Using satellite imagery analysis to classify and redesign provincial parks for a better cooling effect on cities

The case study of South Holland

Icaza, Leyre Echevarría; Dobbelsteen, Andy Van Den; Hoeven, Frank Van der

DOI
10.7480/rius.4.904

Publication date
2016

Document Version
Final published version

Published in
Research in Urbanism Series (online)

Citation (APA)
Icaza, L. E., Dobbelsteen, A. V. D., & Hoeven, F. V. D. (2016). Using satellite imagery analysis to classify and redesign provincial parks for a better cooling effect on cities: The case study of South Holland. *Research in Urbanism Series (online)*, *4*(1), 157-183. https://doi.org/10.7480/rius.4.904

Using Satellite Imagery Analysis to Redesign Provincial Parks for a Better Cooling Effect on Cities

The case of South Holland

LEYRE ECHEVARRIA ICAZA, ANDY VAN DEN DOBBELSTEEN, FRANK VAN DER HOEVEN

Echevarría Icaza, L., Van Den Dobbelsteen, A., & Van der Hoeven, F. (2016). Using satellite imagery analysis to classify and redesign provincial parks for a better cooling effect on cities. The case study of South Holland. *Research In Urbanism Series*, 4(1), 157-184. doi:10.7480/rius.4.904

Abstract

The purpose of this research is to analyse the thermal behaviour of South Holland provincial parks during heat waves, in order to provide design adaptation guidelines to increase their cooling capacity over the hotspots present in their urban surroundings. This research analyses the thermal behaviour of different land use patches (forests, cropland, grassland, water surfaces, built areas and greenhouse areas) present in the six South Holland provincial parks during heat waves. It studies their average night land surface temperature (LST) (with Modis 11A1), day LST (with Landsat 5TM), NDVI, imperviousness, patch size and patch shape index, and analyses through a multiple regression analysis the impact of each of these last four parameters in the night and day LST for each land use. Within each land use category, NDVI, imperviousness and patch shape index influence differently the thermal behaviour of the patches. NDVI is inversely correlated to day LST for all categories, imperviousness is correlated to day LST for all areas which do not comprise a significant presence of greenhouses (grassland and built patches) and inversely correlated to LST for areas with a high presence of greenhouses (cropland and warehouses). Finally the shape index varies depending on the nature of the surrounding patches, especially for small patches (built areas, forests and greenhouse areas). Most of the hotspots surrounding the Midden-Delfland park are adjacent to grassland patches. The measure to increase the cooling capacity of those patches would consist in a change of land use and or an increase of the NDVI of the existing grassland patches. These suggestions to increase the cooling potential of the parks remain deliberately open in order to allow combining these measures with other spatial planning priorities.

KEYWORDS

urbanism; remote sensing; GIS; urban heat island; cooling effect; climate change adaptation; landscape design

1. INTRODUCTION

1.1 The Urban Heat Island effect

In the Netherlands, a heat wave is defined as a sequence of at least five consecutive summer days (days on which the weather station of De Bilt registers a maximum temperature of 25.0°C or higher), among which there are at least three tropical days (days on which the weather station of De Bilt registers a maximum temperature of 30ºC or more). The European heat wave of the summer of 2003 led to more than 70,000 excess deaths over four months in Central and Western Europe (Brücker, 2005; Robine et al., 2008; Sardon, 2007). More specifically, in the Netherlands, the number of deaths attributed to this event ranged from 1,400 to 2,200 (Garssen et al., 2005). The following European heat wave took place in 2006 and caused in the Netherlands in the month of July alone 1,000 excess deaths (Hoyois et al., 2007) of which 470 in the province of South Holland (Centraal Bureau voor de Statistiek (CBS), 2006). The Dutch province of South Holland was most affected by the 2006 heatwave (CBS, 2006).

During heat waves the urban heat island effect (UHI), which refers to the temperature difference between the built-up areas and their natural surroundings, reaches its peak. The UHI increases daily average temperatures and reduces the capacity to cool off during the night. Urban Heat Islands are caused by changes in the radiative and thermal properties of the environment introduced by human constructions. Recent studies reveal that Dutch cities experience a mean daily UHI effect of 2.3 K and a 95 percentile of 5.3 K during summer (Steeneveld et al., 2011). Moreover, the UHI phenomenon is likely to become a concern in the Netherlands affecting not only larger settlements but also smaller ones (Van Hove et al., 2011). Even though on site air temperature measurements provide a better overview of the intensity of the phenomenon (since it measures directly the temperatures experienced by the population at a particular area) the average night land surface temperature LST is often used as an indicator because for large surfaces it provides a more global overview of the temperature distribution. Because of that reason, most of the previous climatological studies on the cooling potential of parks analyse the LST instead of air temperature (Cao et al. 2010, Choi H. et al. 2012, Cheng X. et al., 2014).

1.2 Greenery as a cooling source

During heat waves cities can benefit from the cooling effect of different greenery typologies existing in and around them. Previous studies on the cooling role of greenery can be divided in two groups: studies dealing with large green infrastructure, and studies concentrating on urban parks.

Green infrastructure

In the first group (studies on large green infrastructure) landscape is considered as an existing natural cooling source. The landscape supports a climate design of the urban environment that promotes cool wind flows within cities. An example of applying air circulation patterns in spatial planning can be found in the Climate Analysis Map for the Stuttgart region, 2008 (City of Stuttgart, 2008; Hebbert & Jankovi, 2010; Hebbert & Webb, 2011; Kazmierczak & Carter, 2010), in the Urban Climate Analysis Map for the Dutch city of Arnhem (developed within the Future Cities project), and in the cool wind corridors of the German city of Freiburg, where the adoption of a Sustainable Urban Development Policy and the Land Use Plan 2020 (Freiburg, 2013). The last plan envisions the transformation of 30 hectares of building space into open areas, not only extend and connect the cities' green infrastructure, but also 'emphasize the cool air flow areas and urban ventilation lines within and outside the city' (Burghardt et al., 2010; City of Freiburg, 2013).

Urban Parks

The second group (studies on the cooling role of greenery) concentrates on urban parks with sizes of up to 500 ha. They analyses the cooling effect these parks have on the surrounding urban environment during calm weather conditions. These studies use several indicators to quantify the cooling capacity of the parks in their surrounding urban areas. Chang et al. (2007) define the local cool island intensity as the temperature difference between the interior of the park and the urban nearby surroundings; Cheng et al. (2014) define the maximum local cool island intensity as the maximum mean land surface temperature of the parks' surroundings and the mean land surface temperature of the parks. Cheng also analyses the maximum cooling range of the parks, which is defined as the maximum distance of maximum local cool island intensity. In principle, the longer the cooling distances the smaller the local cool island intensity. Finally, Cheng also defines the maximum cooling area of the parks, as the largest area influenced by the cooling effect of the park. The local cool island intensity, the maximum cool island intensity, the maximum cooling distance and the maximum cooling area of parks are different indicators of the parks cooling effect; however, they are all interrelated.

The main factors influencing the local cool island intensity under calm weather conditions are the size of the parks (Von Stülpnagel et al., 1990; Upmanis et al., 1998; Cheng et al, 2014), the height and structure of the surrounding constructions (Upmanis et al., 1998; Jauregui, 1975, 1990-1991; Spronken-Smith, 1994), and the design of the parks. Regarding the design of the parks, previous studies concluded that the role of vegetation in parks differs, depending on whether it is day or night. During the day, local cool island intensity is related to the area of trees and shrubs inside the park (Cao et al., 2010; Potchter et al., 2006; Yu & Hien, 2006; Zhou et al., 2011), while at night the coolest parks are those without trees (Chang et al., 2007; Taha, 1991). Thus, grassland presents higher diurnal surface temperatures than tree areas while at night the surface temperature of grassland drops further compared to the wooded areas, especially when grassland is irrigated (Spronken-Smith & Oke, 2000). A strong correlation was also found between paved surfaces and LST (Zhou et al., 2011; Li et al., 2011); more specifically, diurnal LST is correlated with the largest patch index of the urban land-use type (Cheng et al., 2014). The same impervious surface produces a smaller UHI effect when it is spatially distributed (Li et al., 2011).

Finally, the role of water surfaces is unclear, but appears to depend on the size and depth of the body of water. Some studies revealed water had a positive effect on local cool island intensity (Saaroni & Ziv, 2003), while others have suggested its contribution is negligible (Cao et al., 2010).

South Holland provincial parks

This research falls somewhere between these two groups. On the one hand the South Holland provincial parks analysed (Midden-Delfland, Duin Horst en Weide, Wijk en Wouden, Bentwoud/Rottemeren, Hollands Plassengebied and IJsselmonde) are large enough to be considered as part of the landscape (Figure 1) and on the other hand these are man-made parks that were completely designed. All trees were planted and most water elements were dug out. The provincial main strategic guidelines aim at creating a province that is resilient to climate change and that is characterised by its spatial and sustainable quality however its spatial vision (Structuurvisie Zuid-Holland, 2010) doesn´t specifically address the UHI phenomenon. Furthermore, with 1227 inhabitants per km2 the province of South Holland is the densest province in The Netherlands and the one most affected by the UHI effect (Centraal Bureau voor de Statistiek, 2006).

1.3 Research questions

In order to allow urban areas to benefit from the cooling capacity that provincial parks may offer, we need a better understanding of the thermal behaviour of regional parks and their spatial components.

The main research question underlying this paper is:

- How can the development of the regional park system in the province of South Holland be optimised in order to provide surrounding urban areas with a long-term source of natural cooling capacity?

In order to answer this question we have formulated several sub-questions:

- What is the thermal behaviour of the different land-use categories (forests, cropland, grassland, water surfaces, built areas and greenhouse areas) that can be found in South Holland provincial parks? How do the normalized difference vegetation index (NDVI), imperviousness coefficient, patch size and patch shape index affect their average night-time LST and their average day-time LST during heat waves?

- How can we design adaptation guidelines to increase the cooling capacity of provincial parks? Can we use remote sensing to diagnose heat accumulation in urban areas surrounding parks and to prescribe measures to increase the cooling capacity of the adjacent park areas?

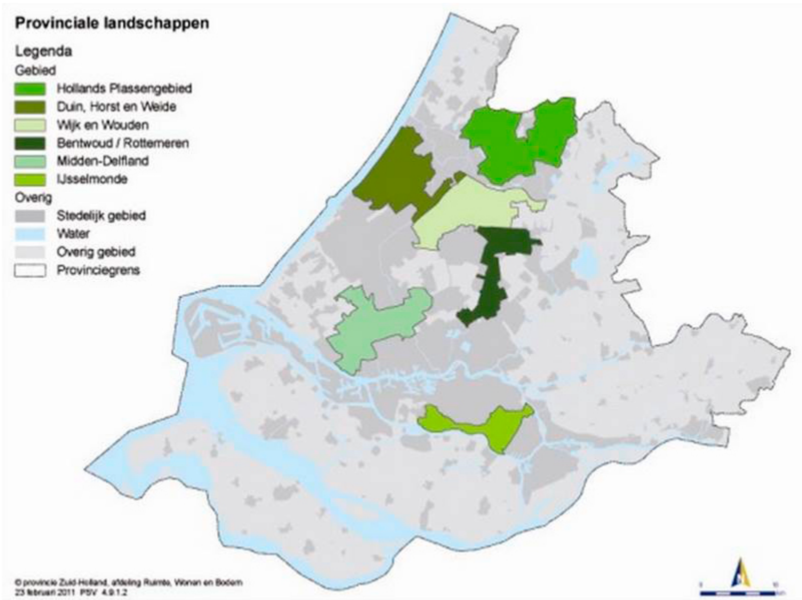


Figure 1: South Holland provincial parks (Province of South Holland, Spatial Planning and Housing Department, 2011)

2. METHODOLOGY

2.1 Definition of thermal behaviour of land-use categories in South Holland provincial parks

The six main land-use categories defined in the Spatial Vision of the region of South Holland, and which can be identified in its six provincial parks are: forests, cropland, grassland, water surfaces, built areas and greenhouse areas. For each of these categories we have used as indicators of thermal behaviour the average night-time land surface temperature (LST) and the average day-time LST, and as influencing parameters: NDVI, imperviousness coefficient, size of the land-use patch and shape index of the surface patch. For each patch in each land-use category we have calculated the average values of the above mentioned parameters, and we have carried out a multiple regression analysis in order to understand what parameters influence most the thermal behaviour of the patches of each land-use category. We have used remote satellite imagery to map and calculate night LST, day LST and NDVI. All satellite images have been obtained through the US Geological Survey (USGS) webpage, Earth Resources Observation and Science Center (EROS).

Mapping thermal behaviour indicators: Night and day LST

We have used nine Modis 11A1 satellite images (from the 15th till the 20th of July), retrieved during the second heat wave of 2006 to map and calculate average night-time LST. Modis 11A1 is a Modis product which bands provide LST and emissivity values on a daily basis with a 1 km resolution. For the calculation of the day LST we have used Landsat 5 TM satellite imagery (retrieved on the 16th of July). Landsat 5 has a 16-day repeat cycle referenced to the Worldwide Reference System 2. Its data files, which consist of seven spectral bands, were downloaded from the US Geological Survey (USGS), EROS Center webpage. We calculated and mapped the diurnal LST using ENVI 4.7 software and following the Yale Center for Earth Observation 2010 instructions to convert thermal infrared band 6 into temperatures. Landsat TM collects band 6 at a resolution of 120 m and further resamples it to 30 meters. We first made a geometrical correction and calibrated band 6. The atmospherically corrected radiance was then obtained by applying Coll's equation (Coll et al., 2010):

$$CVR2 = [(CVR1 - L)/] - [(1-)*(L)/] \qquad \text{(Equation 1)}$$

Where:

- CVR2 is the atmospherically corrected cell value as radiance
- CVR1 is the cell value as radiance
- L is upwelling radiance
- L is downwelling radiance
- is transmittance
- is emissivity (typically 0.95)

The transmittance and the upwelling, as well as the downwelling radiance, were retrieved from NASA's webpage. Finally, the radiance was transformed into temperatures (Kelvin and Celsius) (Figure 2).

$$T = K2 / [\ln((K1/CVR2) + 1)] \qquad \text{(Equation 2)}$$

Where:

- T is degrees Kelvin
- CVR2 is the atmospherically corrected cell value as radiance

The result of the processed Landsat 5 TM imagery is shown in Figure 2.

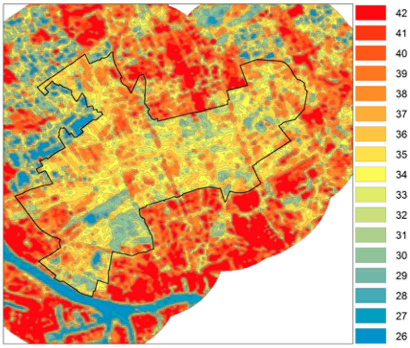


Figure 2: Land surface temperature image retrieved from Landsat 5TM

Mapping influencing parameters: NDVI, imperviousness, patch size and shape

We have used Landsat 5TM imagery retrieved during the heat wave of 2006 to map and (on the 16th of July) to calculate the average NDVI. We have used ATCOR 2.3 to correct geometrically and atmospherically the raw satellite imagery. The index is defined as (NIR-VIS)/(NIR+VIS), where VIS (visible radiation obtained in band 3) is the surface reflectance in the red region (650 nm) and NIR (near-infrared radiation obtained in band 4) is the surface reflectance in the near-infrared region (850 nm)

We have used TOP 10 NL GIS file to calculate the impervious surface area within the parks, considering the areas covered by buildings and roads as 100% impervious surfaces and the rest of the surfaces as 0% impervious surfaces.

In order to estimate the influence of the patch shape on the thermal behaviour of the patches per land-use category, we have used the landscape shape index (LSI) defined by Patton (1975) and that calculates the compactness degree (Cao et al., 2010):

$$LSI = Pt/(2\sqrt{(\pi.A)}) \qquad \text{(Equation 3)}$$

Where Pt is the perimeter of the patch and A is the area of the patch.

Overall, we analysed the thermal indicators (night and day LST) and the influencing parameters (NDVI, imperviousness and size and shape index) of 32 forest patches, 68 cropland patches, 115 grassland patches, 28 water surfaces, and 2284 urban areas and 339 greenhouse areas.

Surface thermal classification of South Holland provincial parks

Even though NDVI and imperviousness of the patches have different influences on night and day LST depending on the analysed land use, the average values of these parameters are often similar. In order to obtain a better understanding of the thermal behaviour of the different land-use patches, we have carried out in GIS an unsupervised classification of the overlap of the day LST, NDVI and imperviousness maps, and we have obtained five thermal clusters in the South Holland provincial parks. We have further calculated the proportion of each of these thermal clusters for each of the studied land uses.

2.2 Definition of design adaptation guidelines to increase the cooling capacity of Midden-Delfland provincial park

In this section we have studied how we could use remote sensing to diagnose heat accumulation in urban areas surrounding parks and how we could prescribe measures to increase the cooling capacity of the adjacent park areas.

Heat diagnosis: heat accumulation in urban areas surrounding parks

As revealed by the climatologic studies previously discussed, the design of parks influences their cooling capacity. One of the indicators used to evaluate a park's cooling capacity is the local cool island intensity, which measures the temperature difference of the park's immediate surroundings and the temperature inside the park. For large parks such as the South Holland provincial parks, which sizes range from 3,745 to 10,658 ha it is complicated to define the local cool island intensity, since the temperatures within the parks vary greatly and the same occurs with the areas surrounding the parks. The local cool island intensity varies consistently, depending on which area of the park is selected, and which area surrounding the park is picked. Therefore for this study we have chosen to analyse the temperature differences between the urban hotspots surrounding one of the parks, and the park areas adjacent to those hotspots and closer than 500 m. We have chosen Midden-Delfland park, which is the South Holland provincial park located between the region of The Hague and Rotterdam.

We have defined two types of hotspots within a distance of 500 m from the parks boundary. The first category comprises areas with an LST above 42°C and areas greater than 10 ha. The second hotspot group comprises areas with an LST above 36°C and with lengths connecting the park larger than 1500 m.

Tool: We have used day LST maps obtained through Landsat 5TM processing to map the hotspots in the urban areas surrounding the park. We have chosen to map only day LST hotspot, due to the higher resolution of Landsat 5TM imagery (120m) compared to Modis 11A1 (1km). Landsat 5TM seems more appropriate for urban analysis (Figure 2).

Identifying park areas adjacent to hotspots with an improvable cooling capacity

We further analysed the park areas adjacent to the hotspots and we identified the areas that had LST differences of less than 10°C compared with the hotspots. We call those areas "park adaptation areas" (PAA). These are the areas for which we suggest to modify the park design in order to increase the temperature difference with the hotspots, and thus to increase the local cool island intensity corresponding to those hotspots.

Tool: We imported and combined LST images into Arcmap 10 to calculate the temperature difference between the different pixels throughout the LST map (Figure 3).

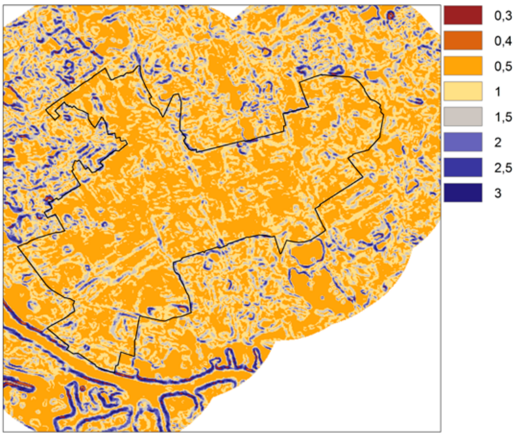


Figure 3: Land surface temperature differences in Midden-Delfland

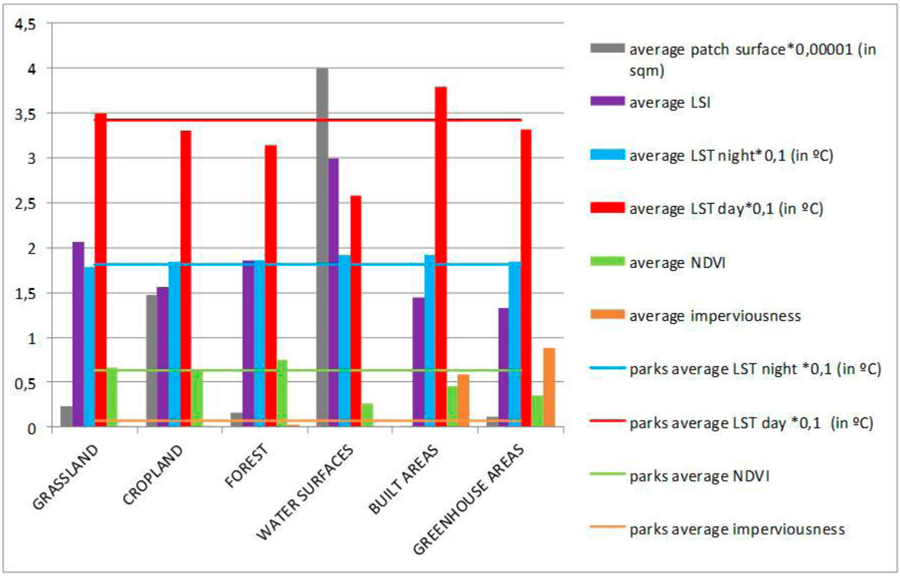
Prescribing measures to increase the cooling capacity of the park areas adjacent to hotspots

We have used the results obtained in section 1 to define adaptation measures in order to increase the cooling capacity of the PAAs. The measures consist, either in a change of land use, or on the increase of NDVI, decrease of imperviousness or on changing the size and/or shape index of the patches currently occupying the PAAs.

3. RESULTS

3.1 Results of the analysis of night LST, day LST, NDVI, imperviousness, patch surface and patch shape index for six main land-use categories in South Holland provincial parks

The analysis of the average night LST reveals that the values presented for each land use only vary in 1,4ºC. Maximum night LST is 19,2ºC registered in built areas and water surfaces and minimum night LST is 17,8ºC registered in grassland surfaces. In turn, the average day LST presents differences of up to 12ºC with an average day LST of 25,8ºC for water surfaces and 37,9ºC for built areas. Forest patches present the second lowest day LST with 31,4ºC. Greenhouse patches and cropland present an average LST 1,8ºC lower than grassland. Greenhouses are characterized by highly reflective glass roofs, which help reduce the surface temperatures. The difference between cropland and grassland is mainly due to the irrigation of cropland (Graph 1).



Graph 1: Average night LST, day LST, NDVI, imperviousness, patch surface and patch shape index for the six main land-use typologies of South Holland provincial parks.

Forests

As concluded by previous scholars, surfaces of trees contribute to increasing the diurnal cooling capacity of parks (Cao et al., 2010; Potchter et al., 2006; Yu et al., 2006; Zhou et al., 2011). Indeed, the average day LST of forested areas is 2,7ºC below the park's average, whereas the forested areas night LST is slightly above the parks average (Graph 1). The multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 16 forest patches with surfaces of more than 1 ha of South Holland provincial parks (Graph 2) reveals that a multiple correlation coefficient of R = 0,8 and R2 = 0,6 relating day LST to the rest of parameters for forest patches, with the following coefficients:

LST d = 76,4 – 59,5*NDVI + 0,1*I + 1,5E-05*S -0,2*LSI, where LST d is the day LST, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index. (Graph 2).

NDVI and LSI play the most important role for the determination of day LST. The inverse correlation between day-time LST and NDVI (which range from 0,7 to 0,8, Graph 2) is aligned with previous research, in turn, the inverse correlation between day LST and the slenderness of the patches is surprising. A more detailed analysis of the size and shape of the forest patches reveals that these are relatively small and the larger patches contain numerous narrowings. South Holland provincial parks include a total of 7,774 forest patches, of which only 585 patches (7,5 percent) have surfaces of more than 10 ha. GIS is only able to calculate the average day LST of 2,7 percent of these 585 patches, due to the amount of bottlenecks which prevent the program from calculating with Landsat the average patch LST (Landsat 5TM band 6, which is the one used for the day LST calculation, has a resolution of 120 m, which has been further resampled into 30 m; this resolution does not allow to calculate LST values of the finer narrowings). The analysed patches (Graph 2), present an average patch surface of 1,6 ha, and an average patch LSI of 1,9. They are the ones presenting shapes regular enough to allow GIS to extract the average LST, however, some of the analysed patches present widths below 100 m. Therefore, the inverse correlation found between the day LST and the slenderness of the shape might be the result of the influence of the surroundings of the analysed patches (Figure 4), which might increase or decrease the average temperature of the forest patch depending on its land use.

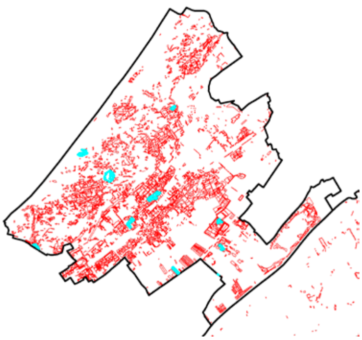
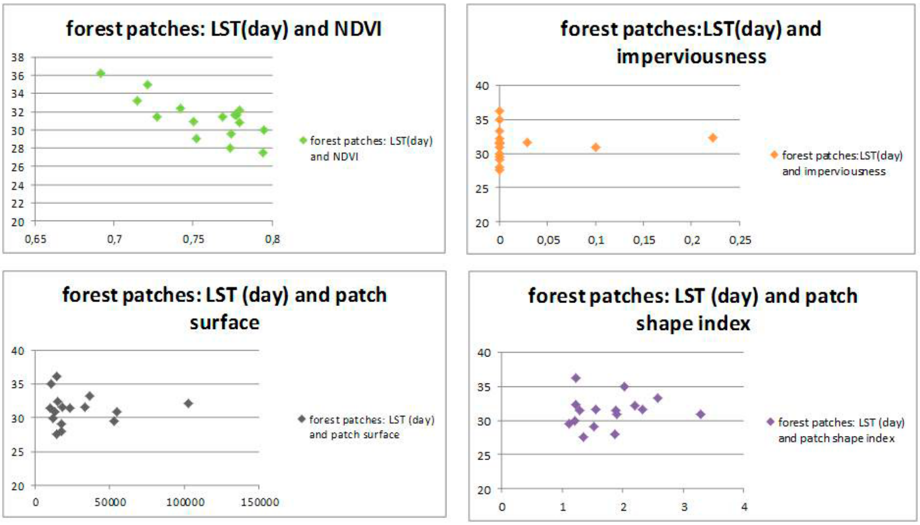


Figure 4: In red, forest patches of Duin, Horst en Weide provincial park, with small surfaces and numerous narrowings. In blue, analysed forest patches.



Graph 2: Analysis of the relationship between the different parameters and day-time LST for forest patches with surfaces above 1 ha in South Holland provincial parks.

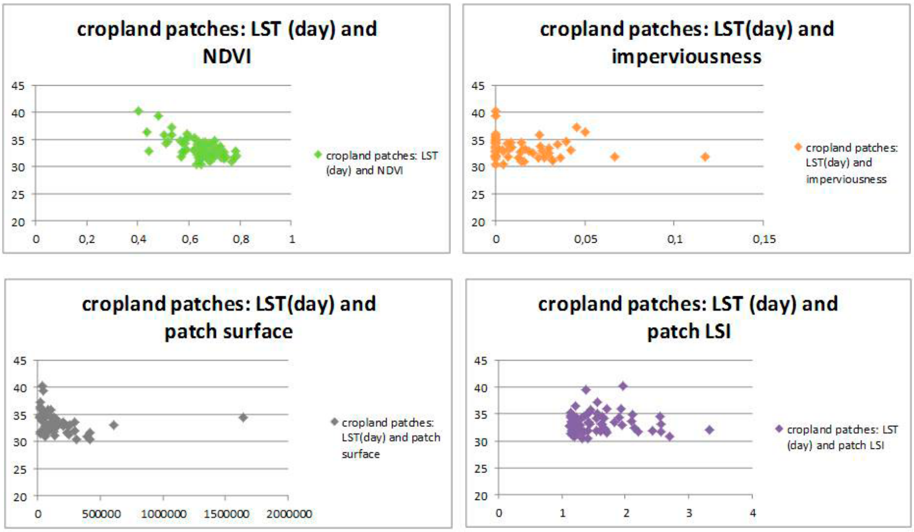
Cropland

Cropland average day LST is approximately 1ºC below the average park day LST (graph 1). The multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 68 analysed cropland patches of South Holland provincial parks reveals that a multiple correlation coefficient of R = 0,7 and R2 = 0,5 relating day LST to the rest of parameters for cropland patches, with the following coefficients:

LST d = 42,8 – 15,2*NDVI –18,8*I – 1,4E-06*S + 0,5*LSI, where LST d is the day LST, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

Imperviousness and NDVI play the most important role for the determination of day LST. As discussed earlier the inverse correlation between day LST and NDVI seems predictable. In turn, imperviousness is typically correlated with day LST, whereas in this case we find an inverse correlation. If we analyse the imperviousness of the cropland patches, we can see that most of the impervious surface is covered by greenhouses, and that, as described in 3.1., due to the reflectance of the glass, the average day LST of greenhouses is 1ºC lower than the park average surface temperature and presents a similar average LST as the cropland patches, thus contributing to the cooling potential of the patches.

The regression analysis also reveals that day LST is correlated to the slenderness of the patches. The average size of the analysed patches is 14,7 ha, and the average LSI of the analysed patches is 1,5. The more compact the cropland patch, the cooler its surface (Graph 3).



Graph 3: Analysis of the relationship between the different parameters and day-time LST for cropland patches in South Holland provincial parks.

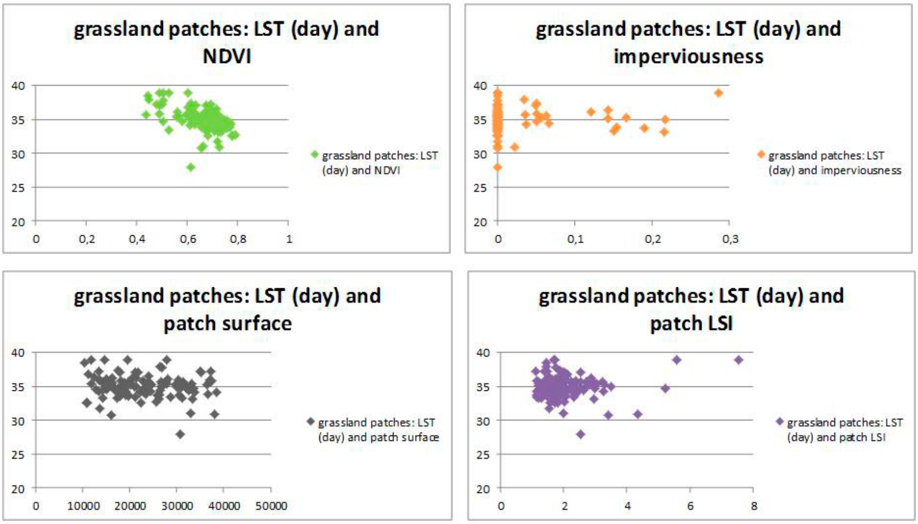
Grassland

Grassland is the land use with the worst thermal behaviour present in South Holland parks, and it actually presents an average day LST 0,7ºC higher than the parks average (Graph 1). The multiple regression analysis (Graph 4) of the average day LST, NDVI, imperviousness, size and shape index of 189 grassland patches with surfaces above 1 ha of South Holland provincial parks reveals that a multiple correlation coefficient of R = 0,5 and R2 = 0,3 relating day LST to the rest of parameters for grassland patches, with the following coefficients:

LST d = 42,7 – 10,9*NDVI + 0,5*I - 2,3E-05*S + 0,02*LSI, where LST d is the day LST, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

Even though the multiple correlation analysis presents a pretty weak correlation (R2 = 0,3), we observe that NDVI and imperviousness play the most important role for the determination of day LST. Compared to the cropland patch analysis, the imperviousness is correlated to the day LST in the case of the grassland patches. This is due to the fact that most of the impervious surfaces comprise conventional roof and pavement surface materials (instead of glass roofs, which are found in the cropland patches).

Since the main difference between cropland and grassland is their irrigation pattern, it seems that in this case evapotranspiration is generating the surface temperature difference between these two land uses. Spronken-Smith (2000) already highlighted the importance of irrigation to increase the cooling effect of parks.



Graph 4: Analysis of the relationship between the different parameters and day-time LST for grassland patches in South Holland provincial parks.

Water surfaces

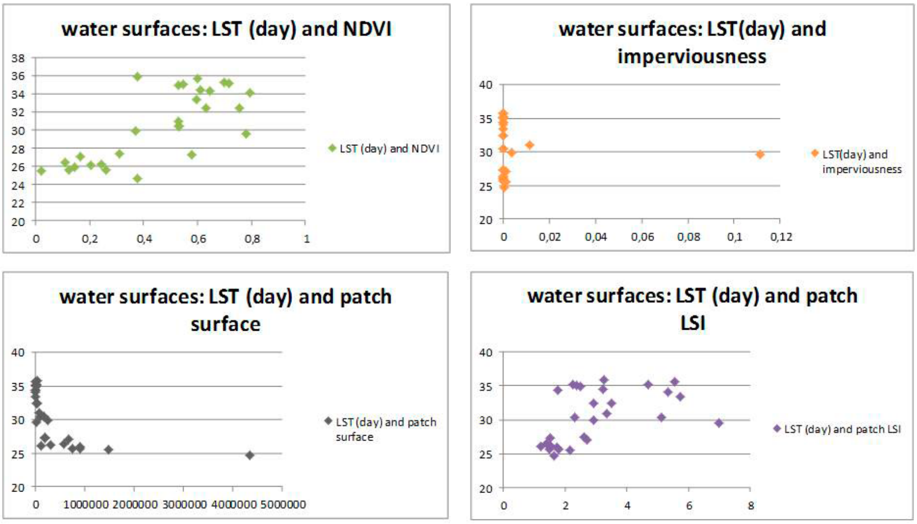
The cooling effect of water surfaces is unclear and seems to vary from case to case (Saaroni and Ziv, 2003; Cao et al., 2010). In the summer of 2006, in the South Holland provincial parks, water surfaces seem to present the lowest average LST with 25,8ºC (Graph1). The sizes of the patches present great variations, and have surfaces that range from 600 sqm till 433 ha. Overall the average patch surface is the highest, with 40 ha, and the average LSI is also the highest, with a value of 3. Small surfaces with high shape indexes correspond to canals, whereas large compact water surfaces correspond to water ponds.

The multiple regression analysis of the average day LST, NDVI, imperviousness and size and shape index of 28 analysed water surface patches of South Holland provincial parks (graph 5) that a multiple correlation coefficient of R = 0,8 and R2 = 0,6 relating day LST to the rest of parameters for water surface patches, with the following coefficients:

LST d = 26 + 10,7*NDVI - 1,4E-06*S + 0,02*LSI, where LST d is the day LST, S is the surface of the patch and LSI is the patch shape index.

NDVI plays the most important role for the determination of day LST, and it increases the water surface temperature. During the summer, in the Netherlands, the water surfaces get covered with lily pads and other water surface vegetation, which have a negative contribution on the water surface cooling capacity.

It seems there is a slight positive correlation between the slenderness of the patch and the day LST.



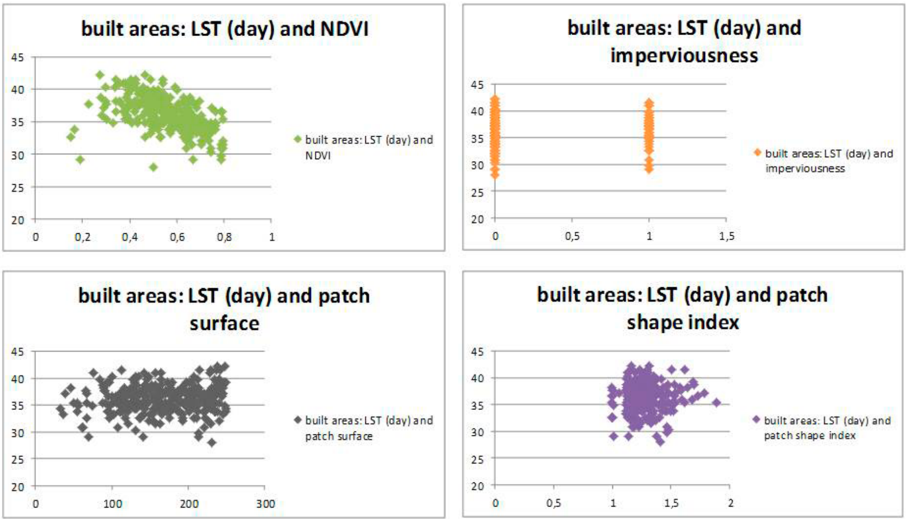
Graph 5: Analysis of the relationship between the different parameters and day-time LST for water surfaces in South Holland provincial parks.

Building patches

Built areas are the land use presenting the highest day LST of South Holland provincial parks with an average day LST of 37,9°C, 3,7°C higher than the average park day LST. Previous studies concluded that the size of urban patches and the amount of paved surfaces is normally correlated with the increase of LST (Cheng et al., 2014; Zhou et al., 2011; Li et al., 2011). However, the structure of the built patches of South Holland parks is one of small and scattered patches. The average built-up patch size is 970 sqm and the average LSI is 1,4, which hinders the analysis with the use of Landsat imagery. As a matter of fact, the multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 323 built patches with surfaces below 250 m2 of South Holland provincial parks (Graph 6) reveals that only a weak multiple correlation coefficient of R = 0,5 and R2 = 0,2 relates day LST to the rest of the parameters, with the following coefficients:

LST d = 39,7 − 9,1*NDVI - 0,02*I + 4,2E-03*S + 0,6*LSI, where LST d is the day LST, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

In this case, NDVI and LSI play the most important role for the determination of day LST. Most of these patches are surrounded by other urban patches, thus the more slender the patch, the more influenced by the surrounding urban environment. The use of Landsat imagery for the assessment of small land-use patches can thus be misleading due to the lack of resolution of the satellite imagery.



Graph 6: Analysis of the relationship between the different parameters and day-time LST for built patches with surfaces below 250 m2 in South Holland provincial parks.

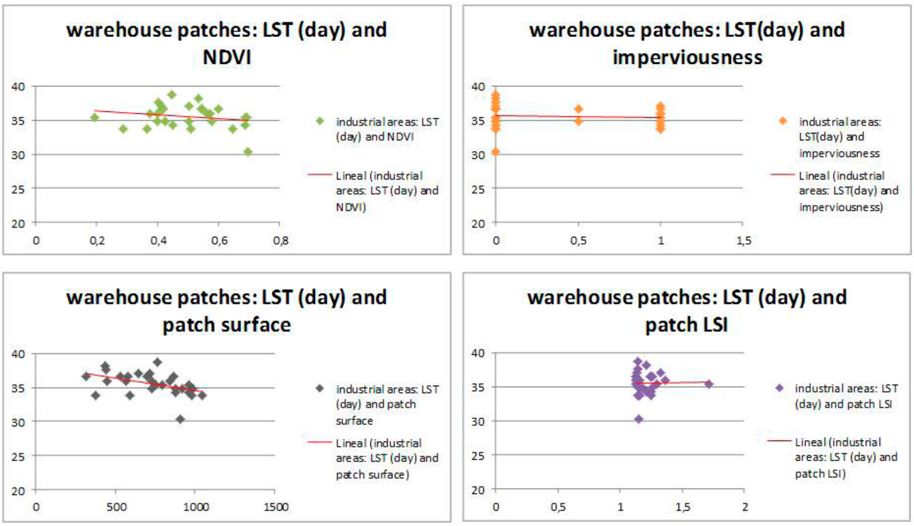
Greenhouse patches

Warehouse patches present an average day LST of 33,1ºC, which is 1ºC lower than the average South Holland park LSTs (Graph 1). Thus they have a cooling effect. Most of the warehouses present in South Holland provincial parks are actually greenhouses with highly reflective glass roofs, which is what contributes to the reduction of the surface temperature of these patches.

The multiple regression analysis of the average day LST, NDVI, imperviousness, size and shape index of 28 industrial patches with surfaces below 1,000 m2 of South Holland provincial parks (Graph 7) reveals that a multiple correlation coefficient of R = 0,5 and R2 = 0,3 relating day LST to the rest of parameters, with the following coefficients:

LST d = 39,8 – 4,1*NDVI -0,6*I – 3,7E-03*S + 0,6*LSI, where LST d is the day LST, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

NDVI, imperviousness and LSI play the most important role for the determination of day LST. We have found an inverse correlation between day LST and imperviousness due to the fact that even though greenhouse areas represent surfaces with high imperviousness, they contribute to the reduction of the surface temperature due to the high reflectance of their glass roofs. We have also noted that day LST is slightly correlated to the slenderness of the patches, due to the influence of warmer surroundings.



Graph 7: Analysis of the relationship between the different parameters and day-time LST for warehouse patches with surfaces below 1,000 sqm in South Holland provincial parks.

Conclusion

The analysis of all the land-use patches shows that the LST of the different park components varies depending on their land use. The multiple correlation analysis of the patch night LST and day LST for each land use reveals that NDVI is inversely correlated to LST (in both cases) for all studied land uses (forest, cropland, grassland, water surface, built areas and warehouse areas). In turn, imperviousness and the shape of patches vary differently depending on the land use, and the size of the patches.

As far as imperviousness is concerned, generally imperviousness is correlated to the day LST, except for cropland and greenhouse areas, where the impervious surfaces represent greenhouse surfaces, which have highly reflective roofs which contribute to the reduction of day LST.

The conclusions regarding the influence of the patch shape in the average LST are highly influenced by the nature of the areas surrounding the studied patches. In that sense we can organize the studied land uses in three groups. The first group is made of large patches surrounded with warmer areas: it is the case of cropland, grassland and water surfaces. The second group is made of small patches clustered around each other: this is the case of forest patches and built area patches. The third group is formed by small-scattered patches, surrounded by warmer areas: this is the case of the warehouse patches. The first land-use group (cropland, grassland and water surfaces) sees its average LST increase with the increase of the slenderness of its patches. The more slender, the more influenced by their warmer surroundings. The second group (forest and built areas) is influenced by the average LST of their own patches. The more slender the forest patch, the cooler the temperature due to the presence of the surrounding forests. The more slender the built area, the more influenced it will be by the high LST of the surrounding built areas. The third group of greenhouses, is surrounded by warm areas, the more slender the patches, the higher the day LST.

Surface thermal classification

The unsupervised thermal classification of the day LST, NDVI and imperviousness layers reveals that there are five surface clusters in South Holland provincial parks, each of these clusters have different average day LST, NDVI and imperviousness combinations. The average night LST doesn´t vary much between the different clusters, in turn, day LST varies considerably, and presents the lowest average values for cluster 1 and the highest values for cluster 5 (graph 8). The analysis of the cluster composition of the different land-use categories (graph 9) reveals that cluster 1 can be assimilated to water surfaces, cluster 2 to trees and bush areas, cluster 3 could be assimilated with greener grassland patches, whereas cluster 4 covers warmer grassland patches, and finally cluster 5 can be identified with urban areas and bare soil zones (Figure 6).

Since the greenhouse patches only represent a very small part of the parks surface the unsupervised classification hasn´t produced a specific cluster assimilable to glass surfaces. In turn, greenhouse surfaces fall sometimes into the cluster 1 category (assimilated with water), and other times into cluster 2 category (assimilated with trees and bush areas) (Figure 5).

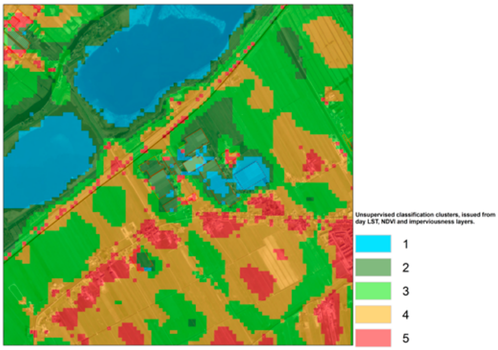


Figure 5: Unsupervised classification clusters from day LST, NDVI and imperviousness. The greenhouse areas are classified either in the same cluster as water or on the same cluster of forested areas. Due to their small presence in the parks, they are grouped with categories with similar thermal behaviour.

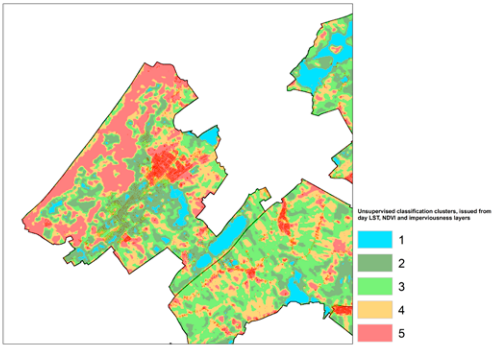
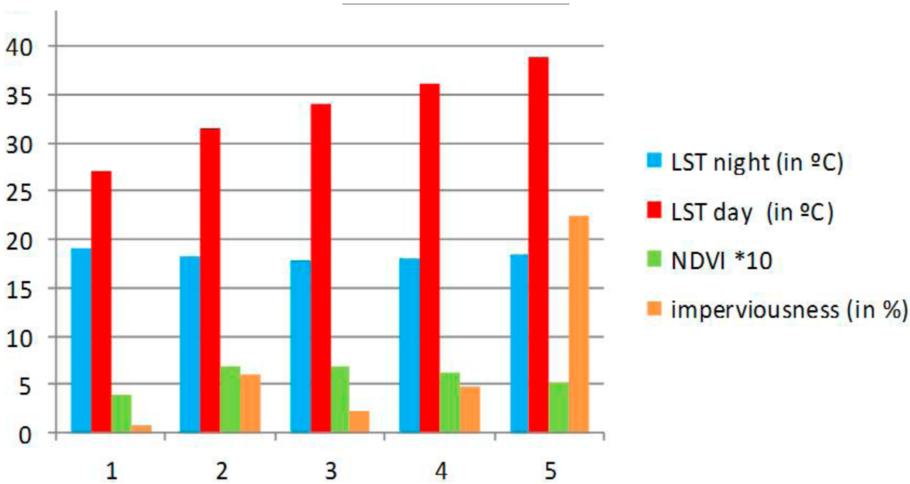
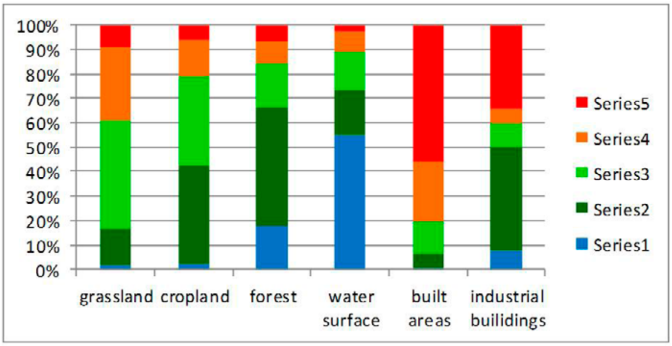


Figure 6: Unsupervised classification clusters from day LST, NDVI and imperviousness. The bare soil areas of the coast are classified in the same cluster as the built up areas. They have a similar thermal behaviour.



Graph 8: Average day LST, night LST, NDVI and imperviousness for the five different clusters produced by the unsupervised classification of the day LST, NDVI and imperviousness maps.



Graph 9: Cluster composition of the different land use present in South Holland provincial parks.

3.2 Defining adaptation measures to improve provincial parks cooling capacity

Once we have analysed the thermal behaviour of the different land-use typologies encountered in South Holland provincial parks, we have identified park adaptation areas (PAA) which are park areas adjacent to urban hotspots surrounding the parks, and which could potentially help cool these hotspots.

Identifying hotspots in the urban areas surrounding the parks

Hotspots with LST above 41ºC

The analysis of the hotspots surrounding the Midden-Delfland park reveals that there are 8 major hotspots with an LST above 41ºC and with an average size of 86 ha within a distance of 500 m from the park's boundary. All of them correspond with industrial areas (Figure 7). They are scattered around the park's perimeter and the length of the hotspots (hotspot's sides connecting to the park) ranges from 450 m (corresponding to hotspot 1) to 1,000 m (corresponding to hotspot 4) (Figure 7).

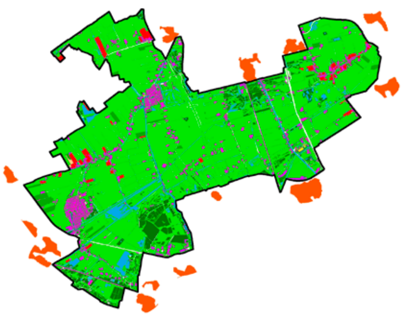


Figure 7: Midden-Delfland hotspots with and LST>41ºC surrounding the park.

Hotspots with an LST between 36ºC and 41ºC

The analysis of the hotspots surrounding the Midden-Delfland park reveals that there are 3 major hotspots with an LST ranging from 36ºC till 41ºC and with a connecting length with the park longer than 1500 m (Figure 8). These hotspots have areas that range from 300 to 600 ha, and their dominant land use is residential. The PAA has areas that range from 100 to 600 ha for each hotspot. In this case the dominant land use in the hotspots is residential.

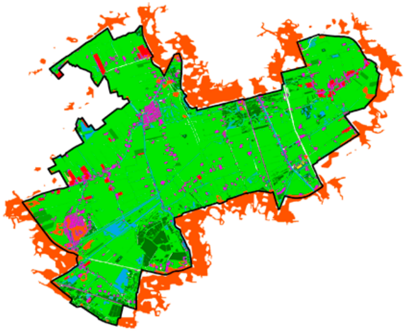


Figure 8. Midden-Delfland hotspots with 41ºC>LST>36ºC surrounding the park.

Prescribing measures to improve the cooling capacity of the park areas adjacent to the urban hotspots

Once the hotspots have been identified, we have prepared a chart to analyse the park adaptation areas (PAA) and the measures that could help increase the cooling capacity of the PAA, thus reducing the intensity of the hotspots (Figures 9 and 10). For each identified hotspot we have calculated the day LST difference between the hotspot and the PAA. The measures to redesign the PAA´s which have a LST difference below 10ºC with the hotspots (for hotspots above 41ºC: hotspots 2, 3, 4, 5 and 8; and for hotspots with LST´s between 36ºC and 41ºC: hotspots 1, 2 and 3) primarily consist in a change of land use. The dominant land use of the before-mentioned PAA´s is grassland, which is the land use with the second worst thermal behaviour encountered in South Holland provincial parks (Graph 1), after the built up patches. The conversion of those patches into cropland (reduction of up to 1,8ºC), forest (reduction of up to 4ºC), water surfaces (reduction of up to 8ºC) of greenhouse areas (reduction of up to 1,7ºC) would increase their cooling capacity. Further, in case the grassland land use is to be maintained, an increase of the existing patches NDVI (through the increase of irrigation or introduction of particular vegetation species) would also contribute to the increase of the cooling capacity of those PAAs. A reduction of those grassland patches' imperviousness would also theoretically contribute to a decrease of their average LST, however, the analysis reveals that the analysed PAAs seem to present pretty low imperviousness values already. Overall, there are several options to increase the cooling capacity of the PAAs, which allows combining the thermal considerations with other spatial planning priorities.

Hotspots number 1, 6 and 7 with LST above 41ºC, present LST differences with their corresponding PAA´s greater than 12ºC. Those patches are primarily occupied by forested areas. The adaptation measures to be introduced would consist in increasing the advection between hotspot and park (through the creation of cool wind corridors, reduction of the height of buildings surrounding the parks…) rather than modifying the land use of the park adjacent area, since forests already present the second lowest surface temperature after water surfaces.

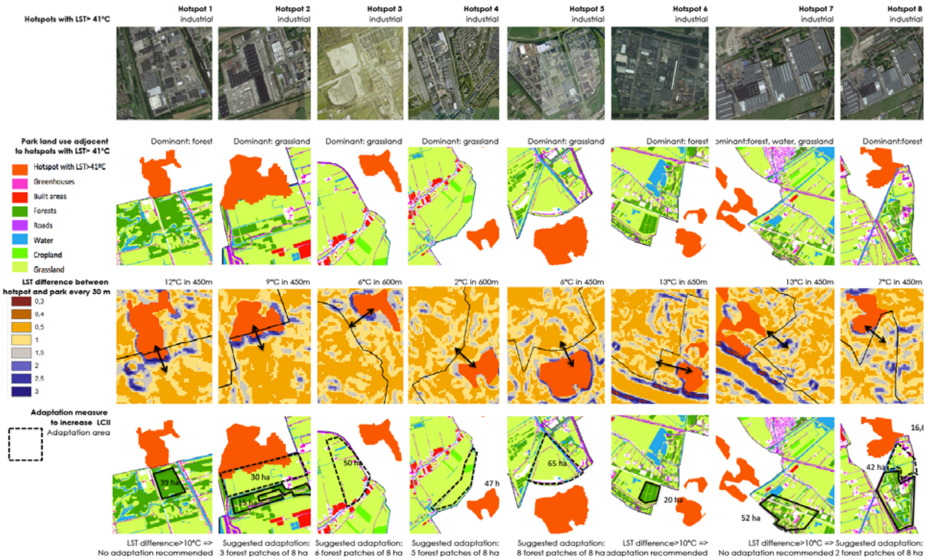


Figure 9. Diagnosis and adaptation design for hotspots with an LST>41ºC.

4. CONCLUSIONS

The average LST of South Holland provincial parks varies depending on the land use. The average LST increases from 25,9ºC for water surfaces, to 31,4ºC for forests, 33ºC for cropland, 33,1ºC for greenhouse areas, 34,9ºC for grassland patches and 37,9ºC for built areas. Within each land-use category, NDVI, imperviousness and patch shape index influence differently their thermal behaviour of the patches. NDVI is inversely correlated to day LST for all categories, imperviousness is correlated to day LST for all areas which do not comprise a significant presence of greenhouses (grassland and built patches) and inversely correlated to LST for areas with a high presence of greenhouses (cropland and warehouses). Finally LSI varies depending on the nature of the surrounding patches, especially for small patches (built areas, forests and greenhouse areas).

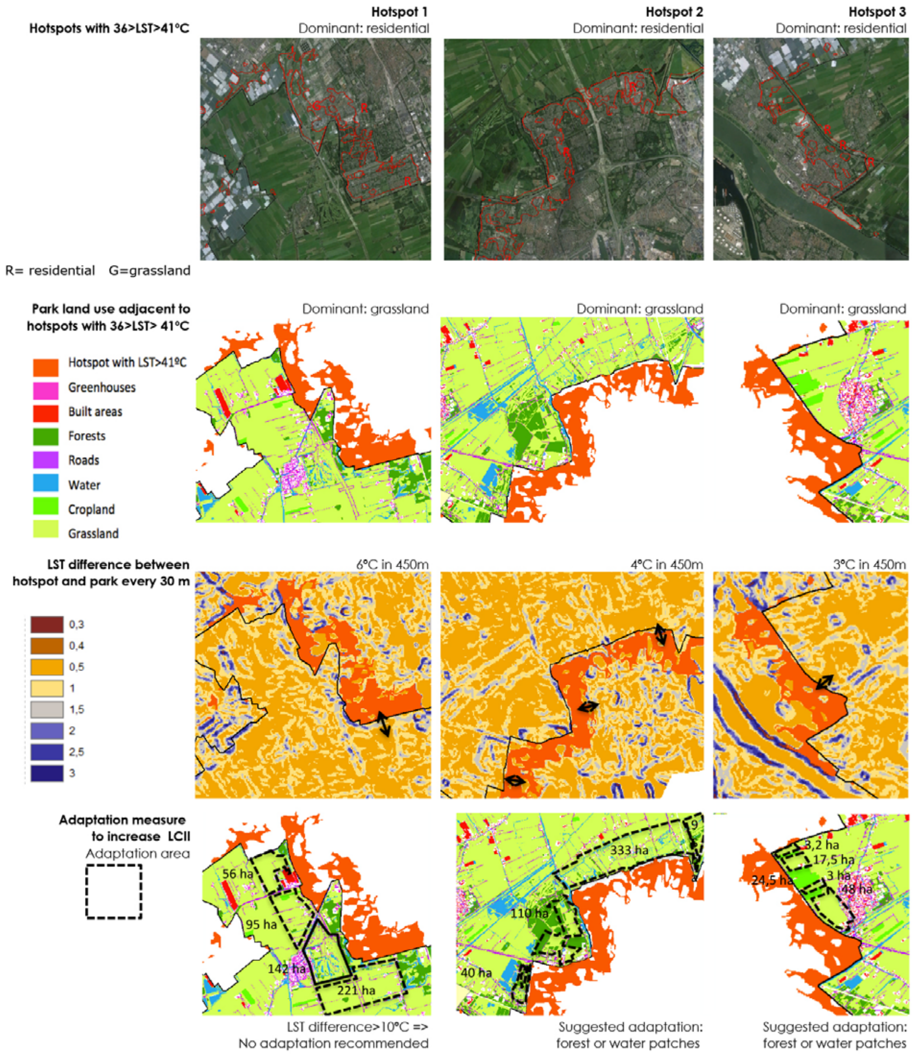


Figure 10. Diagnosis and adaptation design for hotspots with an LST ranging from 36°C till 41°C.

Remote sensing combined with GIS allows identifying the urban hotspots surrounding the parks, identifying the park areas adjacent to these (PAA), their surfaces and their land use, in order to design adaptation measures to increase the cooling capacity of these. In the case of South Holland provincial parks, most of the hotspots surrounding the park are adjacent to grassland patches. The measure to increase the cooling capacity of those patches would consist in a change of land use and an increase of the NDVI of the existing grassland patches. These suggestions to increase the cooling potential of the parks remain deliberately open in order to allow combining these measures with other spatial planning priorities.

5. DISCUSSION

The research questions presented in section 1.3. have been answered, as ultimately, this study provides a methodology to allow the development of design guidelines for the improvement of the cooling capacity of the park perimeter areas over the hotspots surrounding the parks. The provincial parks of such scale surely have a cooling influence in areas and cities located at a greater distance from the park; however such analysis falls outside the scope of this study. In any case, increasing the cooling capacity of the park edges contributes to increasing the cooling capacity of the park as a whole. The study delves deeper into the specific case of Midden-Delfland provincial park, to illustrate the proposed methodology, which could be replicated in the rest of South Holland provincial parks.

The first part studies how the different land-use categories encountered in South Holland parks (grassland, cropland, forests, water surfaces, built areas and industrial areas) present, during heat waves, different thermal behaviours (Indicators: night and day LST; and influencing parameters: average NDVI index, imperviousness coefficient, patch size and patch shape). It provides an overview of the correlation coefficient of the influencing parameters and the indicators, depending on the analysed land-use categories. The influencing parameters are patch characteristics which can be altered through design. Land-use and patch characteristics (within each land-use category) are the main design categories which have an influence on the thermal behaviour of the park.

The second part of the study aims at identifying park areas adjacent to urban hotspots surrounding the parks, where the implementation of cooling measures (identified in the first section) would contribute to the reduction of the urban heat of the adjacent hotspots. The exercise is carried out for the Midden-Delfland park. The hotspots are identified using Landsat 5TM imagery, the mitigating design measures are proposed for park areas adjacent to hotspots and presenting LST differences with the hotspots, below 10ºC. The idea is to use remote sensing and GIS not only to carry out the analysis of the cooling capacity of the park, but also to identify the areas that could benefit from the implementation of cooling design measures. The same technology for the analysis and for the implementation.

REFERENCES

Brücker, G. (2005). Vulnerable populations: lessons learnt from the summer 2003 heat waves in Europe. Euro Surveillance, 10(7), 147.

Burghardt, R., Katzschner, L., Kupski, S., Chao, R., & Spit, T. (2010). Urban Climatic Map of Arnhem City. Future Cities, urban networks to face climate change. Interreg IV. (www.future-cities.eu)

Cao, X., Onishi, A., Chen, J., and Imura, H. (2010). Quantifying the cool island intensity of urban parks using ASTER and IKONOS data. Landscape and urban planning, 96(4), 224-231.

Centraal Bureau voor de Statistiek (CBS) (2006). http://www.cbs.nl/nr/exeres/CA1F091F-F641-47E6-AB18-D517143A609D.htm

Chang, C. R., Li, M. H., & Chang, S. D. (2007). A preliminary study on the local cool-island intensity of Taipei city parks. Landscape and Urban Planning 80(4), 386-395.

Cheng, X., Wei, B., Chen, G., Li, J., & Song C. (2014). Influence of Park Size and Its Surrounding Urban Landscape Patterns on the Park Cooling Effect. Journal Urban Planning Development, 141(3), A4014002.

Choi, H. A, Lee, W. K., Byun, W. H. (2012). Determining the Effect of Green Spaces on Urban Heat Distribution Using Satellite Imagery. Asian Journal of Atmospheric Environment, 6(2), 127-135.

City of Freiburg (2013). http://planning.cityenergy.org.za/index.php/world-cities/europe/city-of-freiburg-germany.

City of Stuttgart (2008). Office for Environmental Protection, Section of Urban Climatology. Climate Atlas of the Region of Stuttgart. http://www.stadtklimastuttgart.de/index.php?climate_climate_atlas_2008

Coll, C., Galve, J. M., Sánchez J. M., & Caselles V. (2010). Validation of Landsat-7/ETM+ Thermal-Band Calibration and Atmospheric Correction With Ground-Based Measurements. IEEE Transactions on Geoscience and Remote Sensing, 48(1), 547-555.

Dousset B., Gourmelon F., Laaidi K., Zeghnoun A., Giraudet E., Bretin P., et al. (2011). Satellite monitoring of summer heat waves in the Paris metropolitan area. Int. Journal of Climatology 31. 313-323.

Freiburg (2013). Sustainable Urban Development Policy and the Land Use Plan 2020. http://planning.cityenergy.org.za/index.php/world-cities/europe/city-of-freiburg-germany).

Garssen J, Harmsen C, de Beer J. (2005). The effect of the summer 2003 heat wave on mortality in the Netherlands. Euro Surveillance 10. 165–168.

Hebbert, M. & Jankovic, V. (2010) Street Canyons and Canyon Streets: the strangely separate histories of urban climatology and urban design. Climate Science in Urban Design, Working Paper 1. Available at: http://www.sed.manchester.ac.uk/architecture/research/csud/workingpapers/StreetCanyonsand-CanyonStr eets.pdf

Hebbert, M. & Webb B. (2011). Towards a Liveable Urban Climate:Lessons from Stuttgart. Liveable Cities: Urbanising World, Wuhan, China, ISOCARP. Knowledge for better Cities.

Hoyois P., Scheuren J-M, Below R., Guha-Sapir D. (2007). Annual Disaster Statistical Review: numbers and trends 2006. Université Catholique de Louvain. CRED. Centre for research on the epidemiology of disasters.

Jauregui E. (1975). Microclima del bosque de chapultepec, Bulletin No.6, Instituto de Geografia, University of Mexico (in Spanish).

Jauregui E. (1990-1991). Influence of a large urban park on temperature and convective precipitation in a tropical city. Energy Build 15(16) 457–463.

Kadaster NL (2013) TOP 10 NL (https://www.kadaster.nl/web/artikel/productartikel/TOP10NL.htm)

Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies.

Li J., Song C., Cao L., Zhu F., Meng X., Wu J. (2011) Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. Remote Sensing of Environment 115(12), 3249-3263.

Patton, D.R., 1975. A diversity index for quantifying habitat "edge". Wildl. Soc. Bull. 3, 171–173.

Potcher O., Cohen P., & Bitan A. (2006). Climatic behaviour of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel. International Journal of Climatology, 26(12),1695-7112.

Robine J. M., Cheung S. L. K., Leroy S., Van Oyen H., Griffiths, C., Michel J.P., & Herrmann F. R. (2008). Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies, 331(2), 171-178.

Saaroni, H. & Ziv, B. (2003). The impact of a small lake on heat stress in a Mediterranean urban park: the case of Tel Aviv, Israel. International Journal of Biometeorology, 47(3), 156-165.

Sardon J.P. (2007).The 2003 heat wave. Euro Surveillance, 12(3) 226.

Spronken-Smith R.A. (1994). Energetics and cooling in urban parks. Unpublished Ph.D. Thesis. The University of British Columbia.

Spronken-Smith R. A., Oke T. R. (1998). The thermal regime of urban parks in two cities with different summer climates. International journal of remote sensing, 19(11), 2085-2104.

Steeneveld G.J., Koopmans S., Heusinkveld B.G., Van Hove L.W.A., Holtslag A.A.M. (2011) Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands.

Taha H., Akbari H., Rosenfeld A. (1991) Heat island and pasis effects of vegetative canopies: Micrometeorological field-measurements. Theoretical and Applied Climatology 44(2), 123-138.

Upmanis H., Eliasson I., Lindqvist S. (1998). The influence of green areas on nocturnal temperatures in a high latitude city (Goteborg, Sweden). International Journal of Climatology 18, 681-700.

US Geological Survey (USGS, 2016) webpage, Earth Resources Observation and Science Center (EROS). http://glovis.usgs.gov/

Von Stulpnagel A, Horbert M, Sukkop H. (1990). The importance of vegetation for the urban climate (Urban Ecology). SPB Academic Publishing, The Hague. 175-193.

Van Hove L.W.A., Steeneveld G.J., Jacobs C.M.J., Heusinkveld B.G., Elbers J.A., Moors E.J., Holtslag A.A.M. (2011). Exploring the Urban Heat Island Intensity of Dutch Cities. (Assessment based on literature review, recent meteorological observations and datasets provided by hobby meteorologists). Altera report 2170. Wageningen.

Yu C. & Hien, W.N. (2006). Thermal benefits of city parks. Energy and Buildings 38, 105–20.

Zhou W., Huang G., Cadenasso M. (2011). Does spatial configuration matter? Understanding the effects of land cover pattern on land surface temperature in urban landscapes. Landscape and Urban Planning 102(1), 54-63.