can significantly affect the magnitude of PCI intensity, and that this relationship changed across seasons. Results from this research can expand our scientific understanding of the effects of urban park characteristics on PCI intensity, and provide insights for urban planners to mitigate UHI by optimizing urban park shape and urban forest structures in parks, which have important theoretical and management implications.

4.1. Theoretical Implications

Results in our study suggested that urban parks are on average 4.52 °C (3.77 °C) cooler than their surroundings in summer (autumn), which confirms the term "urban cool islands". PCI intensity measured by LST is higher than that measured by air temperature in some studies [12,17,32]. Besides, PCI intensity also varied among different seasons. The parks in summer have a stronger cooling effect than in autumn, which further supported the conclusion that the higher the temperature, the stronger the cooling effect [33–35]. Our results also showed that PCI intensity differed greatly among parks and such differences can be related to urban park characteristics.

The relationship between PCI intensity and urban park size is well documented. The positive correlation between LST and PCI intensity found in this study is consistent with previous PCI studies based on air temperature [13,16,17]. This study also shows that urban park size is the most important factor affecting the PCI intensity. Furthermore, larger parks have stronger cooling effects than smaller ones. However, this relationship is non-linear, which suggests the possibility that PCI intensity increases gradually with increases in urban park size when the park size is larger than a certain threshold. However, urban park size still makes a great contribution to the increase in PCI intensity (Table 3, Figure 4). So, an increase in urban park size can be a significant way to increase PCI intensity and mitigate UHI effects.

In addition to urban park size, urban park shape is also significantly correlated to LST. Given a fixed relative area of urban park, PCI intensity can be significantly increased by optimizing urban park shape. Our results showed that urban park shape had a negative relationship with PCI intensity, suggesting that PCI intensity would decrease with increases in the complexity of the shape. It is to say if the urban park area remains the same, the more complex the urban park shape is, the lower the PCI intensity is. This may be because an increase of urban park shape complexity may provide more opportunities for the urban park to come into contact with surrounding built-up areas and facilitate energy flow and exchange, resulting in the decrease of PCI intensity [36].

Besides, the results of regression analysis of PCI intensity revealed that urban forest structures (canopy density, LAI, basal area, height, diameter and stem density) had significant impact on the cooling effects of urban parks (Table 4). This may be because the different kinds of urban forest in parks have different evapotranspiration and thermal emissivity characteristics, so the cooling effects of parks with different forest structures should behave differently. However, urban forest structures such as canopy density, LAI, basal area, height, diameter and stem density played different roles in the PCI phenomenon. The canopy density was the most effective in cooling across all structural factors. As is known to us, canopy density is correlated with shading. Tree shading and evapotranspiration are considered two principal ways to create cooler temperatures. Shashua-Bar and Hoffman [37] found that on average about 80% of the cooling effect in tropical and subtropical climate regions could be contributed to tree shading which attenuates radiant energy flows. Our findings agreed with the study conducted by Shashua-Bar and Hoffman [37,38] that tree shading is the most important way to create cooler temperatures in comparison to evapotranspiration. In our study, it was considered that tree shading can also mainly affect the magnitude of the cooling effect in temperate regions just like Changchun City in China. It may be because the summer in Changchun is characterized by intense solar radiation and a high humidity environment which increases the shading cooling potential and decreases the transpirational cooling potential [22,38]. However, like tree shading, transpiration also plays an important role in the cooling effect of trees. It was further supported by the effect of LAI on PCI intensity. In addition to canopy density, LAI also had a significant impact on the cooling effects and it ranked second in importance of urban forest structures regarding cooling effects. It is well known that LAI is an important variable that influences the exchanges of evapotranspiration between forest ecosystems and the atmosphere that can influence the cooling effects of urban forests. So, it proved that urban forests can significantly decrease the surface temperatures in cities through evaporative cooling in addition to tree shading. It should be noted that our study identified six elements of urban forest structures that impact the cooling effects of urban parks. However, the other factors such as urban tree species and shapes, forest positions, forest health, forest composition and so on still require further research in order to gain more insight into the quantitative relationship between PCI intensity and urban forest structures.

In order to deepen the understanding of the interactions between PCI intensity and urban park characteristics, further research on their relationship at different seasons has been conducted to systematically examine whether this relationship changes across seasons. The noteworthy finding of this study is the seasonal change of the relationship between PCI intensity and urban park characteristics. The results showed that the relationship in summer between PCI intensity and urban park characteristics was stronger than that in autumn. Urban park characteristics such as urban park size, shape and forest structures may also play a more important role in mitigating urban heat islands in summer than in autumn. Our results confirmed the conclusion from previous studies that there are seasonal variations in the relationships between LST and urban land cover characteristics [26,39].

4.2. Management Implications

An examination of the relationship between PCI intensity and urban park characteristics has great management implications for urban planners. This suggests that PCI intensity could be increased by increasing the relative size of urban parks and optimizing their shape and forest structures.

Our results from this study showed that the increase in urban park size can significantly increase PCI intensity which is widely accepted by most researchers [17–19]. So, the increase of urban park size is still an important measure to increase PCI intensity for mitigating the UHI. However, this relationship between PCI intensity and urban park size is non-linear, which suggests that PCI intensity increases rapidly when urban park sizes are small, and then increases slowly with urban park sizes increasing. Besides, increases in urban park size are hardly possible today because of the limited available land area in most cities. Therefore, it is wiser to increase PCI intensity by optimizing urban park shapes and forest structures within the fixed size of the urban park.

It was found in our study that there was a negative correlation between PCI intensity and urban park shape (area/perimeter). Given a fixed area of urban park, the ratio of area/perimeter reaches the lowest value when the urban park shape is round. So, the rounder the urban park shape is, the better the cool island effect. Furthermore, it also suggested that planners should pay attention to the structures of urban forests (canopy density, LAI, basal area, height, diameter and stem density). Urban forest structures had significant impact on the cooling effects of urban parks, among which canopy density and LAI were the most effective in cooling. So, the trees, shrubs and grass should be designed in optimal ways to increase canopy density and LAI to maximize the cooling effect of urban parks. This measure can be done by forest management such as tree selecting, pruning and shaping. In practice, the multilayer forest communities with high canopy density and LAI were obviously the most effective in terms of the cooling effect. These results have important implications for urban planners about how to plan and design urban parks to mitigate UHI, particularly for cities where urban parks are still under construction.

Moreover, the results also showed that the relationship between PCI intensity and urban park characteristics changes across seasons. Urban park characteristics may play a more important role in mitigating urban heat islands in summer than in autumn. Seasons should be considered when exploring the relationship between PCI intensity and urban park characteristics.

It should be noted that PCI intensity was obtained by only two daytime thermal images for summer and autumn in our research. Our study only confirmed PCI intensity at 10:12 a.m. local time in summer and 10:11 a.m. local time in autumn (Table 1). However, some studies based on air temperature with field-based measurements showed there are the diurnal differences in the cooling effects of urban forest [40–44]. They found that the cooling effects in early afternoon are often greater than that in the morning, which may result in a change of relationship between PCI intensity and urban park characteristics. In our study, remote sensing was used to uncover the relationship between PCI intensity and urban park characteristics. However, it cannot be used to explore the diurnal variation of their relationship because of its low temporal resolution. Additionally, it is almost impossible to obtain several remote sensing images at different times for one day in the selected study area. In many previous studies, the field-based measurements were often used to uncover the diurnal variation of the cooling effects for one or several parks. However, it is very difficult to explore the relationship between PCI intensity and urban park characteristics through field-based measurements because it is extremely labor-intensive and time-consuming to obtain PCI intensity simultaneously for many parks used for statistical analyses. So, multi-approaches that integrate remote sensing data with field-based measurement data should be used to estimate the diurnal variation of relationship between PCI intensity and urban park characteristics in future research.

In addition, the different climatic conditions, specifically precipitation and temperature, as well as the individual characteristics of a city may also significantly influence their relationship [45–47]. Spronken-Smith and Oke [16] studied PCI intensity for 10 parks in both Vancouver with a Maritime temperate climate and Sacramento with a dry-summer subtropical climate, which showed that a larger PCI intensity is likely to prevail in Sacramento with its dry-summer subtropical climate. Furthermore, they also showed that a larger PCI is also possible within irrigated parks in Sacramento. Shashua-Bar and Hoffman [37] additionally found the cooling effect of trees can be greater on the days with higher background temperatures in Tel Aviv. However, the cooling effects for urban parks in the arid climate may be non-existent due to the lack of precipitation or irrigation when the temperatures are very high. This might be because the trees shut down their stomata, and due to decreased evapotranspiration from water stress and high temperatures. So, the change of PCI intensity caused by different climate factors, such as precipitation and temperature, may result in a change of relationship between PCI intensity and urban park characteristics. However, whether the relationship between PCI intensity and urban park characteristics changes across different climates is still unknown. Therefore, the above limits should be noted when applying the results from this study to other cities or in different climates. Further studies about the relationship between PCI intensity and urban park characteristics for different times of the day and different climates or cities should be conducted in the future.

5. Conclusions

The establishment of urban parks is a critical measure to mitigate UHI in cities. Understanding the relationship between PCI intensity and urban park characteristics is very important for urban planners to design urban parks to mitigate UHI. Based on the field-based survey, Landsat TM and SPOT imagery in Changchun city, this study estimated the relationship between PCI intensity and urban park characteristics. The following conclusion can be realized:

(1) Urban parks can create PCI effects. However, the PCI intensity varied across seasons and the cooling effect of parks in summer was higher than that in autumn.

(2) Urban park size was the most important factor for mitigating UHI, and increases in urban park size were still an effective measure to mitigate UHI.

(3) Not only does urban park size but also urban park shape significantly affects PCI intensity. Given a fixed size of urban park, LST can be significantly increased or decreased by the different shapes of an urban park. Our results showed that the rounder the urban park shape is, the better the cooling effect achieved. Besides, urban forest structures also had significant impacts on the cooling effects of urban parks, among which the canopy density and LAI were the most effective in cooling. So, the trees, shrubs and grass should be designed in optimal ways to increase canopy density and LAI to maximize the cooling effect of urban parks. Therefore, UHI can be mitigated by optimizing urban park shape and forest structures when undertaking urban park planning, especially in cities where land resources are too limited to increase urban park size.

(4) The relationship in summer between PCI intensity and urban park characteristics was stronger than that in autumn. Urban park characteristics may play a more important role in mitigating urban heat islands in summer than in autumn.

Our study highlights the importance of urban parks as the most effective tool for mitigating UHI effects. The results in our study may help researchers to understand PCI formation and provide practical guidelines for urban planners to design urban parks with stronger cooling effects to mitigate UHI effects in cities like Changchun.

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