7 Using satellite imagery analysis to redesign provincial parks for a better cooling effect on cities – The case of South Holland

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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. Based on these conclusions, a set of design guidelines are provided to improve the cooling capacity of Midden-Delfland park areas which are adjacent to hotspots with day LST above 41 °C and with day LST between 36 °C and 41 °C.

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The average day LST within South Holland provincial parks varies from 25.9°C for water surfaces, to 31.4°C for forests, 33°C for cropland, 33.1°C for greenhouse areas, 34.9°C for grassland patches and 37.9°C for built areas. 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.

§ 7.1 Introduction

§ 7.1.1 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 30°C 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 in The Netherlands caused in the month of July alone 1,000 excess deaths (Hoyois, 2007) of which 470 in the Westen region to which the province of South Holland belongs(Centraal Bureau voor de Statistiek, 2006). The Dutch province of South Holland was in absolute terms the 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, 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) 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. et al. 2012, Cheng. et al. 2014).

§ 7.1.2 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 of large green infrastructure, landscape is considered as an existing natural cooling source and focuses in the design of the urban environment to promote the cool wind flow within the cities. This is the case for air circulation patterns applied to spatial planning in the Climate Analysis Map for the Stuttgart region, 2008 (City of Stuttgart, 2008; Hebbertand Jankovic, 2010; Hebbert, 2011; Kazmierczakand Carter, 2010). For the Urban Climate Analysis Map for the Dutch city of Arnhem (Burghardt et al., 2010), developed within the future cities programme, or for 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 envision the transformation of 30 hectares of building space into open areas, not only to extend and connect the city’s green infrastructure, but also ‘to emphasize the cool air flow areas and urban ventilation lines within and outside the city’ (City of Freiburg, 2013).

– Urban Parks

The second group concentrates on urban parks with sizes of up to 500 ha and analyses their cooling effect in 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 (2007) defines the local cool island intensity as the temperature difference between the interior of the park and the urban nearby surroundings; Cheng (2004) defines 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, 1998; Cheng, 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; Potcher et al., 2006; Yu et al., 2006; Zhou, 2011), while at night the coolest parks are those without trees (Chang, 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, 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 and Ziv, 2003), while others have suggested its contribution is negligible (Cao et al., 2010).

§ 7.1.3 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 7.1) 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 it´s spatial vision ("Structuurvisie Zuid-Holland") doesn´t specifically address the UHI phenomenon. Furthermore, with 1,227 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).

§ 7.1.4 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 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 several sub-questions have been formlated:

- 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 NDVI index, imperviousness coefficient, patch size and patch shape index affect their average night-time LST and their average daytime 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?

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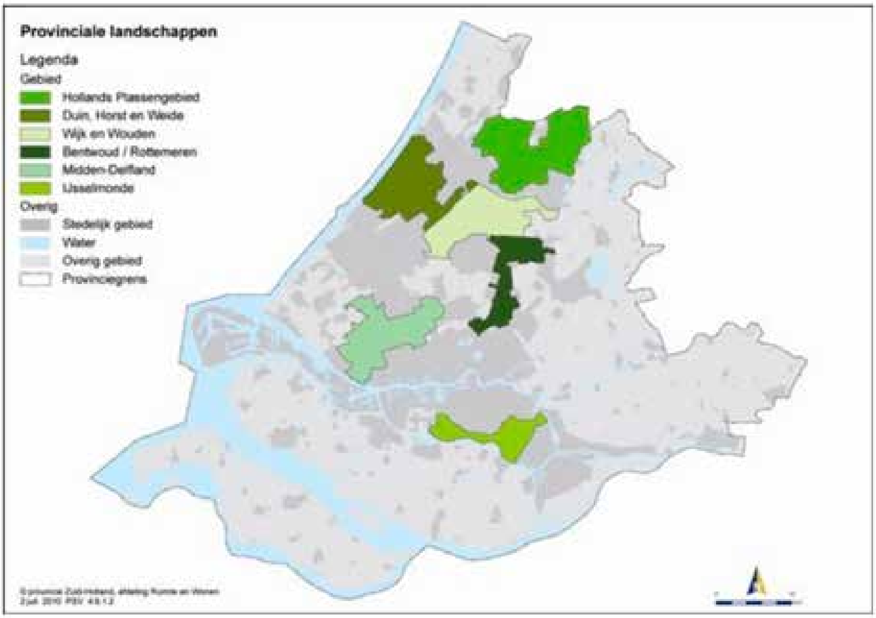

FIGURE 7.1 South Holland provincial parks (Province of South Holland, Spatial Planning and Housing Department, 2011)

§ 7.2 Methodology

§ 7.2.1 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 that can be identified in its six provincial parks are: forests, cropland, grassland, water surfaces, built areas and greenhouse areas. For each of these categories the authors have used as indicators of thermal behaviour the average night-time land surface temperature (LST) and the average daytime LST, and as influencing parameters: Normalised difference vegetation index (NDVI), imperviousness coefficient, size of the land use patch and shape index of the surface patch. For each patch in each land use category the average values of the above mentioned parameters have been calculated, and a multiple regression analysis was carried out in order to understand what parameters influence most the thermal behaviour of the patches of each land use category. Satellite imagery has been used 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.

The authors used nine Modis 11A1 satellite images (from the 15th and 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 the authors 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), Earth Resources Observation and Science (EROS) Center webpage. Diurnal LST was calculated and mapped 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 m. First, the geometrical correction and the calibration of band 6 was carried out. The atmospherically corrected radiance was then obtained by applying Coll’s equation (Coll et al., 2010):

FORMULA 7.1

$$CVR2 = [(CVR1 - L\uparrow)/\varepsilon\tau] - [(1-\varepsilon)*(L\downarrow)/\varepsilon]$$

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

T is transmittance

E 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 7.2).

FORMULA 7.2

$T = K2 / [\ln((K1/CVR2) + 1)]$

Where:

T is degrees Kelvin

CVR2 is the atmospherically corrected cell value as radiance

K1 and K2 are prelaunch calibration constants

The final result of the processed Landsat 5 TM imagery is shown in figure 7.2.

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

Landsat 5TM imagery retrieved during the heat wave of 2006 was used to map and (on the 16th of July) to calculate the average NDVI. ATCOR 2.3 was used to correct geometrically and atmospherically the raw satellite imagery.

FORMULA 7.3

$NDVI = (NIR-VIS)/(NIR+VIS)$. Where NDVI is the Normalised Difference Vegetation Index, VIS is the surface reflectance in the red region (650 nm) and NIR is the surface reflectance in the near infrared region (850 nm).

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

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

FORMULA 7.4.

$$LSI = \frac{P_t}{2\sqrt{\pi \times A}}$$

Where LSI is the Landscape Shape Index Pt is the perimeter of the patch and A is the area of the patch.

Overall, the authors 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 2,284 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, the authors have carried out in GIS an unsupervised classification of the overlap of the day LST, NDVI and imperviousness maps, and they have obtained 5 thermal clusters in the provincial parks of South Holland. Further the proportion of each of these thermal clusters for each of the studied land uses was calculated.

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

In this section the authors have studied how they could use remote sensing to diagnose heat accumulation in urban areas surrounding parks and how they 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

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the parks 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 considerably, depending on what area of the park is selected, and what area surrounding the park is picked. Therefore for this study the authors 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. Midden-Delfland park was analysed, which is the South Holland provincial park located between the region of The Hague and Rotterdam.

Two types of hotspots were defined 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 1,500 m.

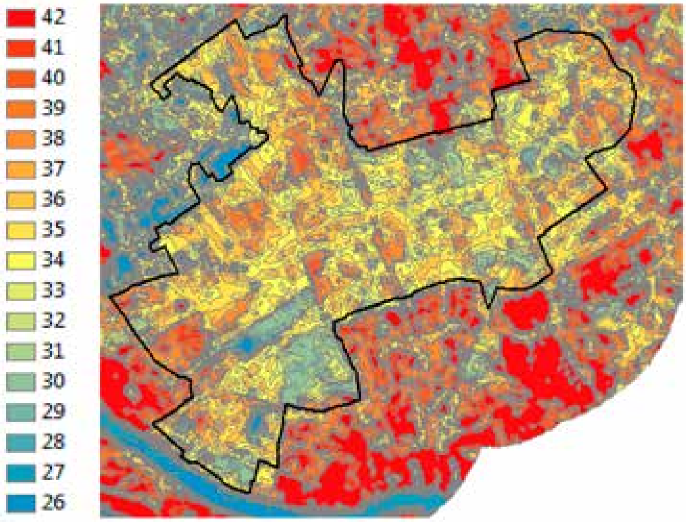

FIGURE 7.2 Land surface temperature image retrieved from Landsat 5TM

Tool:

Day LST maps (obtained through Landsat 5TM processing) were used to map the hotspots in the urban areas surrounding the park. The authors have chosen to map only day LST hotspots, due to the higher resolution of Landsat 5TM imagery (120 m) compared to Modis 11A1 (1 km). Landsat 5TM seems more appropriate for urban analysis (Figure 7.2).

- Identifying park areas adjacent to hotspots with an improvable cooling capacity

Further the park areas adjacent to the hotspots were analysed in order to identify the areas that had LST differences of less than 10°C compared with the hotspots. Those areas have been called "park adaptation areas" (PAA). These are the areas for which the authors 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.

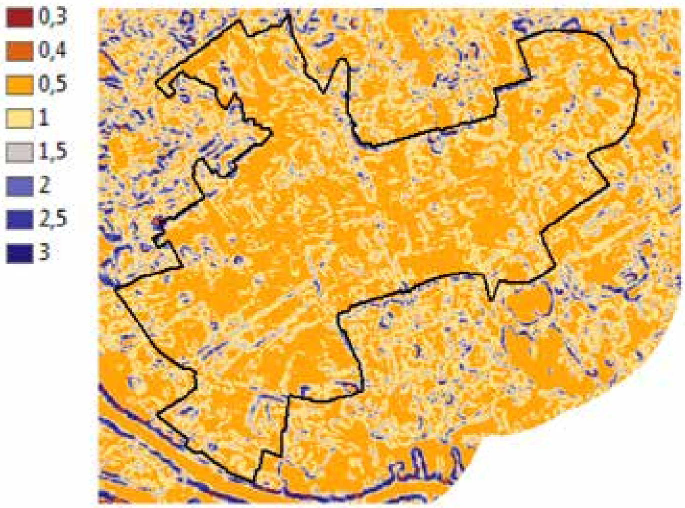

FIGURE 7.3 Land surface temperature differences in Midden-Delfland

Tool:

LST images were imported and combined in Arcmap 10 in order to calculate the temperature difference between the different pixels throughout the LST map (Figure 7.3).

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

The results obtained in the first part of the study were used to define adaptation measures 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.

§ 7.3 Results

§ 7.3.1 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 1.4°C. Maximum night LST is 19.2°C registered in built areas and water surfaces and minimum night LST is 17,8°C registered in grassland surfaces. In turn, the average day LST presents differences of up to 12°C with an average day LST of 25.8°C for water surfaces and 37.9°C for built areas. Forest patches present the second lowest day LST with 31.4°C. Greenhouse patches and cropland present an average LST 1.8°C lower than grassland.

greenhouses are characterized byhighly reflective glass roofs, which help reduce the surface temperatures. The difference between cropland and grassland is mainly due to the irrigation of cropland (Figure 7.4).

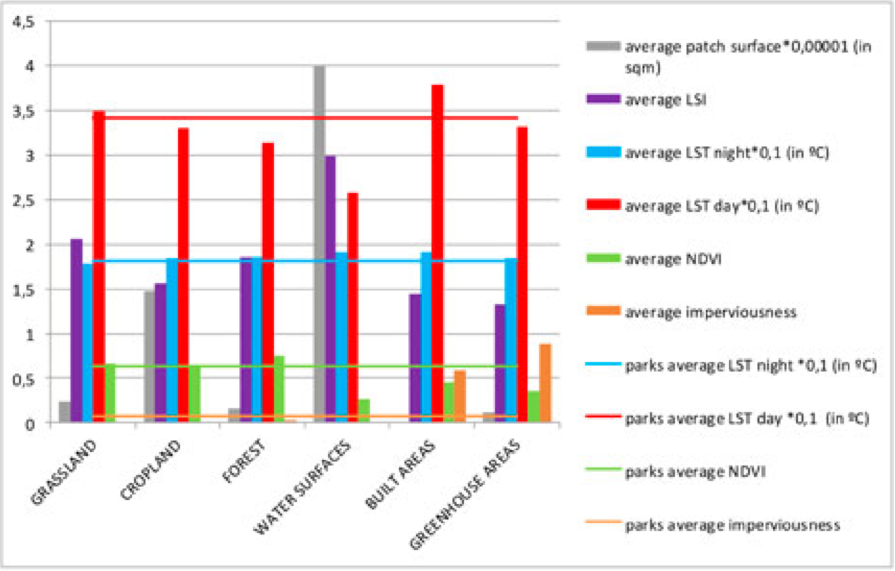

FIGURE 7.4 Average night LST, day LST, NDVI, imperviousness, patch surface and patch shape index for the six main land use typologies of South Holland provincial parks.

– Forests

As concluded by previous scholars, surfaces of trees contribute to increasing the diurnal cooling capacity of parks (Cao et al., 2010; Potcher et al., 2006; Yu et al., 2006; Zhou, 2011). Indeed, the average day LST of forested areas is 2.7°C below the park's average, whereas the forested areas night LST is slightly above the parks average (Figure 7.4). 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 (Figure 7.6) 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:

FORMULA 7.5

$$LST\ d = 76.4 - 59.5 * NDVI + 0.1 * I + 1.5E\text{-}05 * S - 0.2 * LSI.$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

NDVI and LSI play the most important role for the determination of day LST. The inverse correlation between daytime LST and NDVI (which range from 0.7 to 0.8, figure 7.6) 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%) have surfaces of more than 10 ha. GIS is only able to calculate the average day LST of 2.7% 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 30m, this resolution does not allow to calculate LST values of the finer narrowings). The analysed patches (Figure 7.6), present an average patch surface of 1.6 ha, and an average patch LSI of 1.9 ha. 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 7.5), which might increase or decrease the average temperature of the forest patch depending on its land use.

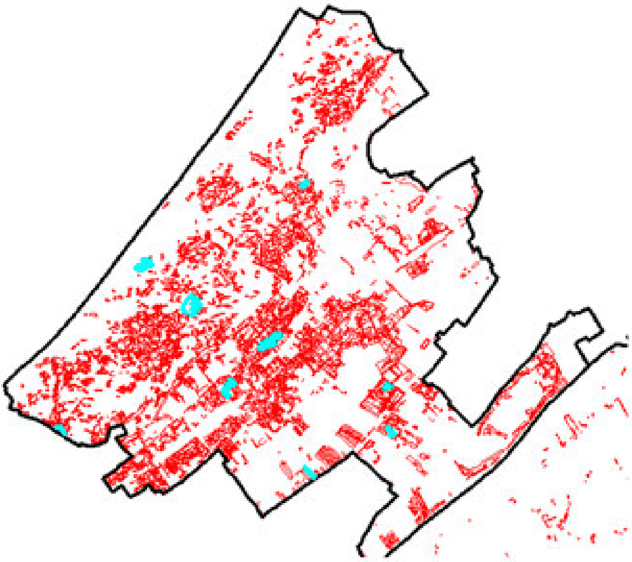

FIGURE 7.5 In red, forest patches of Duin, Horst en Weide provincial park, with small surfaces and numerous narrowings. In blue, analysed forest patches

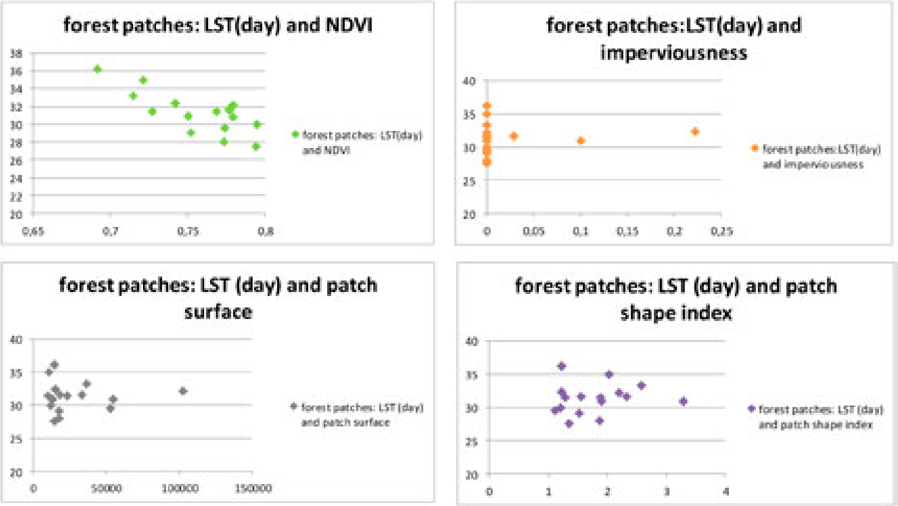

FIGURE 7.6 Analysis of the relationship between the different parameters and daytime LST for forest patches with surfaces above 1 ha in South Holland provincial parks.

- Cropland

Cropland average day LST is approximately 1°C below the average park day LST (Figure 7.4). 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:

FORMULA 7.6

$$LST\ d = 42.8 - 15.2*NDVI - 18.8*I - 1.4E\text{-}06*S + 0.5*LSI.$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, 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 an inverse correlation was found. The analysis of the imperviousness of the cropland patches reveals that most of the impervious surface is covered by greenhouses, and that, as described at the beginning of section 7.3., due to the reflectance of the glass, the average day LST of greenhouses is 1°C 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.

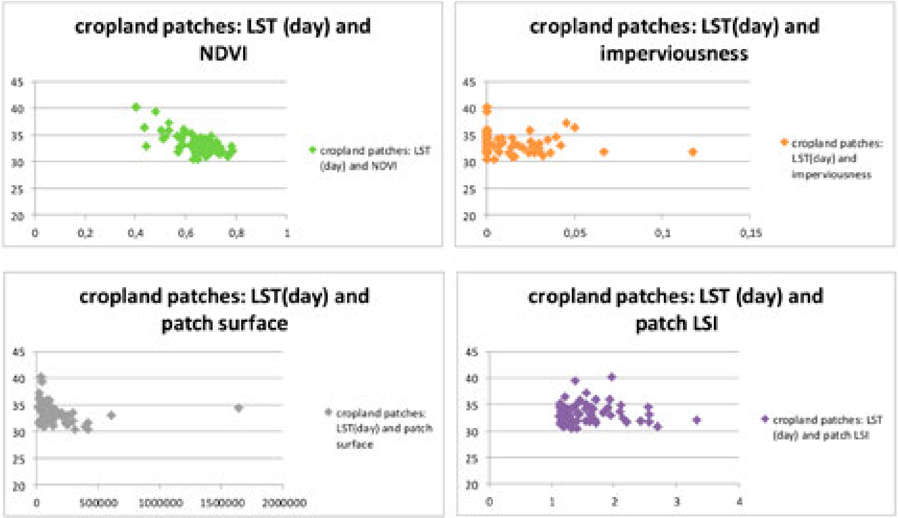

FIGURE 7.7 Analysis of the relationship between the different parameters and daytime LST for cropland patches in South Holland provincial parks.

The regression analysis also reveals that day LST is correlated to the slenderness of the patches. The average size of the analysed patches is of 14.7 ha, and the average LSI of the analysed patches is 1.5. The more compact the cropland patch, the cooler its surface (Figure 7.7).

– Grassland

Grassland is the land use with worst thermal behaviour present in South Holland parks, and it actually presents an average day LST 0.7°C higher than the parks average (Figure 7.4). The multiple regression analysis (Figure 7.8) 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:

FORMULA 7.7

$$LST\ d = 42.7 - 10.9 * NDVI + 0.5 * I - 2.3E\text{-}05 * S + 0.02 * LSI.$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, S is the surface of the patch and LSI is the patch shape index.

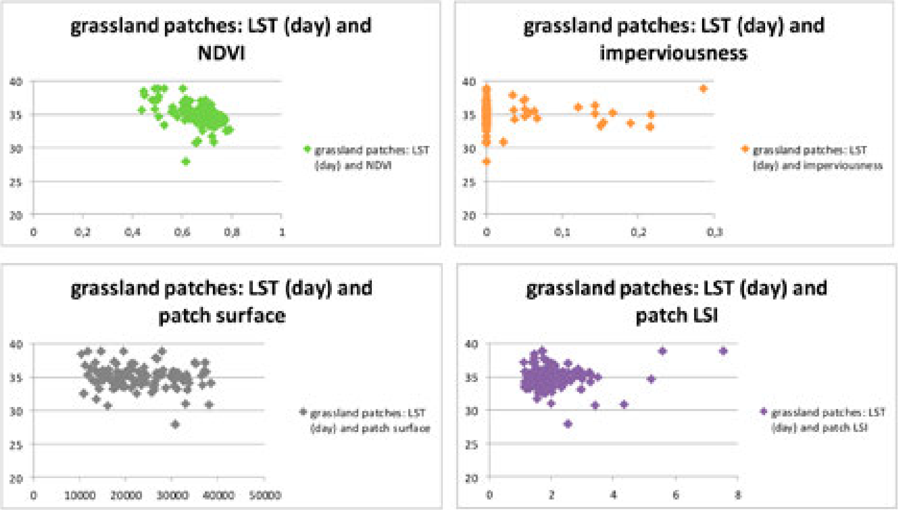

FIGURE 7.8 Analysis of the relationship between the different parameters and daytime LST for grassland patches in South Holland provincial parks.

Even though the multiple correlation analysis presents a pretty weak correlation (R2=0.3), 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.

- 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 25.8°C (Figure 7.4). The sizes of the patches present great variations, and have surfaces that range from 600 sqm til 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 (Figure 7.9) 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:

FORMULA 7.8

$$LST\ d = 26 + 10.7*NDVI - 1.4E\text{-}06*S + 0.02*LSI$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, I is the imperviousness coefficient, 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.

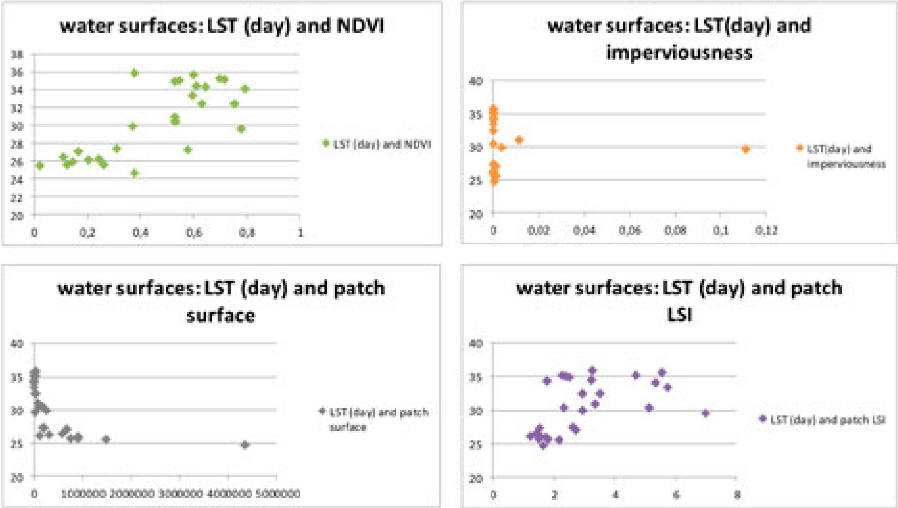

FIGURE 7.9 Analysis of the relationship between the different parameters and daytime LST for water surfaces in South Holland provincial parks.

– 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 m^2 of South Holland provincial parks (Figure 7.10) reveals that only a weak multiple correlation coefficient of R=0.5 and R2=0.2 relates day LST to the rest of parameters, with the following coefficients:

FORMULA 7.9

$$LST\ d = 39.7 - 9.1 * NDVI - 0.02 * I + 4.2E\text{-}03 * S + 0.6 * LSI$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, 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.

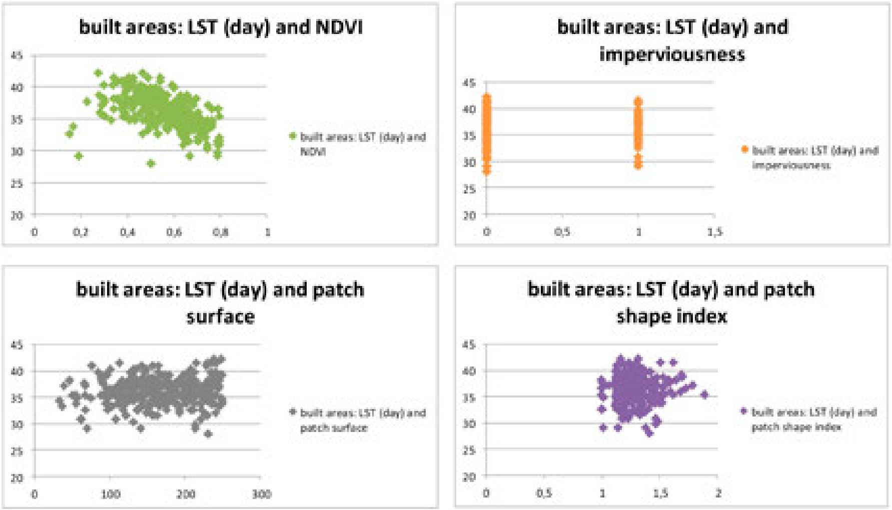

FIGURE 7.10 Analysis of the relationship between the different parameters and daytime LST for built patches with surfaces below 250 m² in South Holland provincial parks.

– Greenhouse patches

Warehouse patches present an average day LST of 33.1°C, which is 1°C lower than the average South Holland park LSTs (Figure 7.4). 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 (Figure 7.11) 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:

FORMULA 7.10

$$LST\ d = 39.8 - 4.1 * NDVI - 0.6 * I - 3.7E\text{-}03 * S + 0.6 * LSI$$

Where LST d is the day LST, NDVI is the Normalised Difference Vegetation Index, 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. An inverse correlation between day LST and imperviousness was found 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. Day LST is slightly correlated to the slenderness of the patches, due to the influence of warmer surroundings.

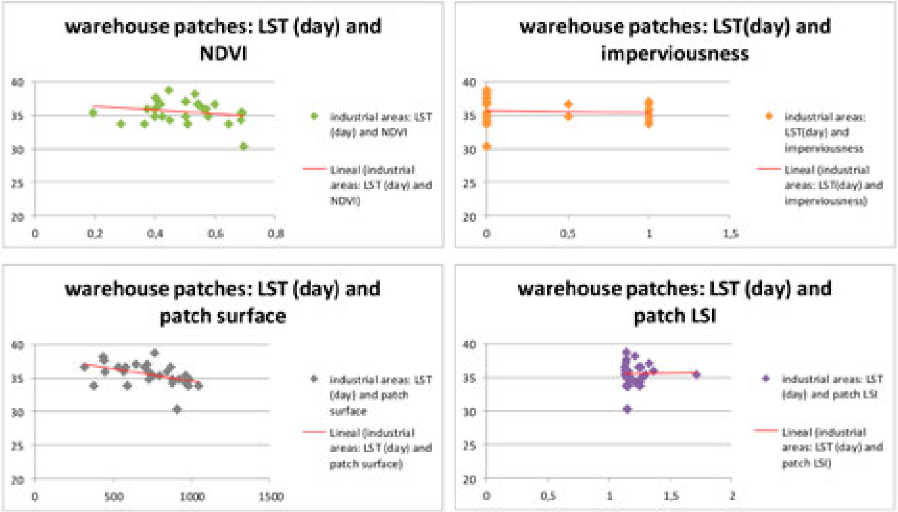

FIGURE 7.11 Analysis of the relationship between the different parameters and daytime LST for warehouse patches with surfaces below 1,000 sqm in South Holland provincial parks.

Conclusion of the patch analysis

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 greenhouseareas, 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 the studied land uses can be organised in three groups. The first group is made of large patches surrounded of 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 ofgreenhouses, is surrounded by warm areas, the more slender the patches, the higher the day LST.

§ 7.3.2 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 a 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 (Figure 7.14). The analysis of the cluster composition of the different land use categories (Figure 7.15) 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 cover warmer grassland patches, and finally cluster 5 can be identified with urban areas and bare soil zones (Figure 7.13).

Since the greenhouse patches only represent a very small part of the parks surface (Figures 7.20, 7.21, 7.22, 7.23, 7.24 and 7.25) the unsupervised classification hasn´t produced a specific cluster assimilable to glass surfaces. In turn, greenhouse surface fall sometimes into the cluster 1 category (assimilated with water), and other times into cluster 2 category (assimilated with trees and bush areas) (Figure 7.12).

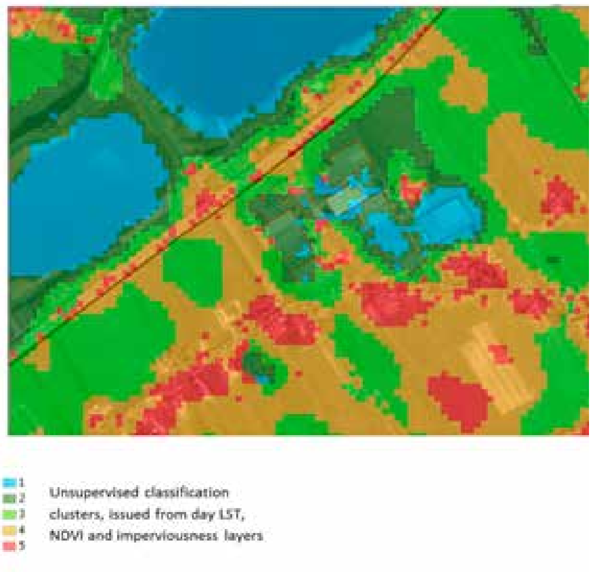

FIGURE 7.12 Unsupervised classification clusters from day LST, NDVI and imperviousness layers. The greenhouse areas are classified either in the same cluster as water or on the same cluster of forested areas. Due to their small presence in the parks, they are grouped with categories with similar thermal behaviour.

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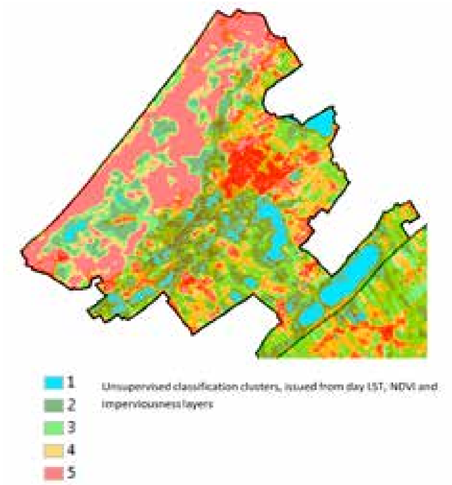

FIGURE 7.13 Unsupervised classification clusters from day LST, NDVI and imperviousness layers. The bare soil areas of the coast are classified in the same cluster as the built up areas, since they have a similar thermal behaviour.

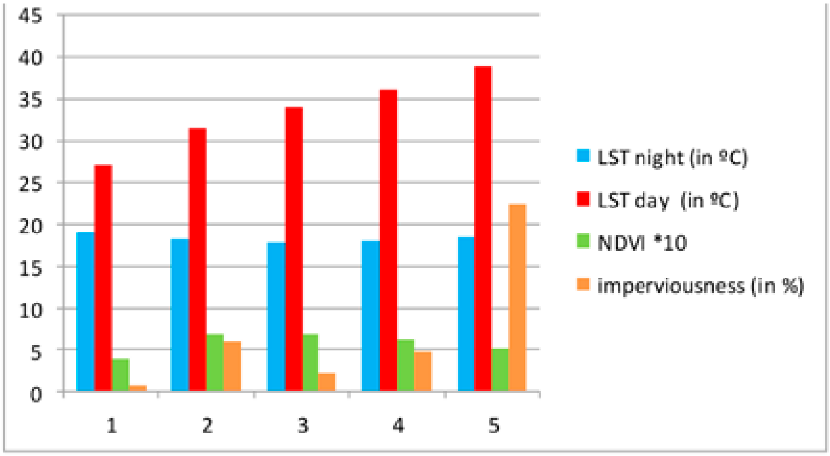

FIGURE 7.14 Average day LST, night LST, NDVI and imperviousness for the five different clusters produced by the unsupervised classification of the day LST, NDVI and imperviousness maps.

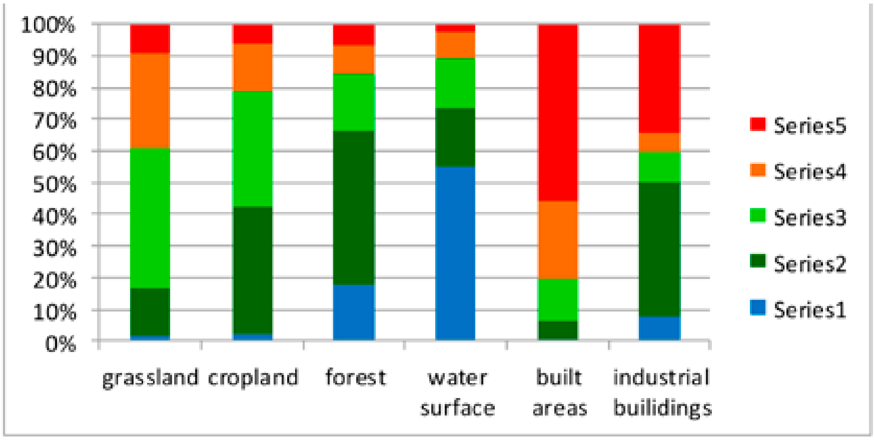

FIGURE 7.15 Cluster composition of the different land use present in South Holland provincial parks.

§ 7.3.3 Defining the adaptation measures to improve provincial parks cooling capacity

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

- Identifying hotspots in the urban areas surrounding the parks
  - Hotspots with LST above 41°C

The analysis of the hotspots surrounding the Midden-Delfland park reveals that there are 8 major hotspots with an LST above 41°C 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 7.16). 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 7.16).

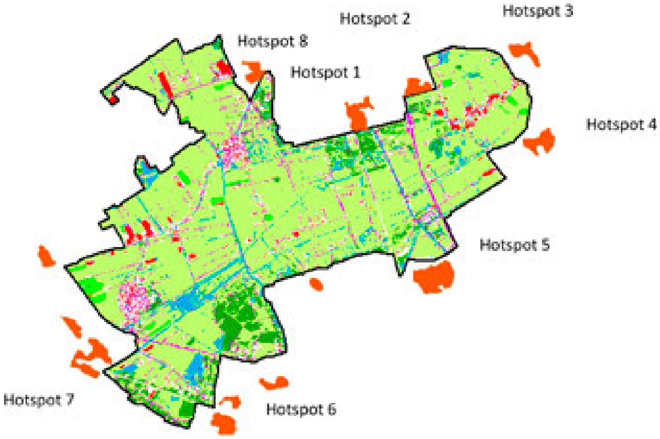

FIGURE 7.16 Midden-Delfland hotspots with and LST>41°C surrounding the park.

- Hotspots with an LST between 36°C and 41°C

The analysis of the hotspots surrounding the Midden-Delfland park reveals that there are 3 major hotspots with an LST ranging from 36°C to 41°C and with a connecting length with the park longer than 1,500 m (Figure 7.17). 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, since the dominant hotspot land use is residential.

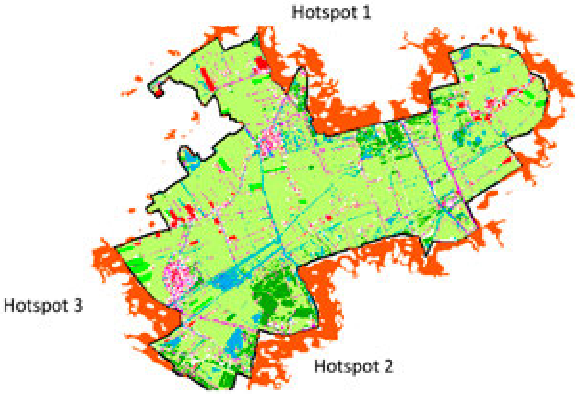

FIGURE 7.17 Midden-Delfland hotspots with 41°C>LST>36°C surrounding the park.

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

Once the hotspots have been identified, the authors 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 7.18 and 7.19). For each identified hotspot, the day LST difference between the hotspot and the PAA. was calculated The measures to redesign the PAA´s which have a LST difference below 10°C with the hotspots (for hotspots above 41°C: hotspot 2, 3, 4, 5 and 8; and for hotspots with LST´s between 36°C and 41°C: 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 (Figure 7.4), after the built up patches. The conversion of those patches into cropland (reduction of up to 1.8°C), forest (reduction of up to 4°C), water surfaces (reduction of up to 8°C) of greenhouse areas (reduction of up to 1.7°C) 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 41°C, present LST differences with their corresponding PAA´s greater than 12°C. 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.

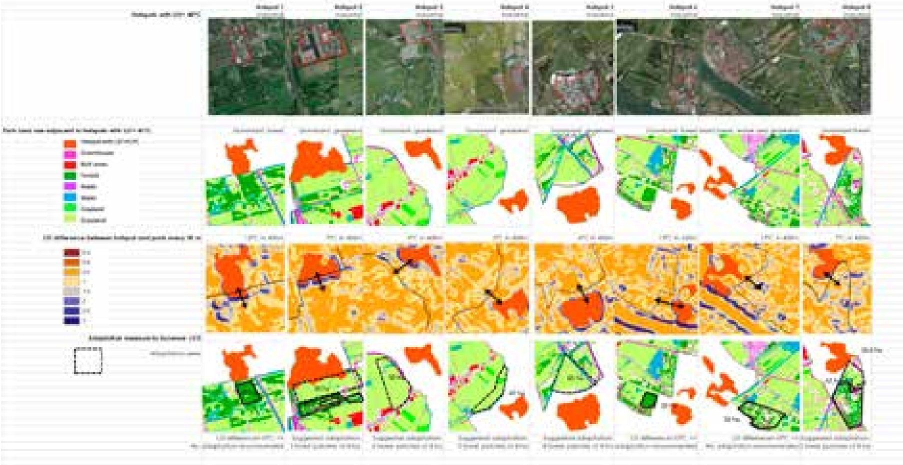

FIGURE 7.18 Diagnosis and adaptation design for hotspots with an LST>41°C.

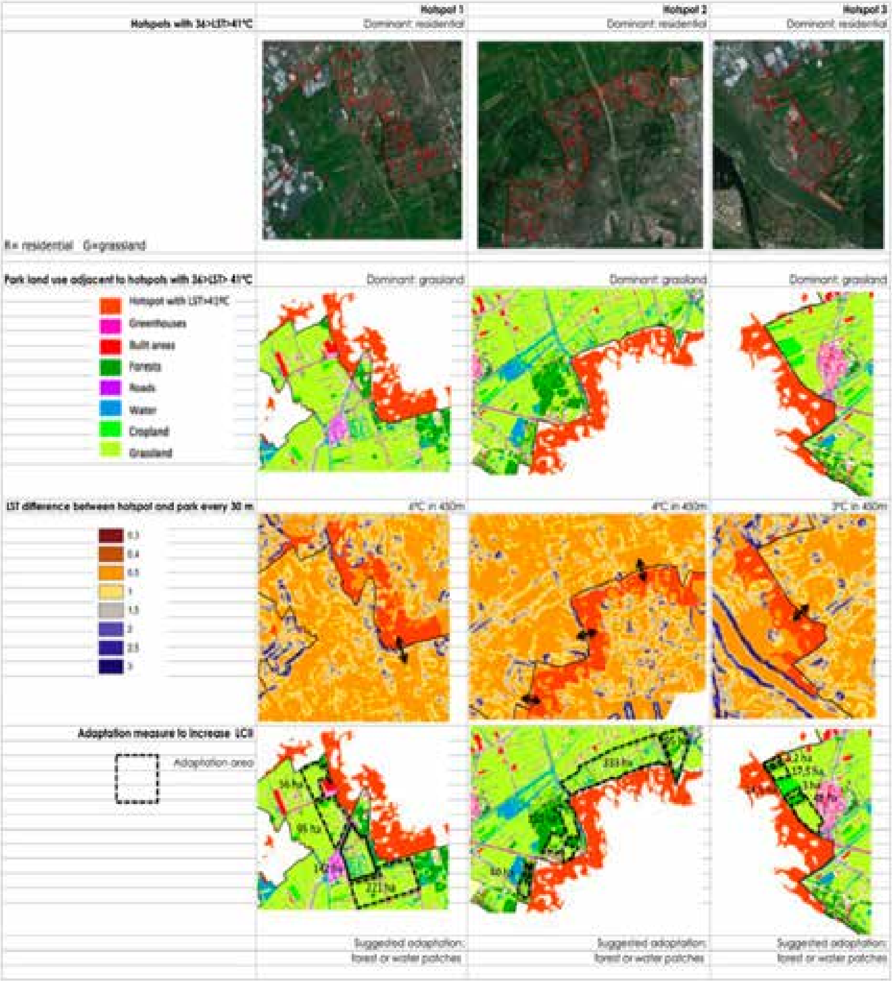

FIGURE 7.19 Diagnosis and adaptation design for hotspots with an LST ranging from 36°C to 41°C.

§ 7.4 Conclusions

The average LST of South Holland provincial parks varies depending on the land use. The average LST increases from 25.9°C for water surfaces, to 31.4°C for forests, 33°C for cropland, 33.1°C for greenhouse areas, 34.9°C for grassland patches and 37.9°C 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).

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 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.

§ 7.5 Discussion

The research questions presented in section 7.1 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 10°C. 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.

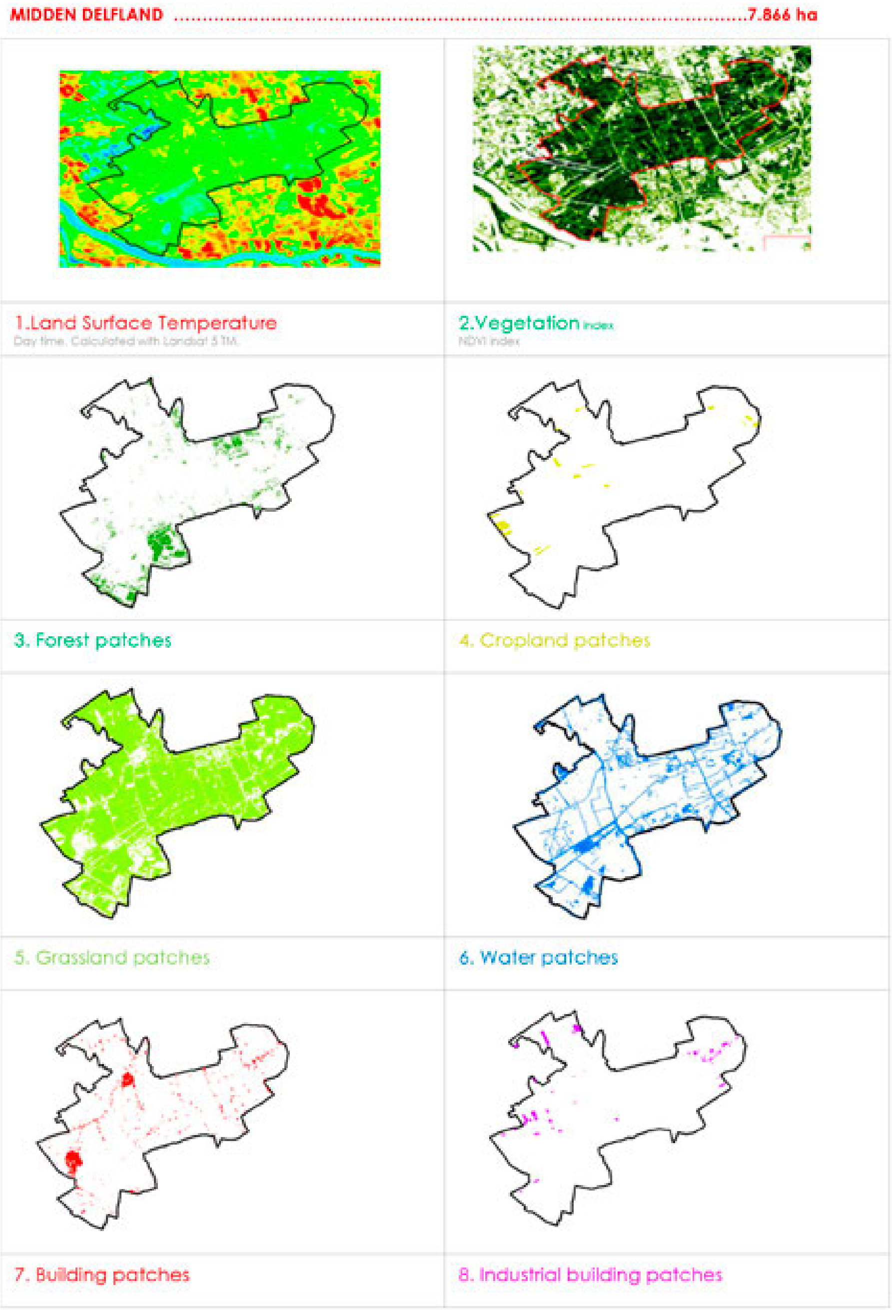

FIGURE 7.20 Midden-Delfland analysis schemes

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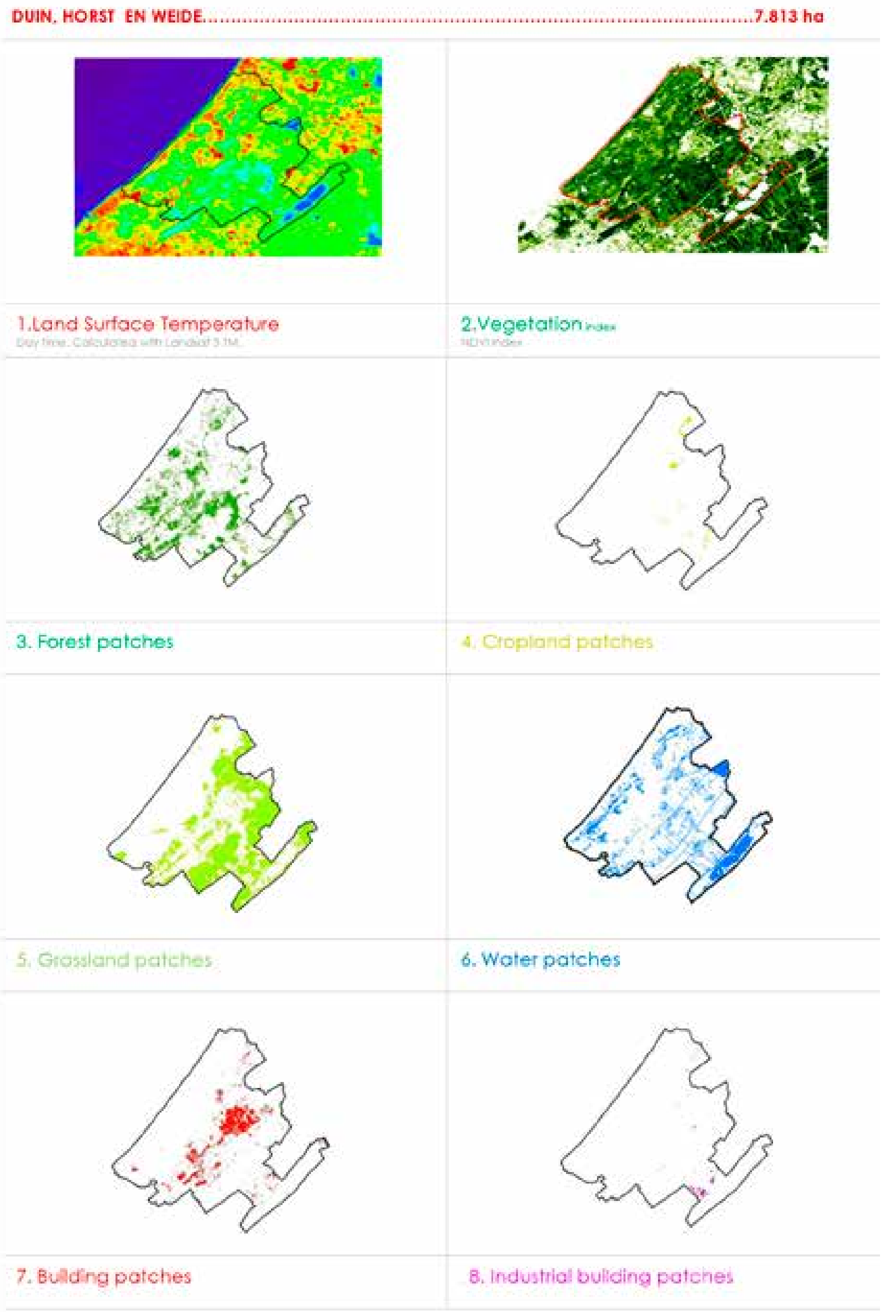

FIGURE 7.21 Duin, Horst en Weide analysis schemes

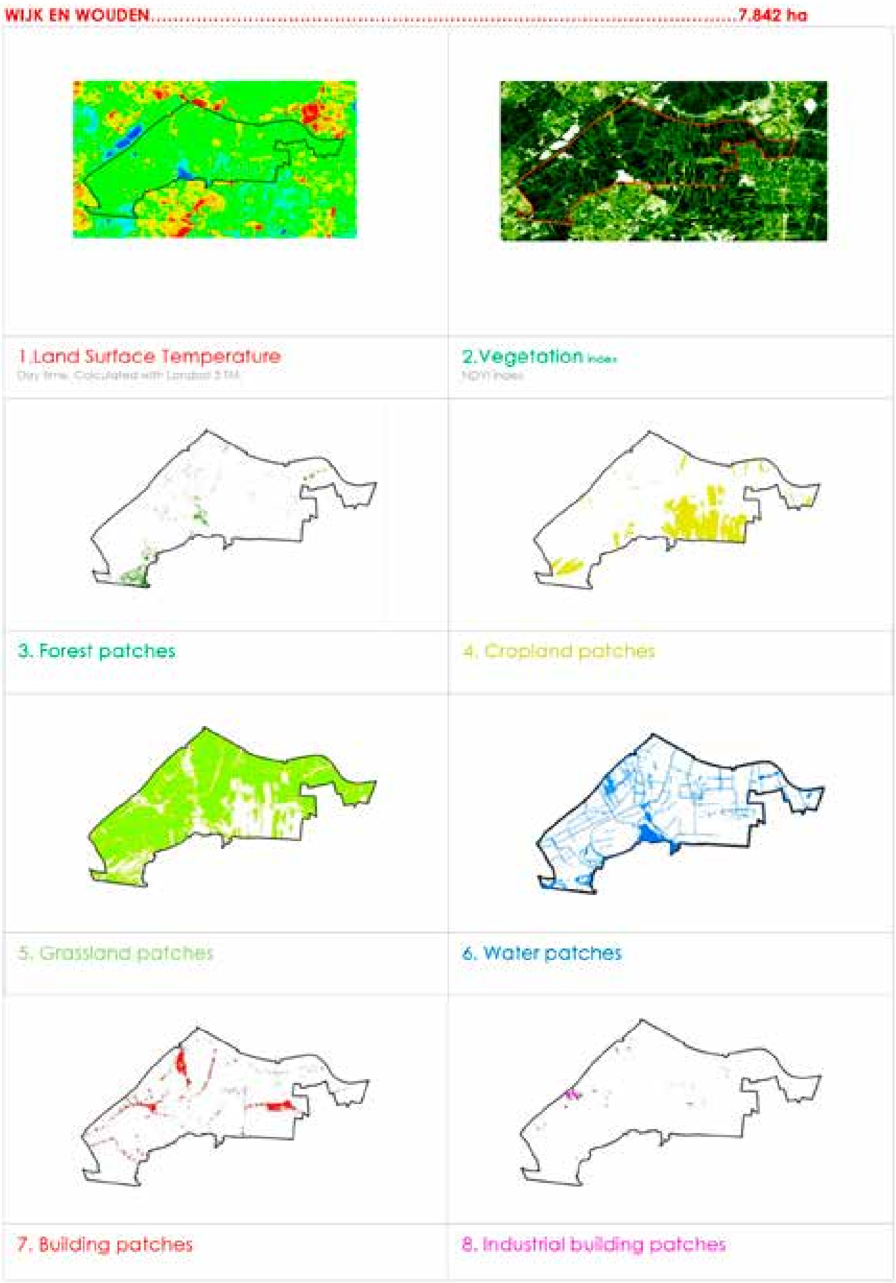

FIGURE 7.22 Wijk en Wouden analysis schemes

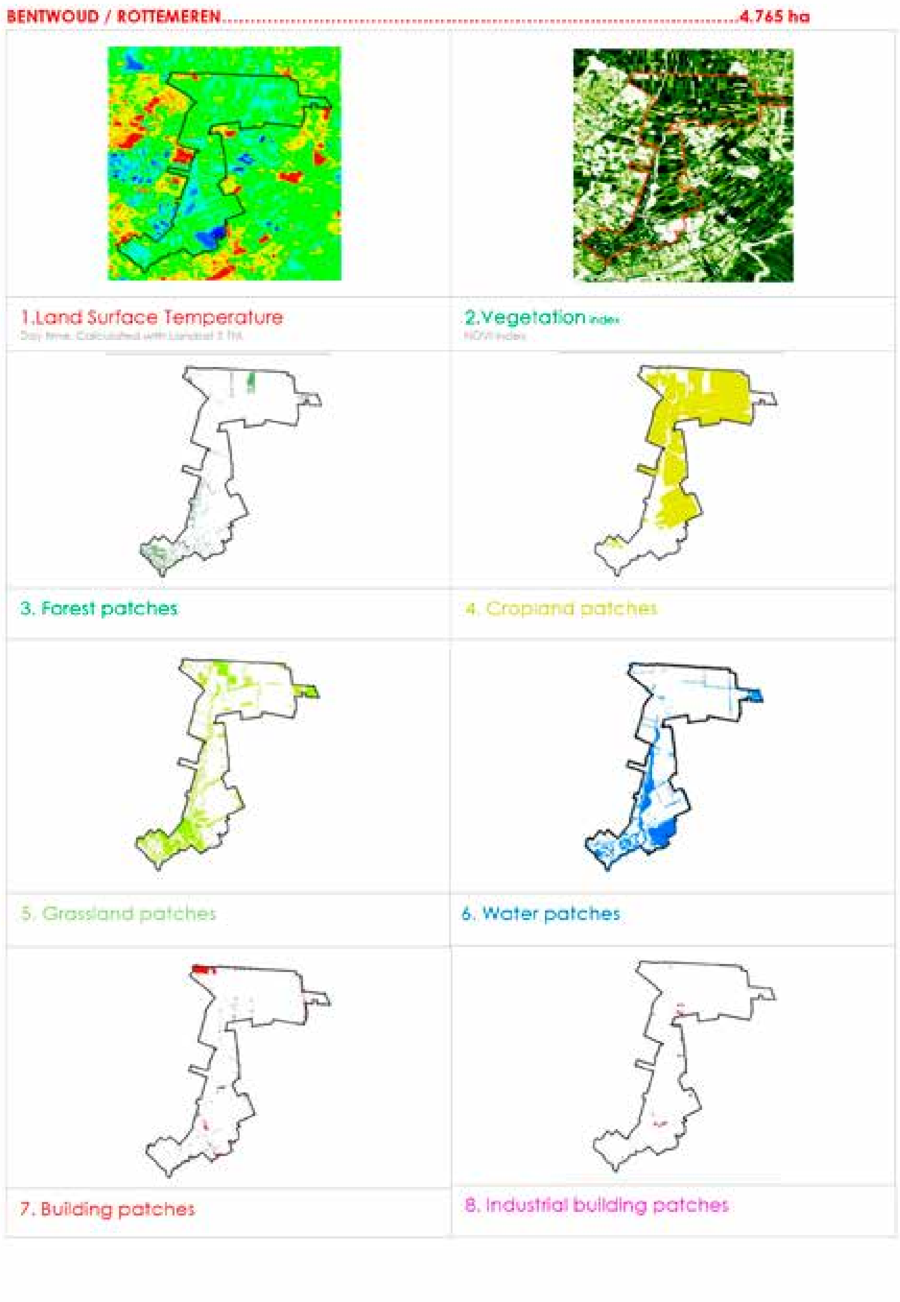

FIGURE 7.23 Bentwoud / Rottemeren analysis schemes

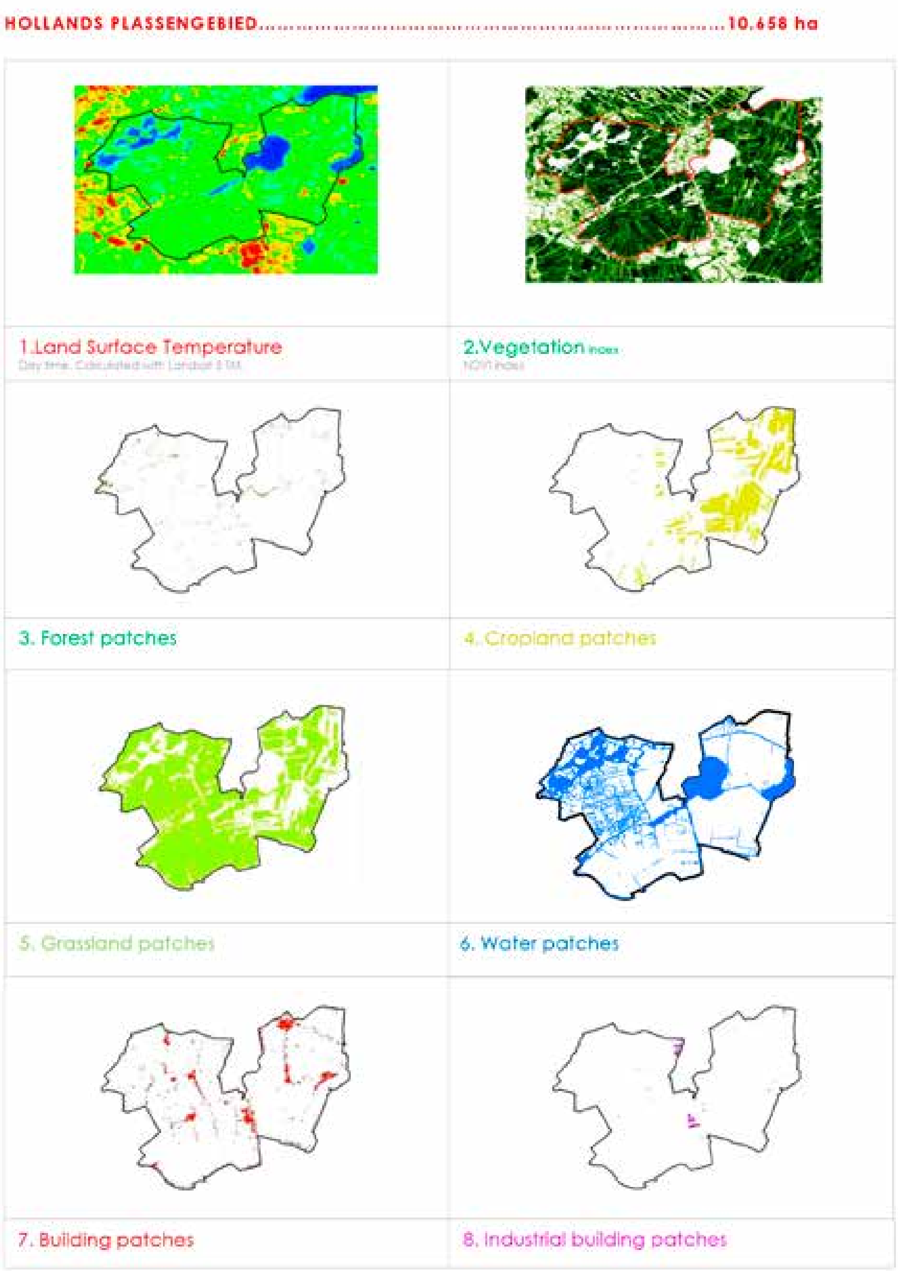

FIGURE 7.24 Hollands Plassengebied analysis schemes

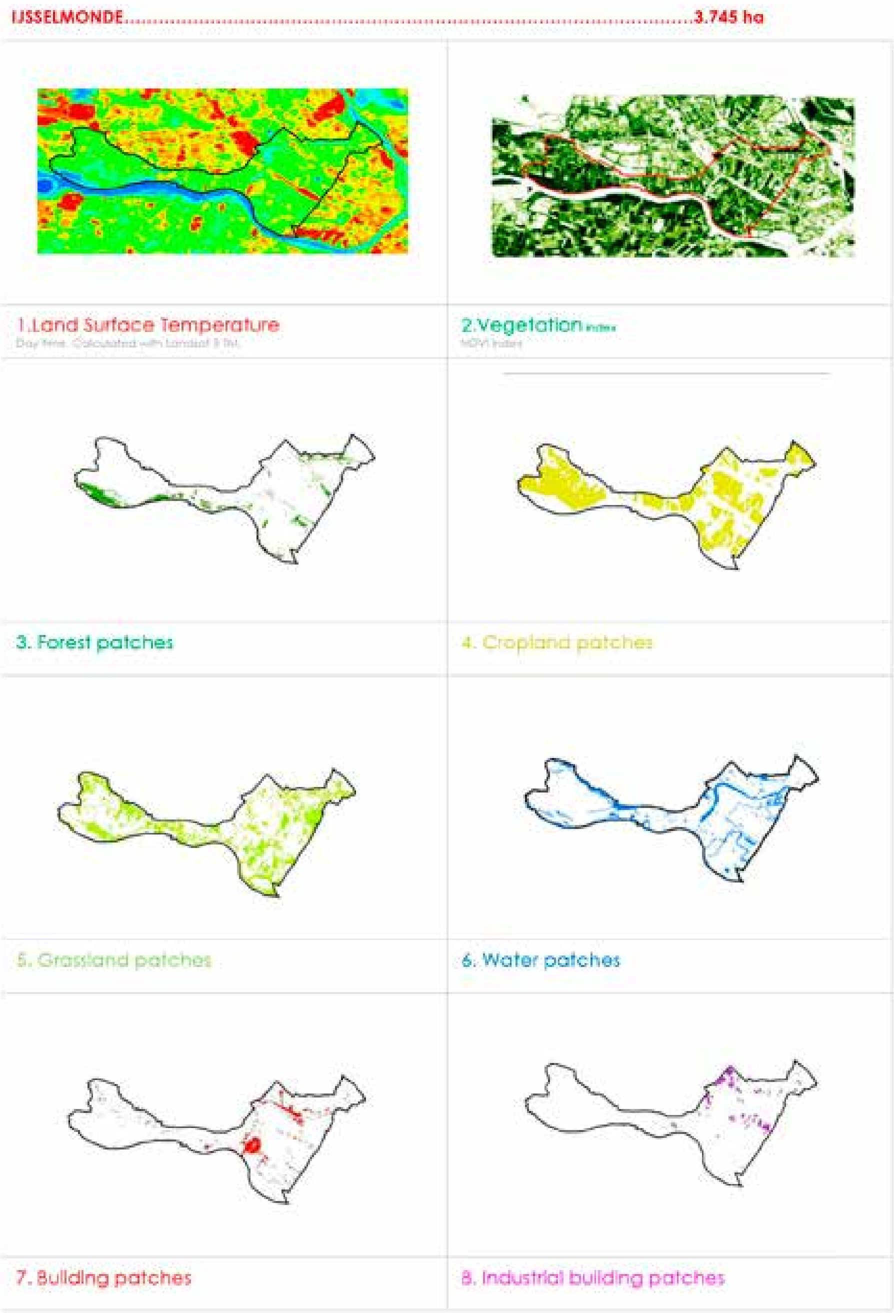

FIGURE 7.25 Isselmonde analysis schemes

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