Report: D3.2:

FUNCTIONAL LINKAGES BETWEEN URBAN GREEN INFRASTRUCTURE, BIODIVERSITY AND HUMAN WELL-BEING

Work package 3: **Functional linkages**

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Description: **The report outlines functional linkages between urban green space, BCD, human health and social cohesion as a part of the EU FP7 (ENV.2013.6.2-5-603567) GREEN SURGE project (2013-2017)**

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LIST OF ABBREVIATIONS

BCD	Biocultural diversity
BD	Biodiversity
DOW	Description of work
ESS	Ecosystem service
EU	European Union
GI	Green infrastructure
MPS	Mean patch size
PF	Planning family
SI	Shape index
TE	Total edge
UGI	Urban green infrastructure
UGS	Urban green space/ urban green spaces
UHI	Urban heat island
ULL	Urban Learning Lab/ Urban Learning Labs
WP	Work package

1 INTRODUCTION TO THE DELIVERABLE 3.2

1.1 Deliverable D3.2 in a frame of the GREEN SURGE project

According to the DOW of the GREEN SURGE project, WP3 studies the functional linkages between urban green space (UGS) and respective types of green infrastructure (UGI) and the ecosystem services (ESS) provided by them, potential impact of UGS diversity, human health, climate change adaptation and well-being. The deliverable D3.2 is based on Milestone 25, dedicated to task 3.3:

Task 3.3: Analysis of the functional linkages
Activities under this task comprise analysis of the linkages between provisioning and demand of/on selected ESS provided by urban green spaces, BD, BCD and human well-being, namely climate change mitigation and adaptation, promotion of health-related quality of life and wellbeing, and enhanced social cohesion (input for WPs 4 and WP7). Methods will include GIS analysis and modelling, dissimilarity indices and regression model statistics. GIS methods include spatial statistics, visualisation methods and accessibility analysis. Dissimilarity indices will be used to assess the dissimilarity of the distribution of UGI within the urban area. Special attention will be given to specific vulnerable groups, such as retired people and children to evaluate health-related quality of life (QoL). The methods will be linked with WP2 to assess linkages with BCD and with WP6 helping to feed the analysis of governance arrangements in different locations and in different UGI projects with data.

Urban green spaces fulfil a full range of functions in cities which are beneficiary for urban dwellers, especially their physical and mental well-being (Haase et al., 2014; Kabisch et al., 2014) but also in terms of urban food production and education about food (urban foraging; McLain et al., 2014), mitigation and adaptation of climate change, namely an increase in the mean and night air temperature in cities (Weber et al., 2014) as well as respective respiratory and cardio-vascular diseases. Moreover, green spaces provide important contributions to human mental well-being and happiness (Haase et al., 2014; Voigt et al., 2014) which expresses itself in both attitude and usage towards and of green spaces (parks, forests, gardens etc.) in cities. All these benefits people receive from urban green spaces are result of ecosystem processes and respective structures/patterns; the latter means the shape and the configuration of green spaces in space: An urban forest could be large in size and with a slightly structured perimeter but also have the same size but exhibiting a rugged perimeter. This diversity of shape and configuration has an enormous effect on the functions mentioned above (Seppelt et al., 2016).

The functional linkages between urban green spaces, urban green space diversity, climate change adaptation and human health are extremely multifaceted and only a subset could be addressed in this deliverable. To cover a wide range of functional linkages, we focussed on four different analyses, which include:

(1) the diversity of different green infrastructure components across Europe using landscape metrics as indicators;

(2) functional linkages between UGS and climate change mitigation and adaptation based on the pan-European datasets of the Urban Atlas and the European Environment Agency (EEA) for Tier 1a and Tier 1b cities;
(3) urban foraging as functional linkage between people and urban ecosystems; and
(4) health of urban dwellers linked to availability of green and blue spaces in their neighbourhood/daily environment.

Each analysis is presented in a separate section of deliverable 3.2.

1.2 Connection of D3.2 with other WPs within GREENSURGE

The results of the deliverable D3.2 serves as input for both WP2, WP4 and WP7 as well as discussion base and reflection ground for the results of WP5. Methodologically, D3.2 is connected with WP2 to assess linkages with BCD, particularly with health relation linkages.

2 THE DIVERSITY OF DIFFERENT GREEN INFRASTRUCTURE COMPONENTS ACROSS EUROPE

2.1 Introduction

In the following section, we refer to UGI when talking about either specific types/landscape classes (as defined in M23). All of these types and classes consist of different components (such as a park consists of trees, hedgerows, flower beds or possibly a lake), elements (e.g. the single tree species *Tilia cordata* at place X), patterns (such as density of the components or elements), structure (composition of the elements), or configuration (spatial shape and arrangement/design of both components or/and elements). We understand under the diversity of UGI components and elements both the total number of them (number of …), the species involved (species richness) but also the spatial properties of the UGI types in terms of size, perimeter and shape.

In order to assess the functional linkages between different types of UGI and regulating ecosystem services including air quality control, air temperature regulation/cooling as well as runoff and flood retention as well as habitat provision for species, their size (land area in m^2/km^2), shape (perimeter in m and index of its arrangement such as shape or shannon indics), structure (which green elements are involved), composition (e.g. in terms pf parks or forests it is the sum of all different park or forest types divided by the total study area).

In terms of biodiversity, larger vegetated green spaces (GS) on average support higher species richness (e.g. in birds and mammals) than small green spaces, because large GS have greater habitat diversity (e.g. Shanahan et al. 2014a) (Davis and Glick, 1978, Marzluff, 2005); open water areas offer habitats for fishes and amphibians (McKinney, 2008), GS with trees and hedgerows offer nesting places for birds, large unfragmented grasslands including wetlands offer suitable ground for breeding birds such as Whitethroat or Skylark (Shanahan et al., 2014a) as well as long edges (perimeters) of green spaces provides habitats for many small mammals and insects including butterflies and dragonflies (McKinney, 2008). In terms of human mental and physical health, large GS (with trees) are particularly preferred for longer stays outside (Shanahan et al., 2014b) and provide useful essentials for the respiratory system (Amoly et al., 2014). Trees also provide shade and cool the air temperature on hot days (Jaganmohan et al., 2016). Open water areas also provide cooling and this way, shore areas belong to preferred recreation places (Haase, 2015). Thus, the geometry of UGI is of importance and delivers nice and suitable proxies to estimate the aborementioned regulation functions insofar they cannot be measured.

In the following, we aim to identify 1) what the different metrics mean by diversity of UGI components, 2) especially when results indicate high diversity and what could be the reason for this, 3) more specific which ecosystem services this diversity could produce/be responsible for and, 4) negative and positive effects of the landscape metrics applied to biodiversity and specific regulating and cultural ecosystem services.

A tool to determine the diversity of UGI composition we chose three different landscape metrics. Landscape metrics have been successfully used for quantitative spatial model building and assessment in biological, habitat and landscape ecological contexts (McKenzie et al., 2011; Uuemaa et al., 2009) and in connection with land use change analysis (DiBari, 2007). In most cases, metrics have been used to characterise open (succession area, low shrubland) and other higher vegetated natural landscapes such as heatland for example (Walz, 2011).

Landscape metrics are quantitative indices that describe compositional and spatial aspects of landscapes based on data from categorial maps, remotely sensed images or GIS coverages. Typically, landscape elements (equals to the composition of the landscape) such as green spaces (parks, forest) and waters in our case, are defined as discrete entities or patches. The diversity of the single types of UGI means thereby its variety of size, perimeter, shape for one city compared to all other cities under investigation.

Landscape composition and configuration is described using metrics developed to quantify patch (e.g. size, shape, isolation) and mosaic (patch richness and diversity, connectivity, contagion) level characteristics (Kupfer, 2012; Walz, 2011).

In order to analyse the diversity of composition and configuration of different green and blue infrastructure components across a large sample of European cities, in this study:

- a set of well-proved and meaningful landscape metrics were calculated describing the diversity of three green infrastructure components (green urban areas; forests; and water) within the city;
- cities have been ranked according to the landscape metrics analysis.

2.2 Methods

2.2.1 Urban land use data

Within the GREENSURGE project, land use data from Urban Atlas (2006 and 2012) represents the most commonly available and standardized data source. It was also used for this study. In particular, we used the thematic classes of *Green urban areas* (including parks, cemetaries, allotment gardens…); *Forest areas* (including broad leaf, mixed and coniferous forests) and *Water areas* (including freshwater like lakes, rivers, ponds, channels, wetlands…). For more information and an extended data discussion, see Deliverable 3.1.

2.2.2 Landscape metrics to determine GI patterns and configuration

For quantification of the diversity of green infrastructure components in cities, based on two expansive literature review papers (Walz, 2011, Uuemaa et al., 2009) and their assessment of landscape metrics' significance, three landscape metrics (Table 2.1) were calculated using the FRAGSTATS manual, formula presented by Farina (2006) in "Principles and Methods in Landscape Ecology" and ArcGIS (McGarigal et al., 2002).

Table 2-1: Landscape Metrics used for the calculation of green infrastructure component diversity across European cities.

Landscape Metric	Calculation	Source
Mean Patch Size	$MPS = \frac{\sum A_{ij}}{n_{ii}}$ where A_i is the area of patches of category i in a map.	Farina (2006)
Total Edge	$TE = \sum_{k=1}^{m} l_{ik}$ where l_{ik} = total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving patch type i. E equals the sum of the lengths (perimeter, m) of all edge segments involving the corresponding patch type.	fragstats.help.4.2.pdf
Shape Index	$SI = \frac{1}{n_i} \sum \frac{L_i}{A_i}$ where n_i is the number of patches of category i in a map, L_i is the perimeter and A_i is the area of each patch in category i. High values indicate the presence of many patches with small interiors.	Farina (2006)

The first metric, Mean Patch Size (MPS), says something about the average size of the patches of a specific landscape or land use type, thus, also applicable to green space typologies. This average size of a patch is often correlated with habitat quality or diversity (number of different habitats) and sufficient patch size for food search for most species of the urban fauna (Uuemaa et al., 2009; Mehnert et al., 2005), in a wider sense with (potential) biodiversity. The second metric, the Total Edge (TE), says something about the contact zones between patches of different size and properties. In cities these zones are often excellent niches for respectively adapted flora and fauna and, what is more, they often form novel micro-habitats as edges are the places where built (artificial) and natural (green, blue) surfaces and (an)organic matter comes together. The higher the Total Edge is, the higher the potential of such niches for "urban adaptation of the species" (Mehnert et al., 2005). Finally, the third metric, the Shape Index (SI), reveals if analysed green space (e.g. forests) are divided into several patches or few larger ones, and it provides a more general measure of landscape diversity, which is often correlated with biodiversity as well. At the same time, a high SI index also indicates that UGI can be fragmented into several small patches. In terms of biodiversity, this can have a contradicting influence, either a decrease or an increase in species richness.

2.3 Results and discussion

For displaying the results of the analysis of almost 300 European cities, we have chosen the bottom (left-hand side in figures) and top 20 cities (right-hand side) to highlight the extreme cases in terms of the three landscape metrics, Mean Patch Size (MPS), Total Edge (TE) and Shape Index (SI) and also use maps of Europe that show how the cities rank according to the metrics. The results are presented for the land cover classes "Green urban areas" in Figure 2-1, Figure 2-4, and Figure 2-7, for "Forest areas" in Figure 2-2, Figure 2-5 and Figure 2-8, and for "Water areas" in Figure 2-3, Figure 2-6, and Figure 2-9.

Starting with the MPS, clear patterns emerge across Europe's cities: the 20 cities with the highest mean patch size of green urban areas (Figure 2-1) are exclusively central and northern as well as north-eastern European cities, and almost no capital cities. The only exception is Alba Iulia in Romania. The highest mean patch size shows Karlovy Vary in Czech Republic followed by the West Midlands (UK), Kaunas (Lithuania) and Antwerp (Belgium). Also five German cities are among the top 20: Köln, Bonn, Weimar, Berlin and Leipzig. These cities can build on rich historic legacies of large green spaces within their city borders.

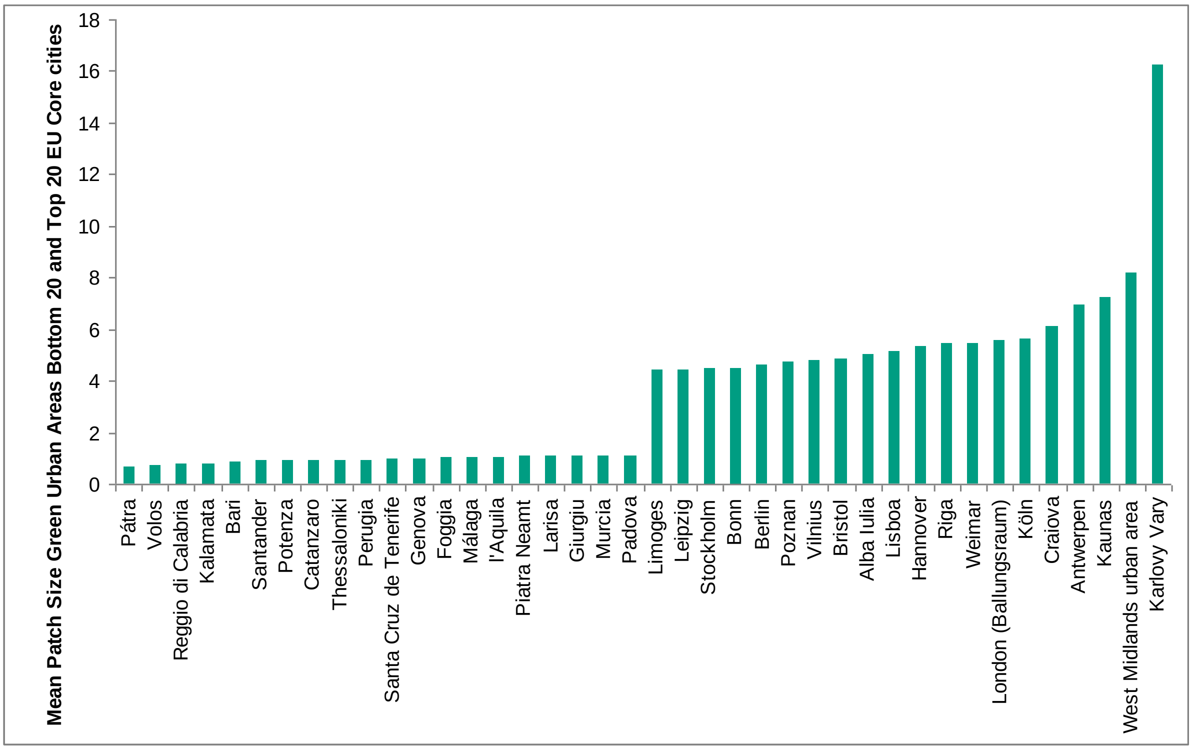


Figure 2-1: Mean Patch Size (ha) of green urban areas in European cities (bottom 20 and top 20).

Interestingly, quite a number of (south)eastern European cities are among the top 20 which is in accordance with a study by Larondelle et al. (2014). Authors found a comparatively high contribution of inner-city areas to the overall urban ecosystem service performance for eastern European cities compared to other regions in Europe. Among the bottom 20 cities in our analysis, most are from southern Europe, namely Greece, Italy, Spain and Romania. This is not surprising as we know that green space in southern Europe is mostly situated outside the city boundaries but it underlines that urban planning might have little influence on the improvement and protection of green urban area in these countries.

When looking at the bottom and top 20 of MPS of forest areas within city boundaries (Figure 2-2), we see almost the same picture as for green urban areas: Central European cities dominate, but also the new member states of the EU such as Romanian cities with Piatra Neamt (highest MPS of urban forest area), Arad, Targu Mures, Timisoara and Sibiu as well as Bulgarian cities with Sofia (capital), Slovakian cities with Bratislava, Presov and Kosice or Czech Republic with Banska Bytrica. A number of German cities are also among the top 20 of forest mean patch size: Freiburg, Augsburg, Göttingen and Wiesbaden (all in western Germany). Also Vienna in Austria is among them. Surprisingly, only two Scandinavian cities are among the top 20, Umea and Uppsala (both in Sweden).

In terms of the bottom 20, the picture is a bit more diverse than for the mean patch size of green urban area: We have again southern European cities here, but also cities in the sparsely-wooded, coastal Netherlands (Amsterdam, Rotterdam), and in the agricultural east of Poland (Rzeszów) as well as in coastal UK (Bristol, Leicester, Portsmouth). Overall, cities in vicinity to the coast exhibit low patch sizes of forest area.

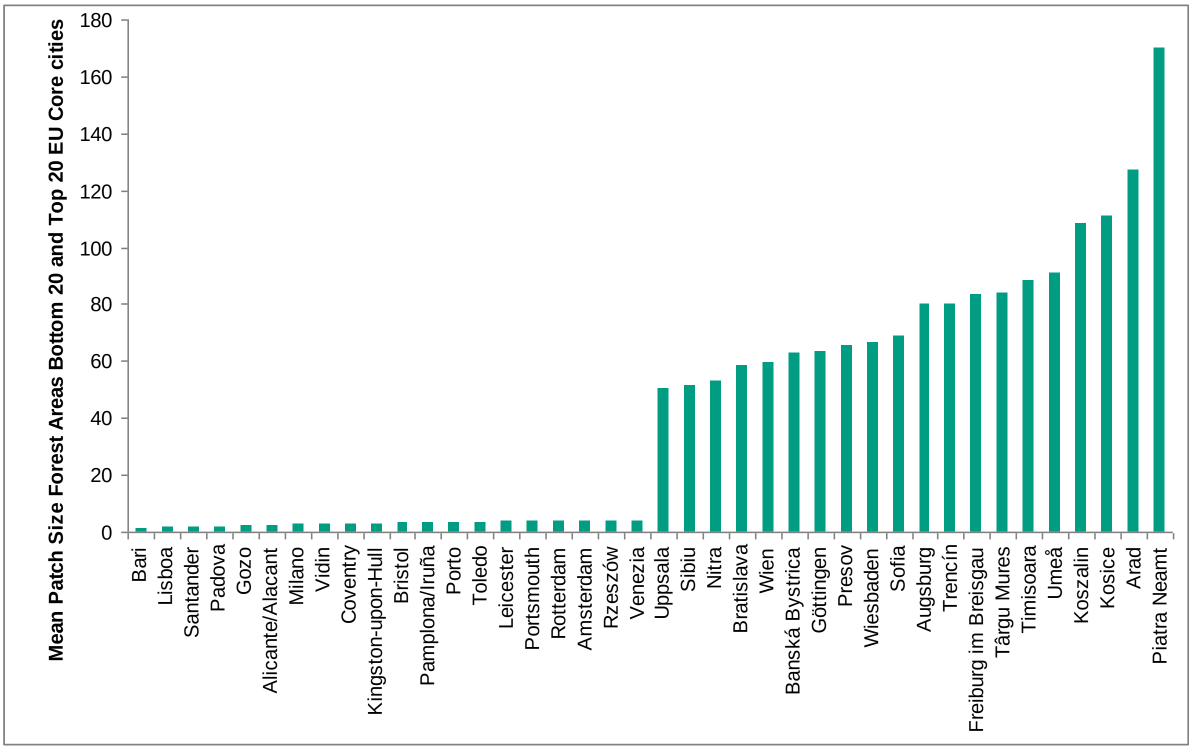


Figure 2-2: Mean Patch Size (ha) of urban forest areas in European cities (bottom 20 and top 20).

Concerning the urban water areas, among the top 20, cities are either located at lakes, large estuaries or rivers: Ioaninna, Jönköping, Schwerin, Örebrö, Tampere und Kaunas are located at lakes. Ruse, Vidin, Giurgiu, und Budapest are located at the river Danube. Cities like Faro, Venezia, Szeczecin, Cagliari, Taranto, Burgas, Valencia and Antwerpen are near the coast and data expresses their richness in coastal lagoons or estuaries within their city border (Figure 2-3).

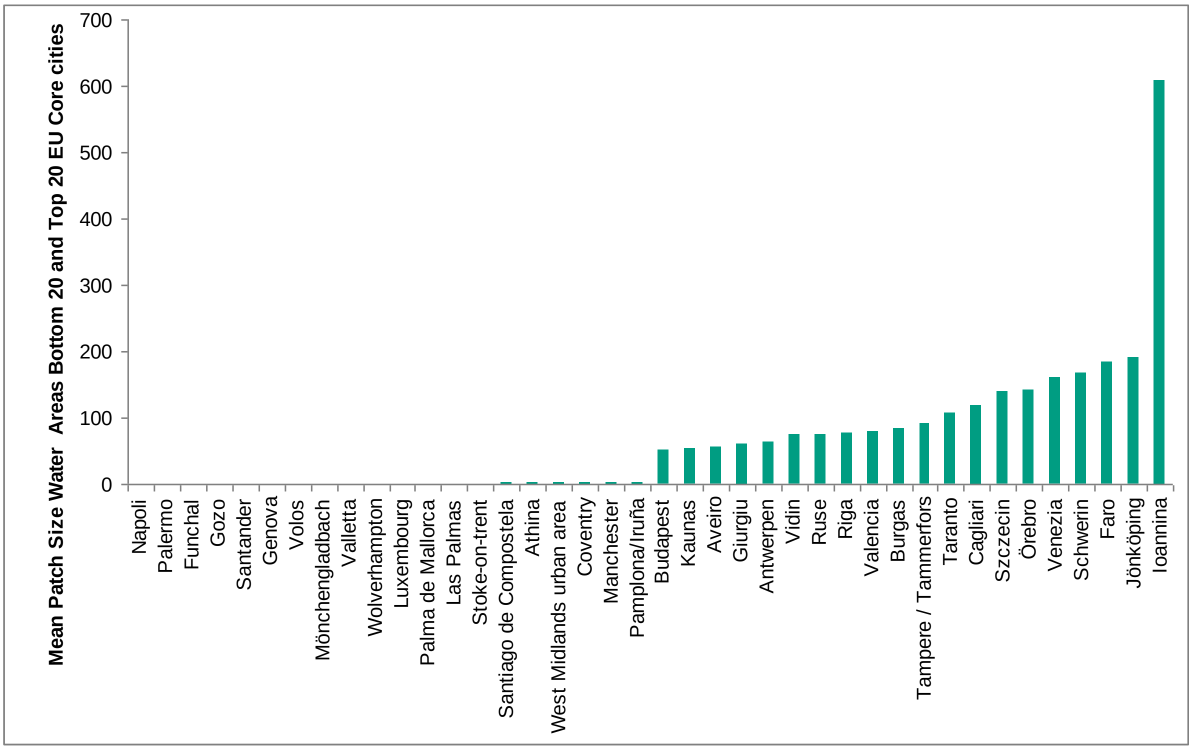


Figure 2-3: Mean Patch Size (ha) of urban waters in European cities (bottom 20 and top 20).

When comparing the top and bottom 20 list of the total edge (TE) of the green urban area across European cities with those for the mean patch size discussed above, we find a completely different picture. Here, among the top 20 many (large in population) capital cities can be found such as Warsaw, Roma, Stockholm, Madrid, Vilnius, Budapest and Vienna, which means TE is clearly depending on space/area size. Thus, larger cities have more niche and ecotone habitat potential than smaller ones which is predominantly a function/effect of size/area: The bigger an total area of a city the higher the area of greenspace included (Figure 2-4; see Haase et al., 2013). This could also include the possibility that these cities have more niches/ecotones for species that can adapt in these transition spaces: Doubtless, species richness is dependent on the quality of the edges so that if urban green space either merges into impervious cover such as roads/buildings or into another green space (e.g. forest, water) has a totally different influence to biodiversity. But this remains a hypothesis so far, because the ecological quality of edge and suitability to provide habitats can vary greatly however, bird species that can utilize edged as habitats are usually generalists with broader environmental tolerance (Bonier et al. 2007; Saarikivi and Herczeg 2014). A neighbourhood analysis of green spaces in terms of which land use classes merge into the green spaces was not carried out due to time and personal resources limitations but could be performed in future research.

Concerning the bottom 20, again comparatively smaller southern European cities dominate, among them the city with the highest MPS of urban green areas, Alba Iulia in Romania. In the city, the green space is clumped into single large patches and thus the “contact zone” between green space and others land uses is small.

When looking the ranking of the TE of forest areas within the city borders (Figure 2-5), we find the expected picture of having many northern European cities in the top 20 (mainly from Sweden) but also southern European cities such as Roma, Nice, Coimbra or Perugia. Among those with the lowest TE are many southern European cities, too, which either miss forest area overall or have it packed into one or two patches.

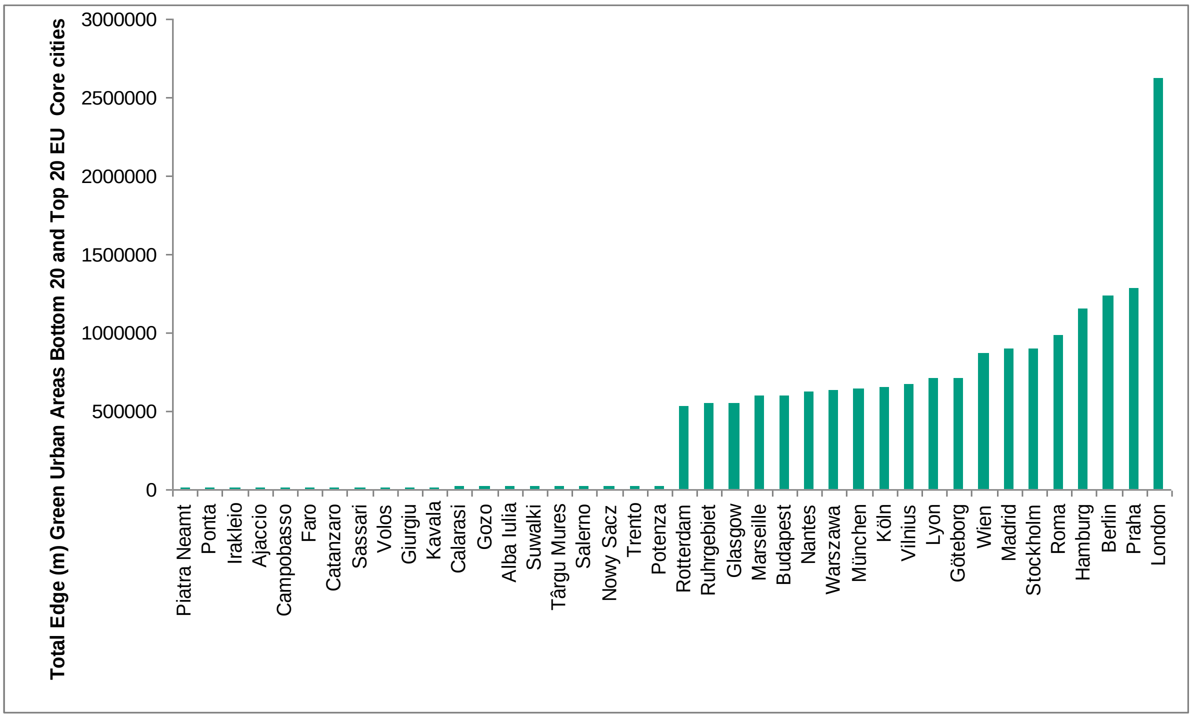


Figure 2-4: Total Edge (m) of green urban areas in European cities (bottom 20 and top 20).

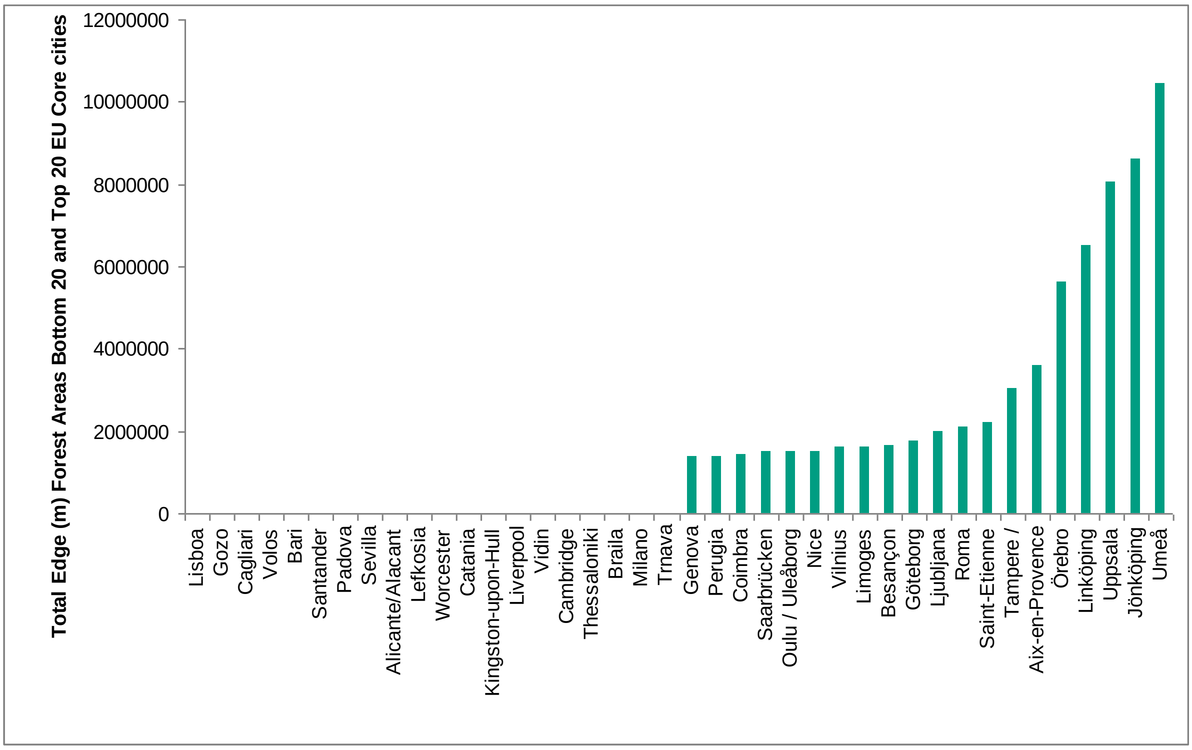


Figure 2-5: Total Edge (m) of urban forest areas in European cities (bottom 20 and top 20).

The TE of the urban water areas (Figure 2-6) reflects the geomorphology and hydrology of the cities: Here those cities in regions with glacial past and respective channel lakes show the highest values regardless their belonging to northern or eastern Europe as well as coastal cities in southern Europe. Conversely, inland cities show low values. There are some exceptions like Córdoba or Strasbourg, which are situated along large rivers.

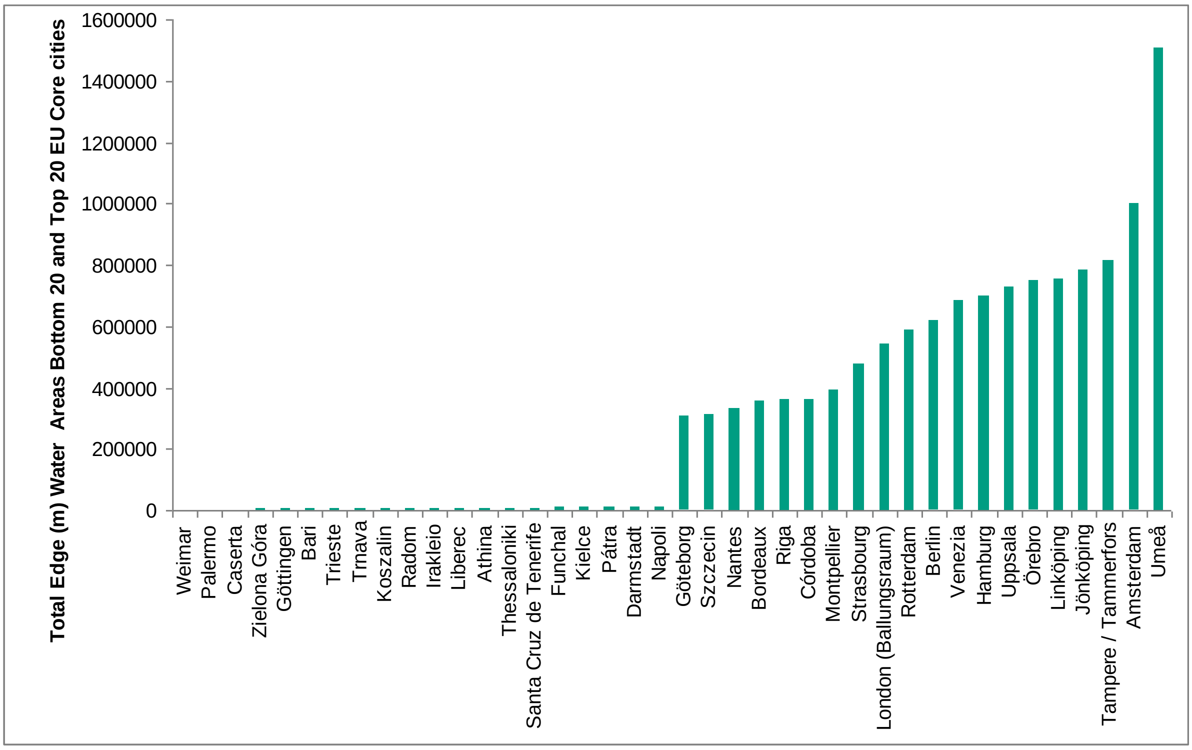


Figure 2-6: Total Edge (m) of urban waters in European cities (bottom 20 and top 20).

Coming finally to the shape index of green urban areas, urban forest areas and water areas, we overall find less differences in the values for all three green and blue infrastructure classes except the highest values which are extreme in all three cases: Thessaloniki (Country) in terms of green urban area (Figure 2-7), resulting from linear seafront parks, Nijmegen (Country) in terms of urban forest (Figure 2-8), resulting from small scale mix for agricultural land and forests, and Stockholm (Sweden) in terms of urban waters (Figure 2-9), a city located on islands in an estuary. As the shape index equals the average area divided by patch for the respective green and blue infrastructure classes, a high shape index means that the form of the respective land use class is spread/fragmented and less compact compared to cities with low shape indices.

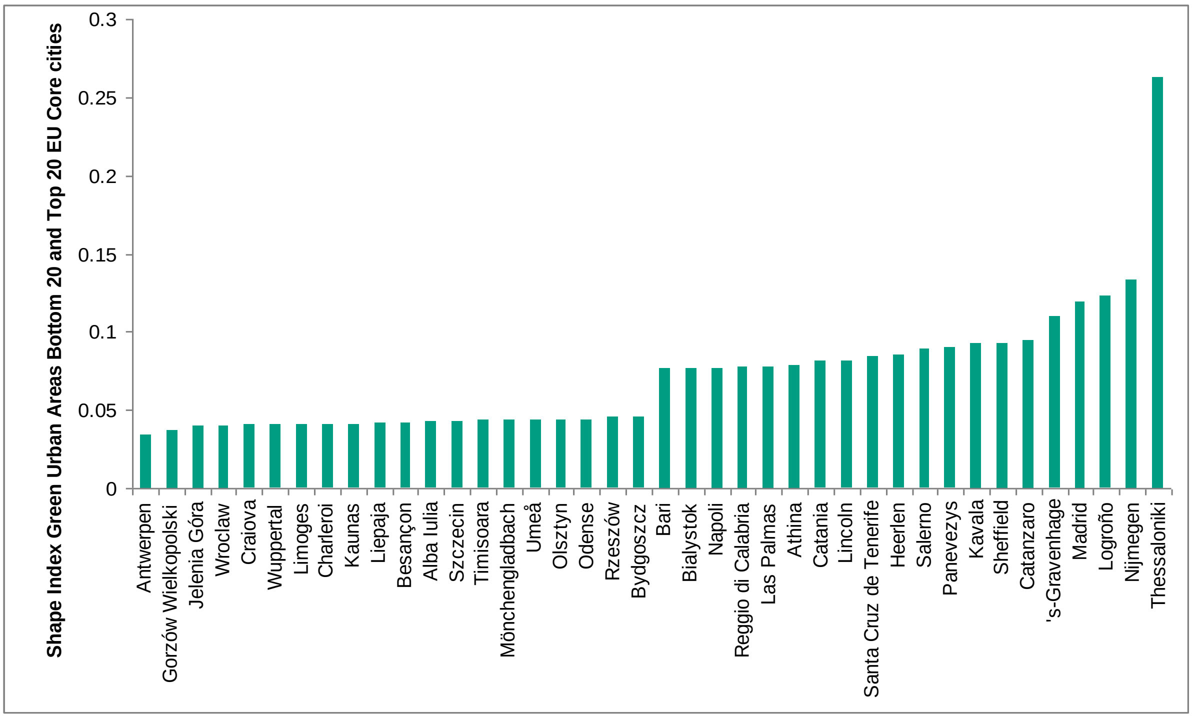


Figure 2-7: Shape Index of green urban areas in European cities (bottom 20 and top 20).

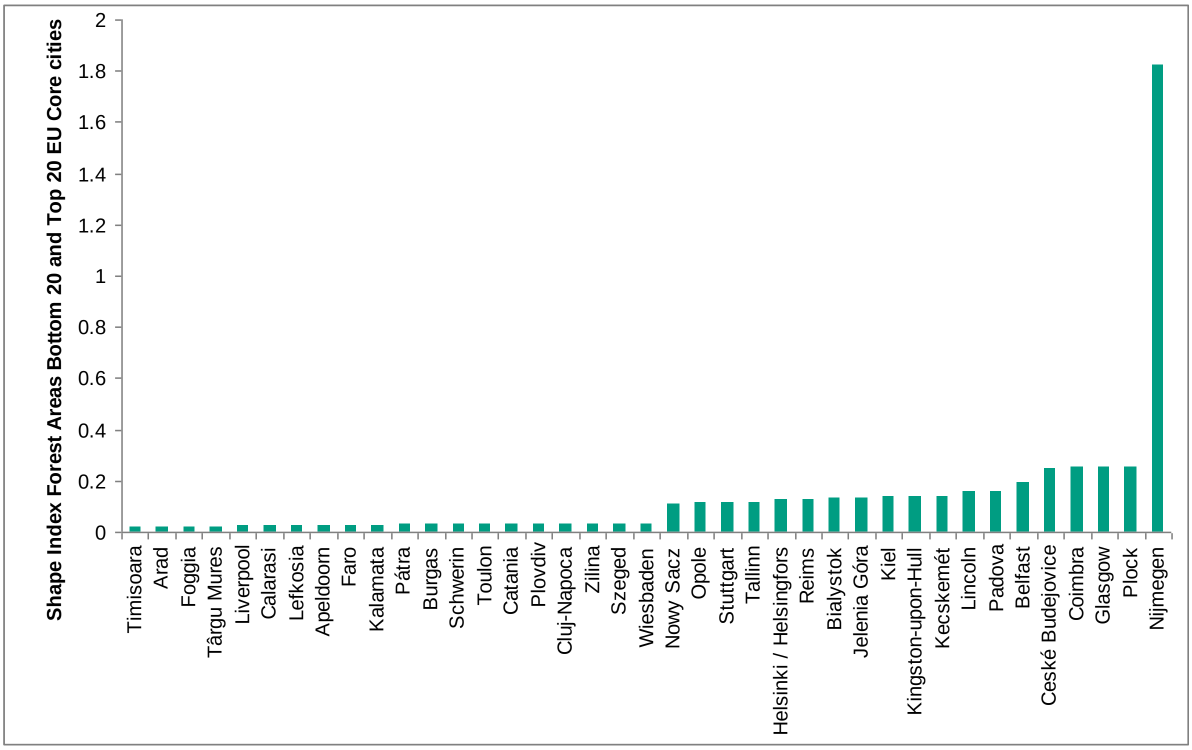


Figure 2-8: Shape Index of urban forest areas in European cities (bottom 20 and top 20).

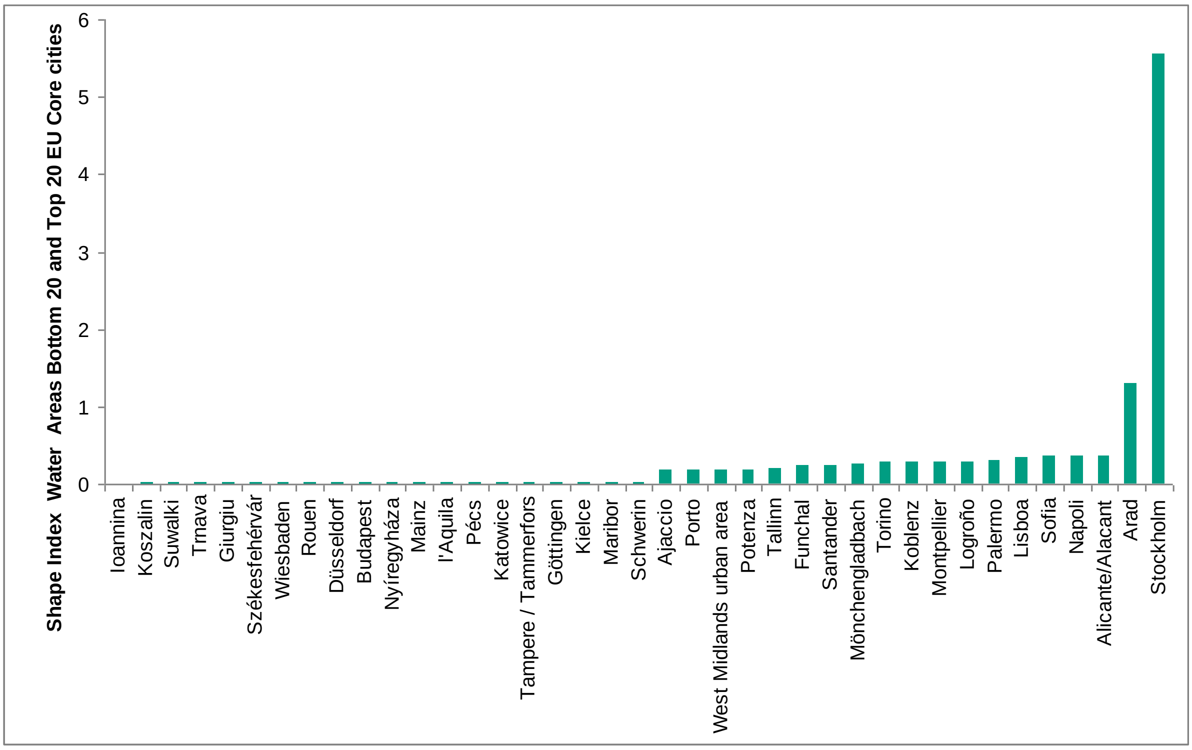


Figure 2-9: Shape Index of urban waters in European cities (bottom 20 and top 20).

The three landscape metrics are displayed again in their spatial patterns for all European cities involved in the calculation in Figure 2-10.

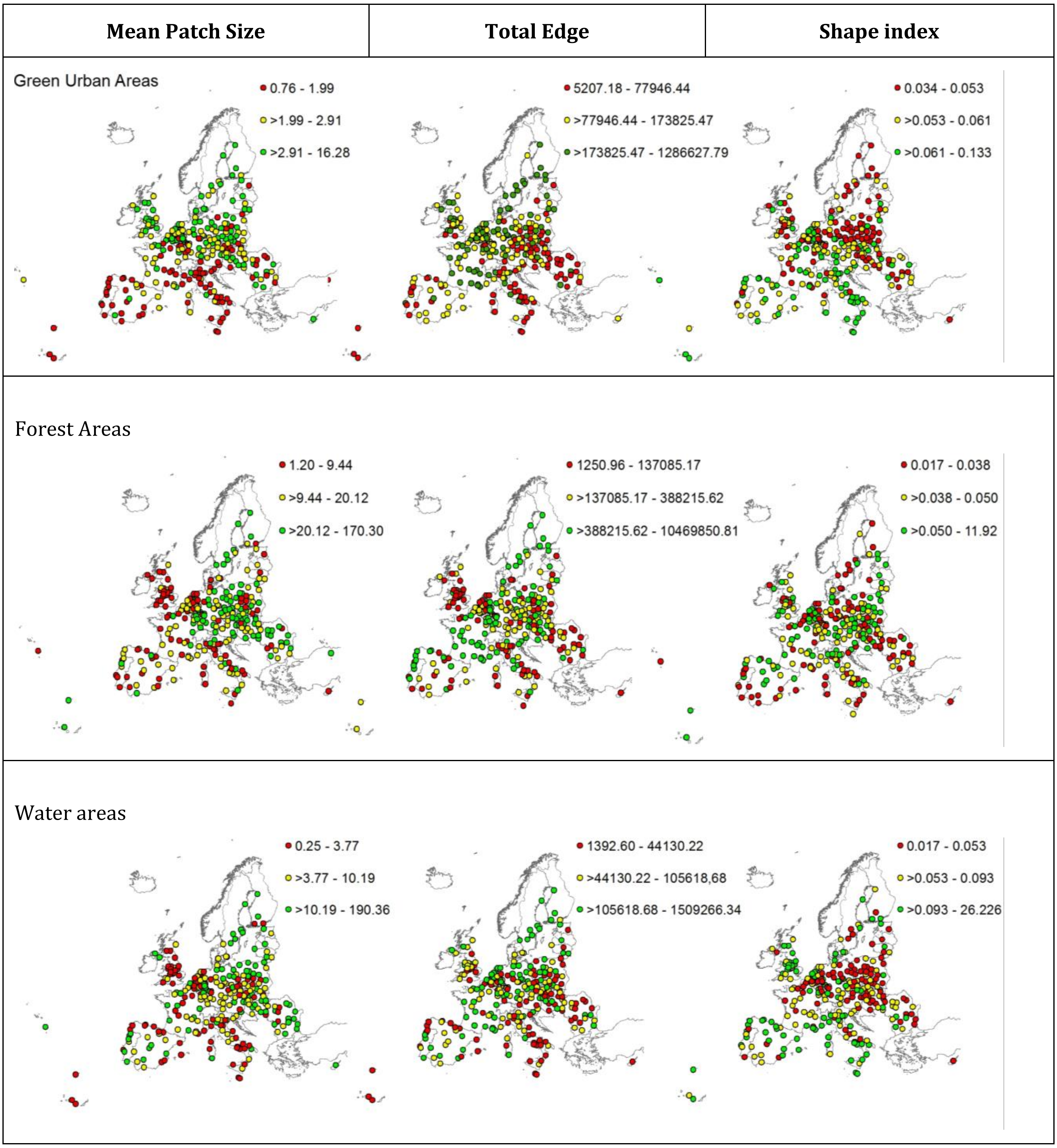


Figure 2-10: Distribution of the three landscape metrics Mean Patch Size, Total Edge and Shape Index across European cities from Urban Atlas (N=295) (breaks in the distribution are 33.3 percentile, 66.6 and 99.9 percentile).

2.4 Conclusions

The results of this study about the diversity of UGI types by analysing mean patch size, total edge and shape index of three different land use classes: urban green (mainly parks), forests, water areas) across a large number of European cities have clearly shown that there is not “the one parameter/variable” that could explain variation in UGI in cities. Using the three landscape metrics, we able to reveal some general patterns in UGI composition and how fragmented UGI is (by ranking the cities according to the values of each metrics we were able to uncover that there are factors that determine the shape of green spaces, forests and water areas) and thus to a certain extent the ecosystem services contribution to human well-being of UGI: (1) situation within Europe and thus the macro-geographical region, (2) geomorphology, terrain, situation at a coast or along a river compared to situation in a plateau situation and (3) to some extent the history of land use over time. In addition, we were able to detect some common patterns in diversity of UGI composition in European cities.

We could find very different potentials/assumptions, not yet evidence itself, for the provisioning of regulating functions/services of urban green spaces, urban forest areas and waters among the large European cities which reach from excellent habitat and recreation provision, mostly in Northern, Central and partially Eastern Europe (Romania, Czech Republic), compared to small sizes and small edge/boundary zones of GI in Southern Europe. Cities with high MPS and ET are good for providing habitats for various species, not only those providing large patches of parks, forests or waters? And from an (utilitarian/human) recreational point of view, fragmented patches of park and forest GI types that are probably easier to access, perceived less ‘dangerous‘ by specific population groups (women, elderly) and thus can support daily recreational use in a very relevant and pragmatic, may be at the end also cost-efficient, way.

Strategies and measures to improve the functional impacts/effects of green have to be different in these regions: Whereas GS maintenance plays the major role in the well-equipped cities, GS enlargement and creation is crucial in less well-equipped cities.

A more detailed analysis of the single green space classes above the current separation level between “green urban areas”, “forest area” and “water areas” would permit to distinguish the importance of the single factors for each class/type of green infrastructure. For green infrastructures like gardens, cemeteries, green roof tops or wall green such a patterns and diversity analysis is still pending as they are insufficiently displayed in the datasets used for analysis.

3 FUNCTIONAL LINKAGES BETWEEN URBAN GREEN INFASTRUCTURE AND CLIMATE CHANGE MITIGATION AND ADAPTATION

3.1 Introduction

Vegetation and trees in an urban environment can mitigate urban heat island development by reducing air temperature and improving the microclimate (Dimoundi et al., 2003; see an extensive review by Bowler et al. 2010). The urban heat island effect is described as higher local air temperatures compared to those in non-urban surroundings. Two main processes are involved in cooling urban climates: (i) shading and (ii) evapotranspiration (Santamouris, 2001).

Studies in Australia have shown that tree shade reduces external air temperature by up to 1°C and wall surface temperature up to 9°C (Berry et al., 2013). In Taipei, the cool island intensity of 61 city parks was stronger in summer than in the winter (Chang et al., 2007). In Germany, land cover classes showed statistically significant relationships with air temperature and land surface temperature (Schwarz et al. 2012). Schwarz et al. (2012) showed that urban land cover types such as *discontinuous urban fabric* and *green urban areas* have significantly different temperature values. They also identified a significant temperature difference between urban area and water surface temperature during the day and even more during the night. Surface water temperature was 1°C cooler during the day and 4°C cooler in the evening and the morning (Schwarz et al., 2012).

Cao et al. (2010) found that the cooling of urban green areas depends on park size. Larger parks show greater surface temperature differences compared to their vicinity than smaller parks. Moreover, the configuration of urban green areas significantly affects cooling in cities. Among vegetated areas, woody vegetation results in highest temperature differences. Also, evenly distributed woody vegetation reduces surface temperature more than clustered vegetation because the form provides more shade for surrounding non-vegetated surfaces (Zhou et al., 2011). In the study of Hamada et al. (2013) the results showed that the surface temperatures of green areas (agricultural land, forests and lawns) in the daytime were lower than all other categories, except ponds. Among green areas, the temperatures were lower in the forest than above the lawn and agricultural lands. The authors concluded that the cooling effect of green areas could extend to the surrounding urban areas and improve the thermal environment. Moreover, the cooling impact of plants on air and surface temperature vary with environmental factors and plant specific thermal and optical characteristics. Vegetation with highly reflective surface can reduce surface temperature by reducing the amount and intensity of thermal radiation. This may also lower local and downwind heat fluxes from cooler surfaces (Taha, 1997).

Based on historical data, Rohinton et al. (2012) found that during summer, vegetation and urban land cover produces the largest proportionate sensible heat, while urban land cover produces the second largest proportionate latent heat flux. Fujibe (2011) found that there is a warming trend of 0.3-0.4°C/decade for locations with low population density (<100 people per km^2). For areas with larger population density (100-300/km^2) the trend is 0.03-0.05°C/decade. This suggests that recent temperature increase is largely contributed to background climate change. Moreover, Thorsson et al. (2011) found that urban geometry could cause large intra-urban differences in mean radiant temperature on annual, daytime and hourly time scales. They also found, that densely built urban structure mitigate extreme swings in mean radiant temperature and in the generally adopted thermal comfort index by improving outdoor comfort conditions in both winter and summer.

In conclusion, temperature in a city is clearly dependent on urban land use. The studies referred to above indicated, that in particular green spaces with trees but also water areas in cities show significantly lower temperature values than their urban built-up surroundings. Urban green spaces in a city, which consist of a number of different infrastructure components (such as green spaces, forests, waters, see Deliverable D3.1) are, however, not equally distributed across city areas. Further, findings from a European city sample suggests, that the amount of green space in a city varies by geographical location in Europe (Kabisch and Haase, 2012). History, planning culture and biophysical characteristics play a major role in current green space extent and spatial pattern so that northern, southern, western and eastern European cities show different amounts of green space within their city area (Larondelle et al. 2014).

In this study, we show the quantitative patterns of different urban land-use categories (including urban green spaces) in a large sample of European cities and link them with urban planning families. Further, we show the linkage between urban land use categories and their effects on the urban heat island. The following goals were developed:

1. Explore if planning traditions are reflected in urban land-use characteristics.
2. Explore interrelationships between air temperature and city land use in a smaller selection of cities relating urban heat island magnitude with the extent and spatial arrangement of urban green.

3.2 Materials and methods

3.2.1 General approach

The analysis of the linkages between different green infrastructure elements and urban climate across a large sample of European cities was conducted upon three main factors (biophysical features, urban planning traditions and urban land use). The three linkages between these factors were analysed separately in this study (Figure 3-1).

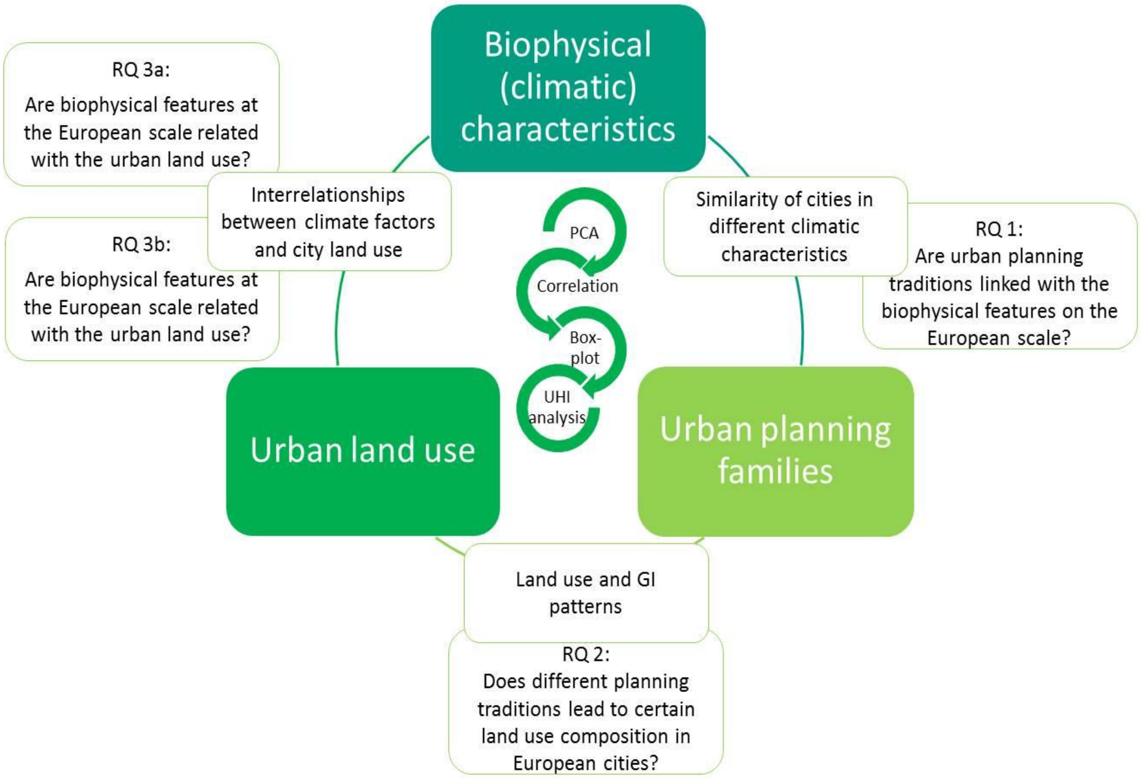


Figure 3-1: Functional linkages (1-3) between three factors acting upon urban green spaces in European cities. The methods used to investigate these linkages are also noted (RQ – research question, UHI – urban heat island).

3.2.2 Data used

For the analyses the following data were used:

1. Urban land use categories used in the analysis is based on Urban Atlas data sets (European Environment Agency 2011). The analyses in this study focus on core cities, delineated using the core city layer from the Urban Audit (European Commission, 2004), which refers to current administrative city boundaries. In this analysis, only cities with full data availability (about 290 cities) have been included.

2. For the assessment of the urban heat island effect (UHI; i.e. differences between city centre and city outskirt) we used the mean summer temperature differences between the city centre and city outskirts. The sample included 20 cities which were defined as the Tier 1b cities (N=20). Main temperature data source was the EuroLST BIOCLIM raster dataset derived from reconstructed MODIS LST at 250m pixel resolution by Fondazione Edmund Mach (2015) (http://gis.cri.fmach.it/eurolst-bioclim/).

3. For urban planning tradition of the European cities the classification in certain European Planning Families (PF) was used. PF's were derived within the GREEN SURGE project

(see Deliverable D5.1 for details). The framework is based on different aspects of spatial, legal and social planning issues. Five main planning families were identified by WP5 GREEN SURGE project partners (Figure 3-2). The selection of 20 Tier 1b cities as described Deliverable 5.1 was chosen as a representative sample of European cities and city regions. In total this cities represent 14 European states and 5 planning families (Hansen et al., 2015).

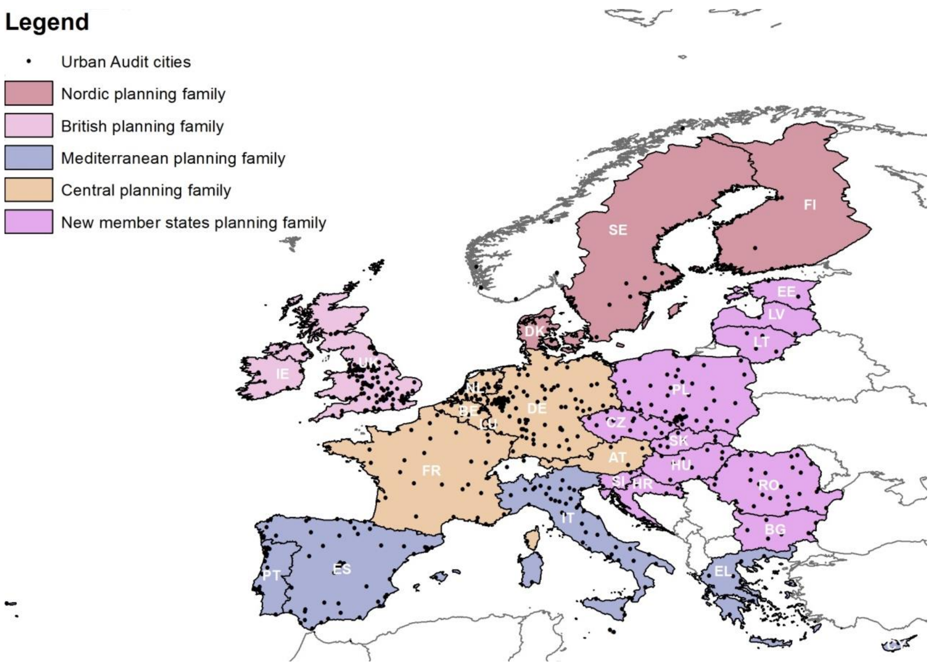


Figure 3-2: The European Urban Audit cities and the corresponding planning families (from Deliverable D5.1)

3.2.3 Analyses

The functional linkages between climate, land use and urban planning were investigated using the following analyses:

To investigate if the **urban planning traditions are reflected in certain spatial characteristics of the European cities** box plots were drawn to show the percentages of main categories of land use for each planning family separately. The numbers of cities in each planning family were the following: British – 29 cities, Central European – 90 cities, Mediterranean – 74 cities, New member – 85 cities and Nordic – 16 cities. On box plots several characteristic points are presented, namely median (thick line), first and second quartile (coloured box), minimum and maximum value (whiskers) and points (outliers).

The **analysis of heat island intensity and its relationship with urban land use** was performed on a smaller selection of European cities (20 tier 1b cities). Heat island intensity was determined as the temperature difference between city centre and city outskirts. First, we defined city centres based on continuous and dense discontinuous land cover classes of the Urban Atlas (codes 11100 and 11210); emerged polygon of these two land-use classes was calculated for each city and a centroid was used as a city centre. For temperature in the city centre average mean summer temperature was used in an area of 250 m around each centroid. For city outskirts, the administrative borders of Urban Audit were used; mean temperature on that border was calculated.

3.3 Results and discussion

3.3.1 Land use green infrastructure patterns and European planning families

The relation between the different shares of land use in the European cities concerning their related planning families (PF) is shown in Figure 3-3 using box-plots. The x-axis shows the planning families respectively for the land use categories of urban green areas, forest areas, agricultural and semi-natural areas, construction areas, ruderal areas all green areas (including urban green and forest areas), and three different categories for urban fabric. Planning families are displayed as British, Central, Mediterranean, New member states and Nordic planning family.

Box-plots clearly indicate that the share of green urban areas is larger in cities in the Nordic and British PF compared to other planning families. The highest variability in percent of forest areas can be found in the Nordic PF, followed by New Member PF and Central PF. Cities of the Mediterranean PF have on average larger percentage of agricultural and semi-natural areas compared to other PF, however the variability in percentage of agricultural and semi-natural areas is the highest in these cities as well. Concerning all green areas combined, there are no considerable differences between PFs, except for British PF. In less dense urban fabric classes such as the discontinuous dense urban fabric cities from Central, Mediterranean, New Member and Nordic PF have smaller average shares compared to British PF with somewhat lower share of these areas. Discontinuous dense urban fabric (medium, low, very low) represented mostly by individual housing and private gardens, is on average considerably larger in British and Nordic PF in comparison to other three PFs.

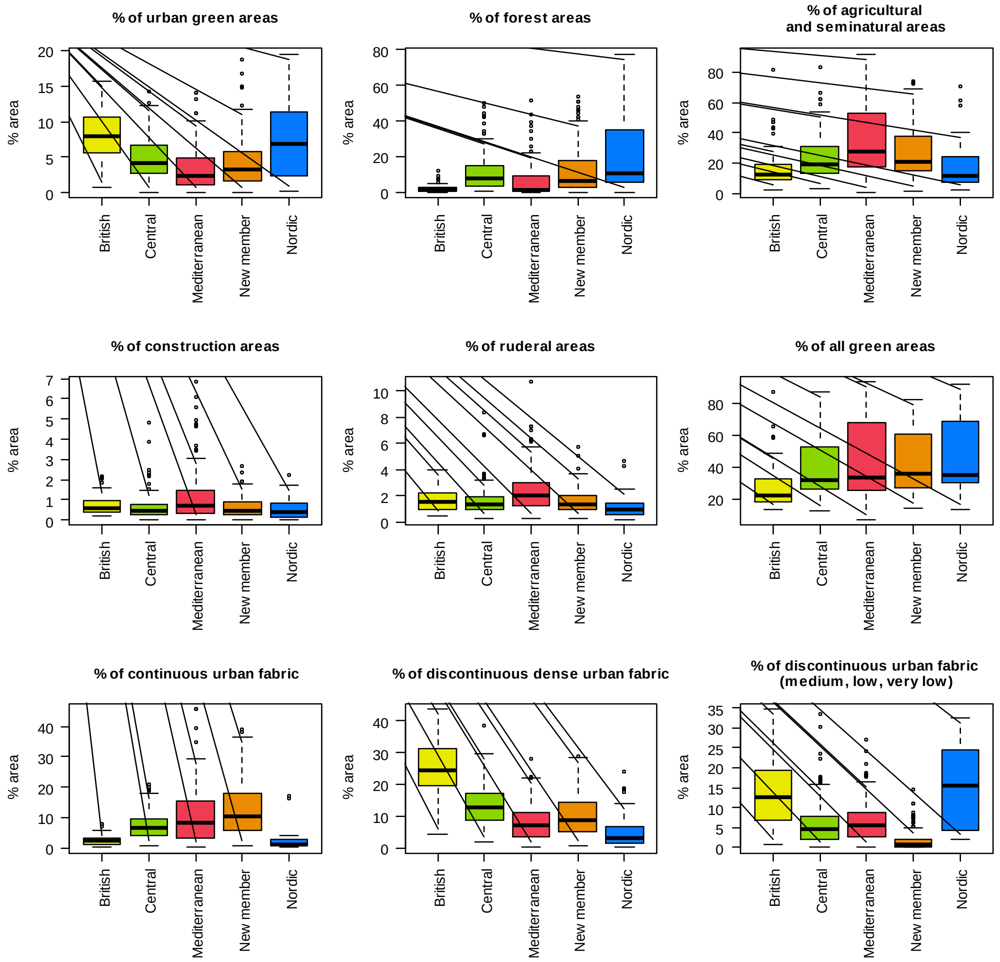


Figure 3-3: Differences in the percentages of different land uses in EU cities between European planning traditions (N=294 cities from Urban Atlas).

3.3.2 Heat island effect and potential of cities for climate change mitigation and adaptation

The amount of the urban heat island (UHI) effect on the extent of different land uses categories was performed for 20 (tier 1b) cities. From the sample of 20 cities, we present here the Urban Learning Lab cities of Berlin, Malmö, Bari, Edinburgh and Ljubljana. The heat island vitalisation of all 20 cities can be found in appendix 1.

As shown in Figure 3-4, the UHI effect of the cities investigated ranges from 0.2°C (min. in Liverpool) to 2.1°C (max. effect Ljubljana). Interestingly, the UHI distribution in Bari shows an inverse heat island effect (temperature differences is minus 0.7°C). We found lower temperatures in the city centre compared to the outskirts. This can be mainly related to Bari's as a coastal city located at the Mediterranean Sea. Bari's city centre is directly located at the coast line and is influenced by the cooling effect of the water areas. Other cities in the Mediterranean planning family are cities with dense built-up surfaces in their city centres with some individual green areas. Moreover, in the Mediterranean PF the UHI effect varies from 2 – 3°C. Most of the cities from Tier 1b in this PF (except Bari) have the largest surface areas of continuous urban fabric. Share of continuous urban fabric is above the average in Mediterranean PF (Table 3-1, Appendix 1).

Ljubljana, as a city of the planning family of the New member states, shows a temperature variation in the city from 1.5 -3°C. The biggest difference can be found in the forest areas, which are the biggest land use category in the city.

In Edinburgh, where agricultural, semi-natural and wetlands prevail in the outer part of the city, the UHI effect is quite big (3°C). Among all cities in this PF Edinburg has large proportion of agricultural, semi-natural and wetland, which is far above the average in this PF (Table 3-1).

In Malmö, the UHI effect is relatively small (1°C). In fact, the UHI effect in Nordic PF is the smallest among all PF (temperature varies from 1–2 °C).

Berlin has the second highest UHI effect of the ULL cities (almost 2°C).

UHI effect seems to be dependent on the land use in the city outskirt. If open landscape (croplands, grasslands) predominates in the outskirts the temperature differences between city centre and outskirts are lower because of generally higher temperatures above croplands and other low-vegetation areas. On the other hand, the temperatures above larger forested areas are considerably lower (see e.g. Berlin, Ljubljana) and hence the UHI effect is bigger.

Not only the size, moreover the configuration of urban green areas affects the phenomenon of heat islands. Among vegetated areas, woody vegetation results in highest temperature differences. Also, evenly distributed woody vegetation reduces surface temperature more than clustered vegetation because the form provides more shade for surrounding non-vegetated surfaces (Zhou et al., 2011). Helsinki is an example for evenly distributed forest and it has a smaller UHI effect. In contrast, Berlin and Ljubljana have a clustered forest distribution and a bigger UHI effect (Figure 3-4, Table 3-1). All three cities have a comparatively high share of forest area in their respective planning family (Figure 3-3).

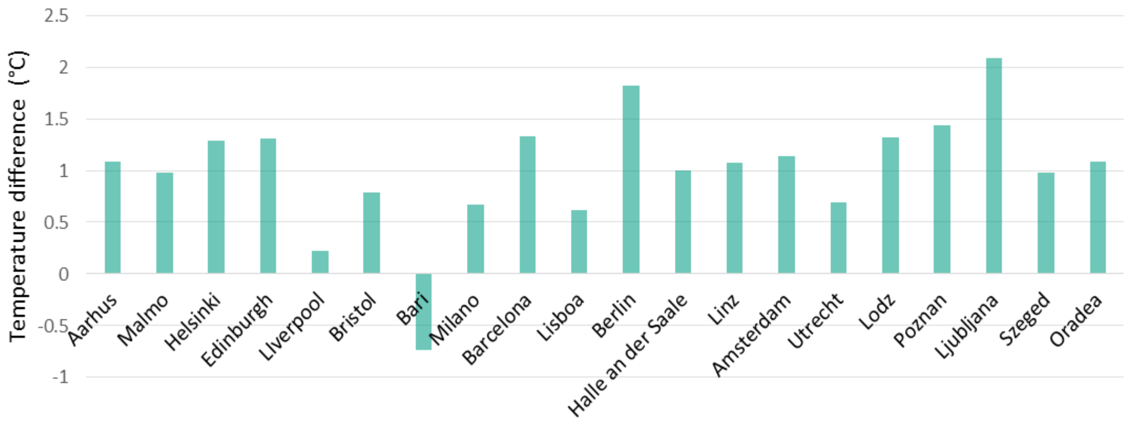


Figure 3-4: Temperature differences (°C) between city centre and city outskirts for Tier 1b cities

Table 3-1: Linkages between land use, planning family and heat island effect for the ULL cities

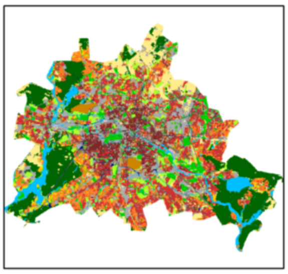
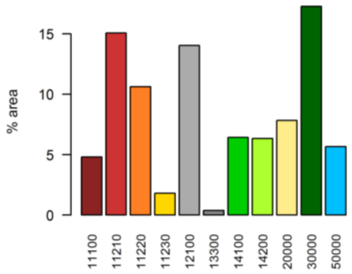
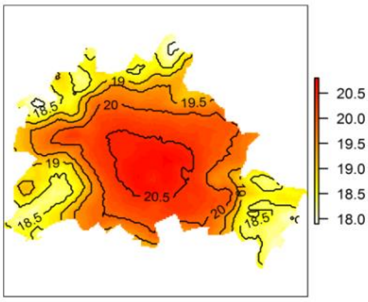
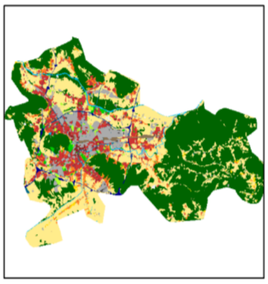
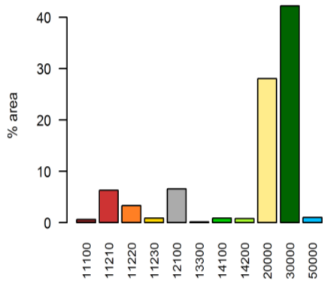
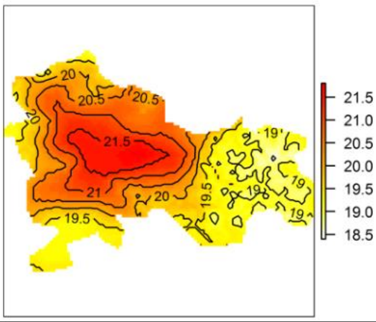
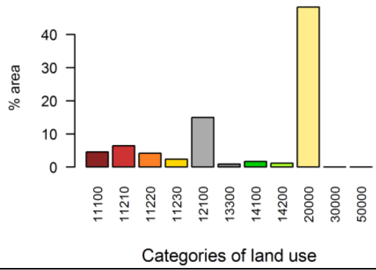
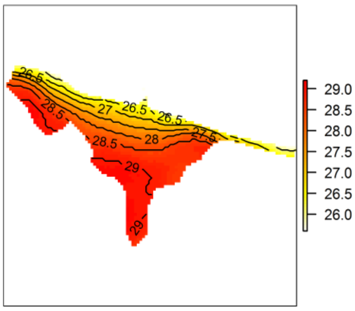
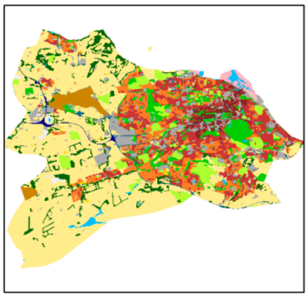
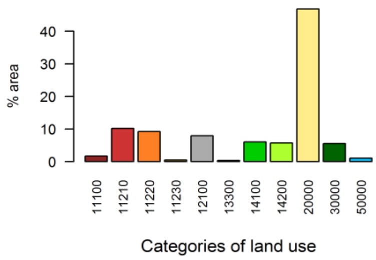
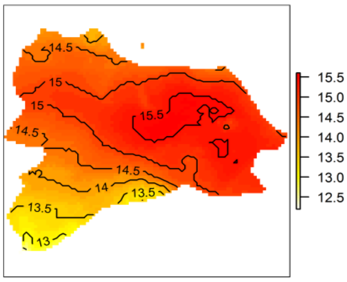
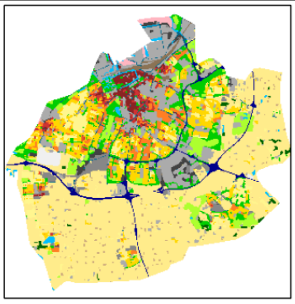
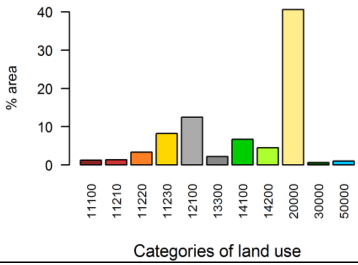
Planning family	Land use	Heath island
Central PF		
BERLIN 		
New member states PF		
LJUBLJANA 		
Mediterranean PF		
BARI 		
British PF		
EDINBURGH 		

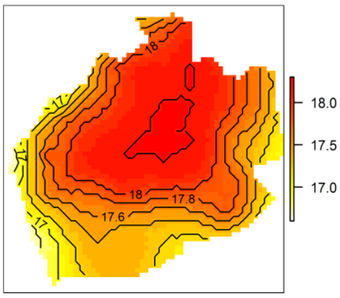
Table 3-1 (continued): Linkages between land use, planning family and heat island effect for the ULL cities.

Planning family	Land use	Heath island
Nordic PF		

MALMO







- 11100 - Continuous Urban Fabric (S.L. > 80%)
- 11210 - Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)
- 11220 - Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%)
- 11230 - Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)
- 12100 - Industrial, commercial, public, military and private units
- 13300 - Construction sites
- 14100 - Green urban areas
- 14200 - Sports and leisure facilities
- 20000 - Agricultural + Semi-natural areas + Wetlands
- 30000 - Forests
- 50000 - Water bodies

3.4 Conclusions

The study confirms the assumption that green infrastructure components are not equally distributed across European cities and planning families. The relation results show different patterns in share of land use between planning families, as well as between land use categories. So we can assume that urban land use is a result of complex factors and planning tradition is one of them.

As seen from the results, UHI effect is connected with land use. It is expected that cities with higher percentage of green areas will have a greater potential for climate change adaptation. In addition to other factors, distribution of land use is the most important factor for the adaptation.

4 URBAN GREEN SPACE AND URBAN FORAGING

4.1 Introduction

The gathering of wild food in cities, i.e. urban foraging, probably represents one of the most direct link between people and urban ecosystems. It has been important for the livelihood of urban dwellers for most of history (Barthel and Isendahl, 2013) and is still essential in cities of the developing world (Hamilton et al., 2013). In Europe, cities today depend mostly on outside sources of food (Folke et al., 1997; Morgan, 2009; Morgan, 2014). But even there and in recent history, local food production and collection has been played an important role during times of crisis, for example during the Great Depression and after the World Wars (Barthel and Isendahl, 2013; Gröning, 1996; Lieske, 2010).

In the absence of food crises, urban foraging has never fully ceased and even become more popular in recent years (McLain et al., 2012; McLain et al., 2014; Poe et al., 2013). The motivation behind contemporary foraging in developed countries is not the lack of food, but rather recreation and sense of place (Herlin and Herlin, 2015; McLain et al., 2014), but also unease about the disconnection from rural areas and the environmental impacts of modern industrial agriculture (McLain et al., 2014). The willingness to gather wild food is certainly influenced by ecological preconditions and by cultural background of the people involved. There is, for example, an important influence of the amount of forest in the vicinity of people on mushroom and wild vascular plant picking across the EU (Schulp et al. 2014). In the same study, it was shown that a lower GDP per capita coincides with increased wild food gathering in a region. The cultural background is also very influential and varies strongly across Europe, for example the importance of wild food in the local cuisine or the level of regulations for gathering wild food.

Little data on the extent of urban foraging and related people engaged exists for European cities. In a Finish study, berry picking by urban dwellers was equally popular among all age groups, but the activity increased with age and decreased with family size (Kangas and Markkanen, 2001). The participation in berry picking increased strongly with the ownership of a summer cottage, so it is likely that the activity happened mostly outside of the city. Like berry picking, mushroom picking is popular in Finland, independent of rural or urban residence (Sievänen et al. 2004). Participation increased with age, but females were more active, too. Outside of Europe, a strong influence of cultural background on urban foraging has been shown (Hall et al. 2013, McLain et al., 2014).

In cities in the US, the elements of urban green infrastructure used for gathering wild food are very diverse and include parks, institutional grounds, private land, street trees, street green / green verges, private land, vacant land, farmland / abandoned orchards, but also cemeteries and botanical gardens (McLain et al., 2014).

Some contemporary foraging movements have merged the ancient activity of gathering wild food with modern technology, like participatory web mapping. In this study, we explore urban foraging for fruits in the ULL city of Berlin, using data from the innovative foraging web portal *mundraub.org*. In particular, we will analyse the number of *mundraub.org* locations within different green infrastructure elements and other land use types.

4.2 Methods

mundraub.org is an internet platform for people interested in foraging for their own food. It includes an interactive web map where users can map edible plants that are publicly accessible. We were provided with all tree- and bush-locations within Berlin as of April 13th 2015 by the mundraub.org team. The locations were intersected with the Urban Atlas land cover data for Berlin (European Environment Agency, 2011). For gaining more insights into which green infrastructure elements were used, the urban green space layer from the municipality of Berlin (Senate Department for Urban Development and the Environment, 2011) was also intersected with the *mundraub.org* locations.

For the land use classes with more than 20% *mundraub.org* locations, we conducted Chi-square tests (Crawley, 2007) in order to find out whether the total numbers were similar to the total coverage of the respective land use classes. As an approximation of the area covered by *mundraub.org* informants, a convex hull was created around all point locations and clipped to the administrative boundary of Berlin. For this subset of Berlin, the areas of the land cover classes were summed up to estimate the expected ratio of locations. For example, if a land use class makes up 50% of the area, it would also contain 50% of the locations if they were equally distributed. The statistical analysis was carried out using the function *chisq.test* of the packages *stats* in *R* (R Core Team, 2014). For the spatial processing we used the packages *maptools* (Bivand and Lewin-Koh, 2014), *sp* (Bivand et al., 2013), *rgdal* (Bivand et al., 2014) and *rgeos* (Bivand and Rundel, 2014).

4.3 Results and discussion

The web mapping portal *mundraub.org* contained 642 entries for fruit trees and bushes in the city of Berlin. The most common species are Apple, Mirabelle plum and Elderberry (Table 4-1).

Table 4-1: The fruit trees and bushes mapped in *mundraub.org* in Berlin with scientific name and number out of a total of 642.

Species name	Scientific name	#
Apple	*Malus domestica* BORKH.	141
Apricot	*Prunus armeniaca L.*	23
Blackthorn	*Prunus spinosa L.*	14
Cherry	*Prunus avium L. / Prunus cerasus L.*	92
Cornelian cherry	*Cornus mas L.*	11
Currant	*Ribes spec.*	8
Elderberry	*Sambucus nigra L.*	106
Hawthorn	*Crataegus spec.*	3
Juneberry	*Amelanchier spec.*	3
Mirabelle plum	*Prunus domestica subsp. syriaca (*BORKH.*)* JANCH. EX MANSF.	109
Mulberry	*Morus spec.*	18
Pear	*Pyrus communis L.*	34
Plum	*Prunus domestica L.*	72
Quince	*Cydonia oblonga* MILL.	8

Especially Mirabelle plum and Elderberry are known to establish themselves naturally, while apple is usually planted. Likewise, Apricot, Quince, Mulberry, and to some extend Plum and Cherry are species that are mostly planted and do not establish themselves. The most exotic fruit is probably Mulberry. The edible fruit-bearing species in Berlin are a mix of native and non-native, and of domesticated and wild species. Many have been domesticated millennia ago and originate outside of Europe (e.g., Apple and Mulberry). Others are not commonly used for food today (e.g., Juneberry or Hawthorn). Altogether, they reflect the rich biogeographic history and biocultural diversity of the region.

The locations from *mundraub.org* cover most parts of Berlin, but inner districts are more densely mapped (Figure 4-1). In the outer districts, private gardens are more common and people can probably pick their own fruit. Another factor behind the distribution of the locations could be that younger and more technology affine people, i.e. people who are more likely to use a web map portal, tend to live in the inner districts of Berlin. This is speculative, though, and more research on the people who forage in Berlin is needed. There is even evidence for a historic legacy in the density of fruit trees in Berlin: Using the *mundraub.org* and other tree survey data, Larondelle and Strohbach (in press.) found a higher density in the former East than in the former West.

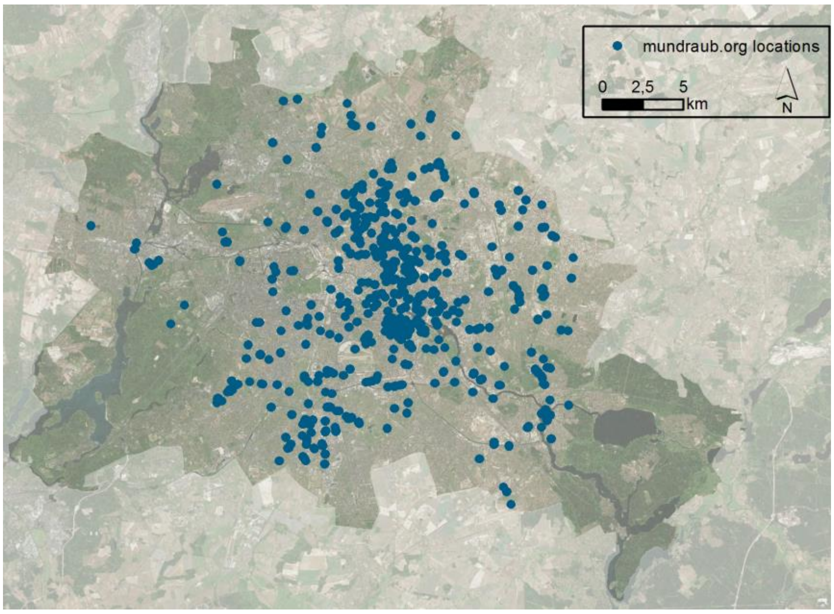


Figure 4-1: The foraging portal *mundraub.org* locations of fruit bearing trees and bushes in Berlin, Germany. Basemap © ESRI, HERE, DeLorme, MapmyIndia, OpenStreetMap contributor and the GIS user community.

The overlay of the *mundraub.org* locations with the land use classes (Figure 4-2) shows that most are located in dense urban land (sealing rate over 50%) and green urban areas, both including over 20% of the locations, each. Dense urban contains a number of *mundraub.org* locations proportional to its general coverage of Berlin (Chi-square test: observed ratio 155:642, expected ratio 142787956:526425704, X^2 =1.7, d.f. = 1, p = 0.1931). Green urban area contains more foraging locations than would be expected from its coverage of Berlin (Chi-square test: observed ratio 140:642, expected ratio 44069808:526425704, X^2 = 113.65, d.f. = 1, p < 0.001). Industrial, commercial and institutional land as well as roads and railway areas each contain more than 10% of the locations. Both are not covered by more or less locations than would be expected from their overall availability in Berlin (Chi-square test for industrial, commercial and public land: observed ratio 106:642, expected ratio 101274009:526425704, X^2 =2.13, d.f. = 1, p = 0.1444 and Chi-square test for roads and railroads: observed ratio 82:642, expected ratio 56224249:526425704, X^2 =2.33, d.f. = 1, p = 0.1266). To summarize, most *mundraub.org* locations can be found outside of green spaces, but green spaces is disproportionally important.

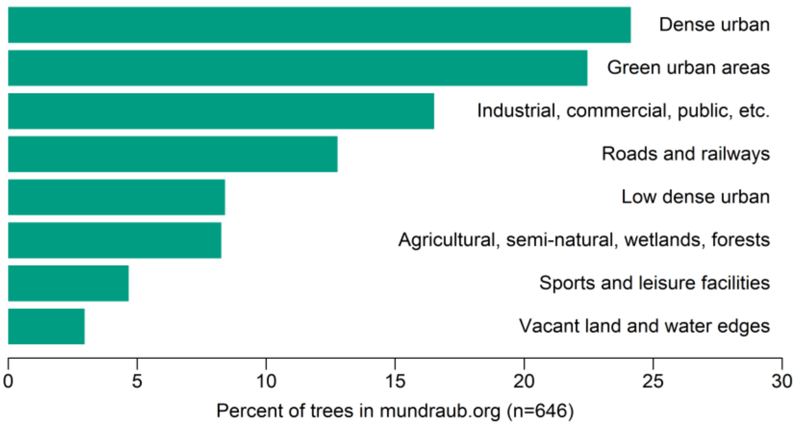


Figure 4-2: The percentage of *mundraub.org* locations within the Urban Atlas classes.

Looking into which green infrastructure elements contain the *mundraub.org* locations (using the urban green space layer from the municipality, Figure 4-3) parks are clearly most important (60%). Sport facilities contain 14% of the locations and vacant land 7.5%. All other green infrastructure elements contain less than 5% of the locations.

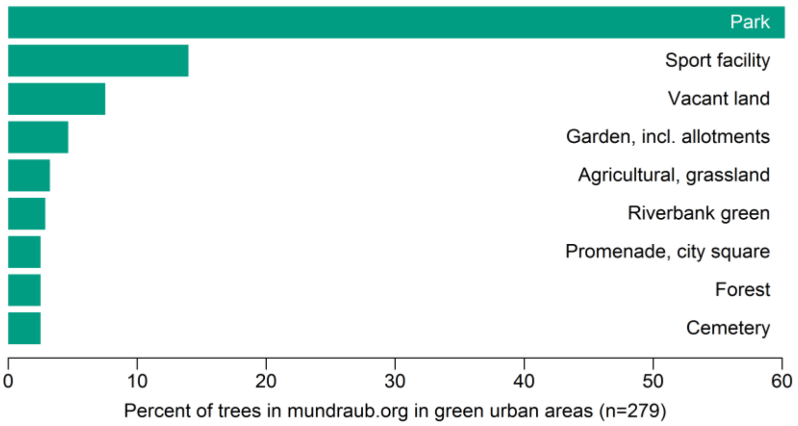


Figure 4-3 : The percentage of mundraub.org locations within the municipality classes.

4.4 Conclusion

Using data from the innovative web mapping portal *mundraub.org*, we could show that 14 different tree and bush species are used by this urban foraging community in Berlin. Surprisingly, most foraging locations are situated in dense urban land. Less surprising, green urban areas contain a disproportionally high number of *mundraub.org* locations, especially parks.

The consumption of fruit harvested at *mundraub.org* locations, providing that they have been thoroughly washed, has been shown to pose no risks concerning heavy metal pollution (von Hoffen and Säumel, 2014). Urban foraging in general represents a direct link between urban ecosystems and people. Harvesting fruit in cities helps with reconnecting people to the living environment (Herlin and Herlin, 2015), may foster environmental learning in childhood, and the trees benefit biodiversity (Savard et al., 2000). Therefore, the existing stock of fruit-bearing trees and bushes represents a valuable part of urban green infrastructure. Where they are lacking, we recommend that more fruit-bearing trees and bushes should be planted in public spaces, especially in parks, along footpaths, but also on school- and playgrounds and around childcare facilities.

5 FUNCTIONAL LINKAGES BETWEEN URBAN GREEN SPACES, ACTIVITIES, HEALTH AND ENVIONMENTAL JUSTICE OF URBAN RESIDENTS

5.1 Introduction

Recent research has demonstrated a broad range of positive health outcomes that are associated with contact with green spaces. These health outcomes include reduced mortality (Gascon et al., 2016), improved pregnancy (Dadvand et al., 2012), cardiovascular health (Tamosiunas et al., 2014), and mental health outcomes (Annerstedt et al., 2012) and reduced symptoms of depression (Reklaitiene et al., 2014). Cognitive, emotional, and motor development are all dependent on exposure to nature, particularly in the case of children (Amoly et al., 2014). In addition, street tree density and other urban greenery have been associated with less childhood obesity (Kim et al., 2014). In addition, older people's health can benefit from quality and quantity of urban green spaces (Barbosa et al., 2007; Takano et al., 2002). Proximity to green space (near home of residents) improves longevity of senior citizens (Takano et al., 2002). A study by Kawachi and Berkman (2001) showed that even the potential to be outside in a green space could increase older people's health. Sugiyama and Ward Thompson (2007) identified that neighbourhood environments are likely to contribute to older people's health by providing places as opportunity spaces to be active. They found that older people who live in a supportive environment including green spaces are likely to walk more, and are vice versa likely to be in better health.

However, sufficient green space may not be available to all the population groups in a city. Because of biophysical and landscape prerequisites, green spaces and the quality of these spaces are often unequally distributed between groups of different socioeconomic status, age, and ethno-racial characteristics (Byrne and Wolch, 2009; Gobster, 1998; Jenkins et al., 2015). Interestingly, many studies have demonstrated that health inequalities tend to decrease in greener areas (Mitchell et al., 2015) and that deprived groups seem to benefit the most from the positive health effects of nature (Ward Thompson et al., 2012).

In this part of the deliverable, we analyse how self-reported health status of participants of a quantitative questionnaire survey may be related to their activities when using an urban green space, such as a park. We further show how the distribution of urban natural spaces in a city area may be related to distribution of health outcomes among children.

5.2 Methods

5.2.1 Activities in urban green infrastructure by users of different health state

Assessment of BCD via field survey in five ULL cities

This part illustrates several results that where elaborated in task 2.2, WP2. Amongst other research, a field survey was conducted in the five ULL cities (Berlin, Ljubljana, Bari, Malmö and Edinburgh) on how people with different social and cultural backgrounds perceive, value and use urban green spaces and how this may be linked to different levels of biodiversity. As one part of the field survey (see Deliverable D.2.2) that consisted of a nature/biodiversity-based section with photographic stimuli material and a socio-cultural section, respondents were asked to indicate how their general state of health is on a five point Likert scale. For the results presented in this Deliverable we used this variable to explore how self-reported health status of the participants is linked to activities and use that the respondents indicated for their visit of urban parks.

The data base derived from the survey integrates a total of 3,814 questionnaires, including the responses of participants with a wide range of different social and cultural backgrounds. For example, about 14% of the respondents indicated to have a migration history. The sample has slightly more female participants and about 42% well-educated participants. For sample details, see Deliverable D2.2.

Indication of health status and socio-cultural background
We aggregated the variable *health status* to two categories (category “bad” with the Likert scale categories “very bad”, “bad”, “fair” and category “good” with the Likert scale categories “good” and “very good”). For the *activity* variable, respondents were asked what they did most often when visiting an urban park. They could choose between 12 categories that included activities such as to take a walk, relax, play with children or watch wildlife – that is, a whole range of different activities possible in a park. Further, interactions with nature and/or biodiversity were listed.

To connect the health status with variables that describe the geographical, social and cultural backgrounds of the respondents, we differentiated the results according to of (1) the *ULL cities* (Bari, Berlin, Edinburgh, Ljubljana and Malmö), (2) the *age class* (five categories: ≤20 years, 21 to 40 years, 41 to 60 years, 61 to 80 years, >80 years), (3) the *migration* background (two categories: with migration background / without migration background); and (4) the *educational* level (with or without university degree) of the respondents.

For full details on the concept and the conduction of the field survey (study design, questionnaire, stimuli development, more results), see Deliverable D2.2 and Milestone MS21.

5.2.2 Indicators for social inequality mapped in space for the ULL city Berlin

Available data on children’s health indicators were acquired from Berlin’s Senate Department for Health and Social Issues. The data are based on the medical check-ups of children (5 to 6 years old) in 2013, prior to school enrolment. In total, 30,427 children received a medical check-up (52% boys, 47% girls, 37.6% migration background; Senatsverwaltung 2013). The best publicly available spatial data are on an anonymized, aggregated level of the 60 sub-districts of Berlin and include both the health outcomes and the social variables of the children and their families (see Table 5-1). The health outcome variable included overweight (see Kabisch et al., in rev., for an in-depth statistical analysis using additional health outcome variables). The social variables reflected the participant’s social position, including the social status index of the parents (defined as educational attainment, graduation, and current employment status), the percentage of children living in single parent households, the percentage of children with a non-German background, and percentage of children with complete measles immunisation.

Local land-use data, stored in a Geographic Information System (GIS), were provided by the Senate Department of Urban Development and the Environment (2011). Land-use data came from Berlin’s Environmental Atlas project and reflected the composition of the city’s blocks. These data included population density. In addition, the total percentage of natural space, and the per capita area of natural space were included in the dataset. In our analyses, we combined the green and blue spaces into one variable: “natural spaces.” In the database, green spaces included urban forest areas, parks and urban green, allotment gardens, and cemeteries. Water areas included all the water bodies such as lakes, rivers and canals.

We visualized the spatial distribution of these data using the geographical delineation of 60 sub-districts based on a spatial hierarchy of Berlin called “living environment areas” (LEAs).

Table 5-1: Description of the variables shown in the maps.

	Description	Year	Data source
Health-outcome variables			
Overweight (%)	Percentage of children overweight as defined by the Body-Mass-Index, BMI (thresholds are defined monthly by Kromeyer-Hausschild)	2013	SDHS
Social variables			
Social status index	Median index (0-18) representing the status of parents based on school education, employment education and employment status: 0-8 low social status, 9-15 medium social status, 16-18 high social status	2013	SDHS
Single parent household (%)	Percentage of children living in single parent households	2013	SDHS
Non-German (%)	Percentage of children with background other than German	2013	SDHS
Complete measles immunization (%)	Percentage of children with at least two doses (considered complete) of measles vaccination	2013	SDHS
Land use indicators			
Natural space (%)	Percentage of green and water spaces in the sub-districts in relation to the total sub-district area. Green spaces include forest areas, urban green and parks, cemeteries and allotment gardens. Water spaces include all the water bodies such as lakes, rivers and canals.	2011	
Per capita natural space (m^2/inhabitant)	Natural space (m^2) / total number of inhabitants in the sub-district	2011	SDUDE
Population density (inhabitants/km^2)	Total number of inhabitants in 2014 / total area of the sub-districts (km^2)	2014	SDUDE, Department for Statistics Berlin-Brandenburg

Note: SDHS – Senate Department for Health and Social Issues – data available at: http://www.gsi-berlin.info; SDUDE – Senate Department for Urban Development and the Environment.

5.3 Results and discussion

5.3.1 Activities in urban green infrastructure by users of different health state

In order to determine whether the health status of urban dwellers was related to their main activities in urban parks and to detect differences between European cities and various social and cultural backgrounds, we related the self-reported health status of more than 3,000 respondents to a range of variables. Our results indicated both general patterns as well as inconsistencies between ULL cities, age classes, people with or without a university degree and those with or without a migration background.

Health status and activities linked to the five ULL cities

With one exception, most participants in the ULL cities with both good and bad health status reported that their main activity in parks was to take a walk (up to ca. 40%) (Figure 5-1). In the Bari ULL, respondents most frequently indicated that they use parks to relax, with similar proportions in the two health status categories (>20%).

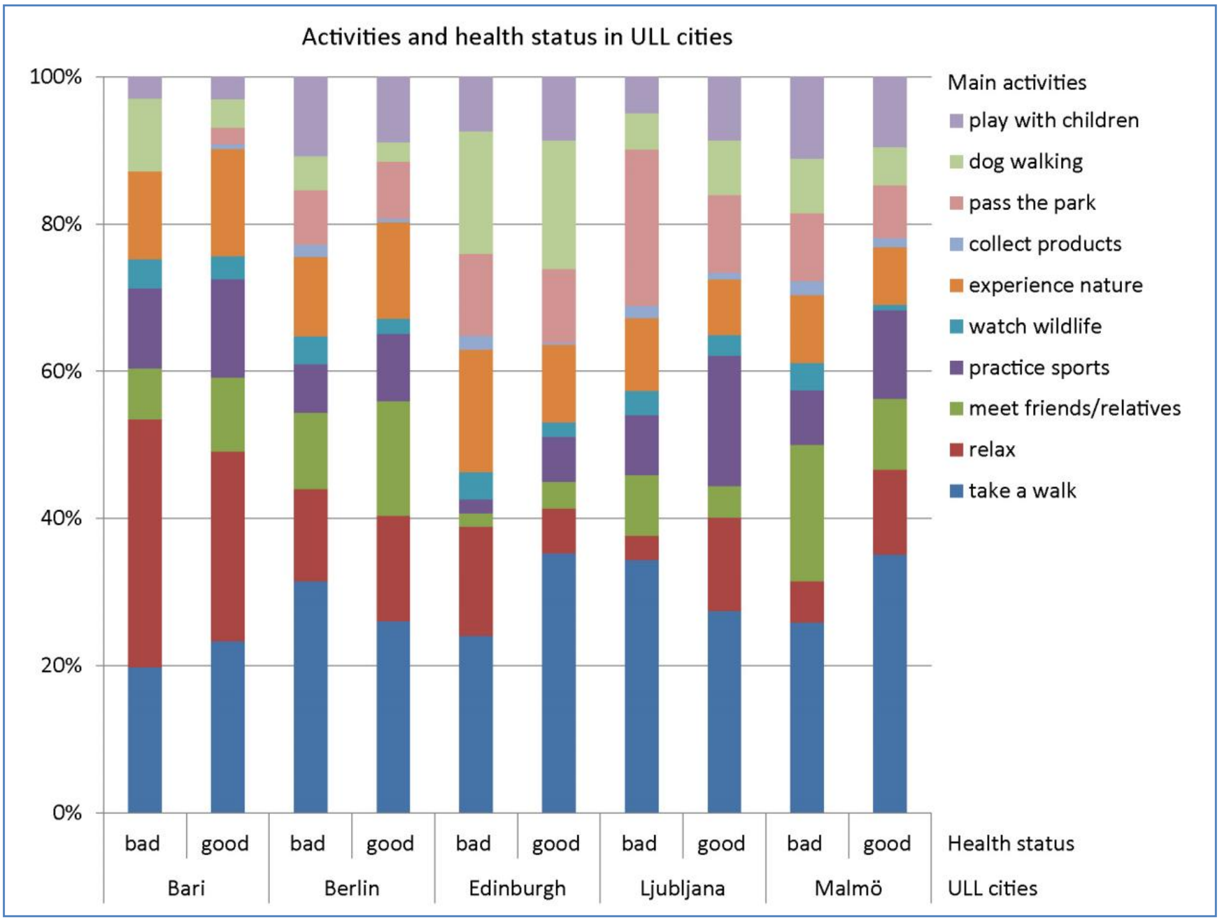


Figure 5-1: Differences in percentages of various activities performed in urban parks, and linked to the self-reported health status of the respondents and each ULL city (*N* = 3,664; NA's and categories "I don't know" and "Never visit a park" not displayed).

While a similar proportion of respondents with bad and good health indicated to experience nature when visiting an urban park throughout the ULL cities, the proportions indicating that a participant frequently met friends and relatives, e.g. for having a picnic or a barbecue, varies widely between the ULL cities. Especially participants that indicated a good health status in Ljubljana practice sports (like jogging, Nordic walking or soccer). Participants from Edinburgh independently from their health status exceeded the other ULL's respondents regarding the activity to walk a dog (ca. 18%).

Health status and activities linked to the respondents' age

Independent from the health status, the proportion of respondents that take a walk when visiting an urban park increased with age (Figure 5-2). There is one exception. Only ca. 25% of the group of persons older than 80 years with a bad health status reported to take a walk when visiting a park. This group of elderly persons visited parks especially to relax, followed by the focus to experience nature. For the age classes covering all ages from ≤20 years to 80 years, at least ca. 10% reported to experience nature, also with an increase in this activity's proportion over the age classes and no general pattern for the health status. Whereas parks were most often used to meet friends and relatives by the younger respondents, we can report a slight difference between the health status for the groups of respondents younger than 20 years and those aged 41 to 60, with less persons doing so that had a good health status. In the age classes covering all respondents up to 60 years, always more participants with a good health status answered that to practice sports was their main activity when visiting urban parks than participants with a bad health status.

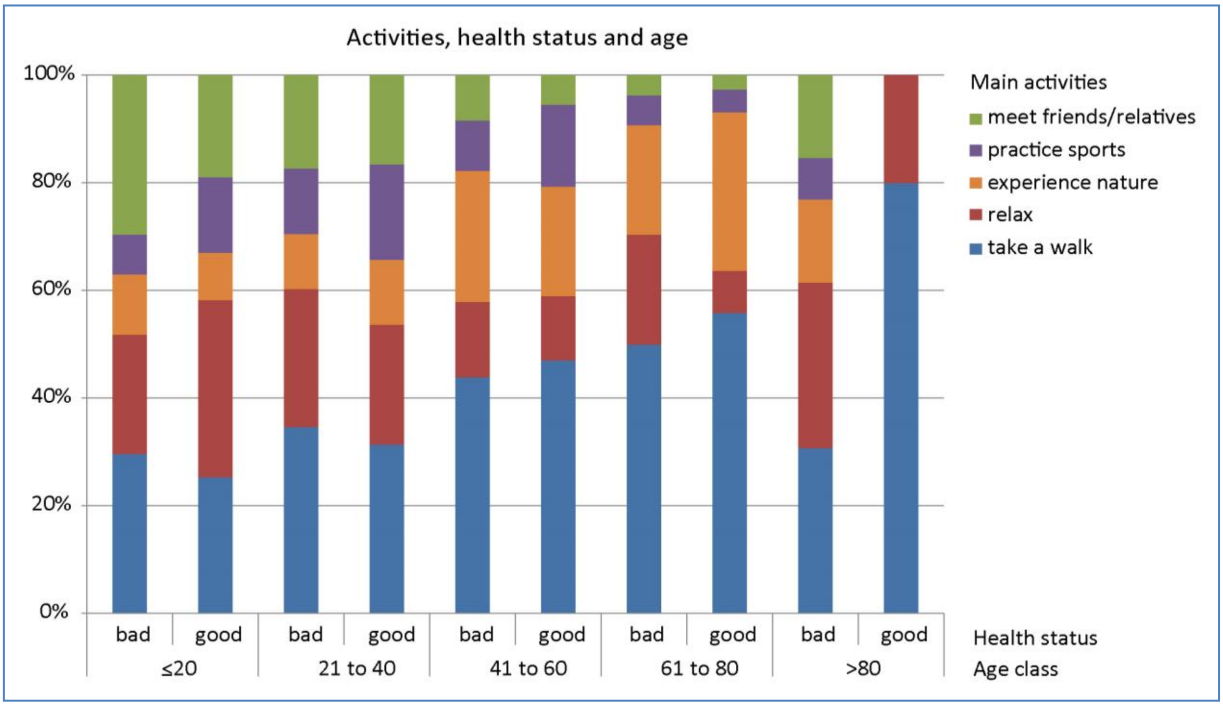


Figure 5-2: Differences in percentages of the five most common activities performed in urban parks, and linked to the self-reported health status of the respondents and to their age in the age classes ≤20 / 21 to 40 / 41 to 60 / 61 to 80 / >80 years old, (*N* = 2,551; NA's and categories "I don't know" and "Never visit a park" not displayed).

Health status and activities linked to the respondents' education

Throughout both health status and the two categories that we used as a proxy for educational background, the respondents indicated that taking a walk is their main activity when visiting an urban park (Figure 5-3). In both health categories, less participants reported to relax when they also indicated an education at university level. A very small proportion, but throughout the health status and the educational level, participants reported to mainly collect nature products when visiting an urban park, for example fruits, nuts, herbs amongst others.

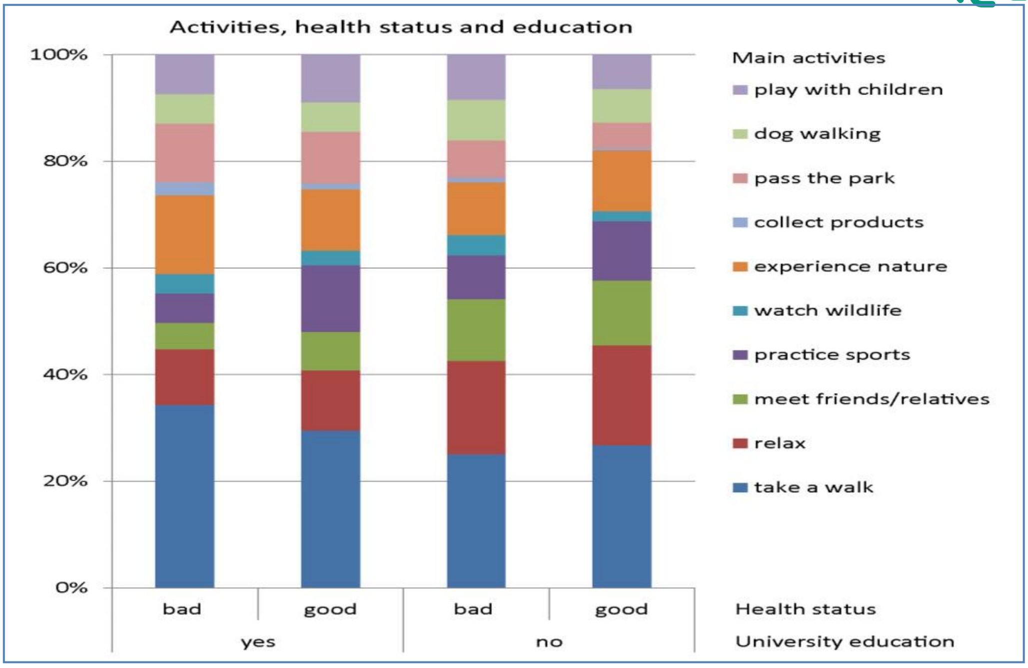


Figure 5-3: Differences in percentages of various activities performed in urban parks, and linked to the self-reported health status of the respondents and whether they indicated a university education or not (*N* = 3,679; NA's and categories "I don't know" and "Never visit a park" not displayed).

Health status and activities linked to the respondents' migration background

In both health status categories, respondents with migration background answered more often that their main activity was to play with children or to meet friends and relatives while visiting urban parks (Figure 5-4) than persons without migration background. A contrasting pattern was detected for the activity dog walking, which was indicated for both health categories more often when respondents had no migration background.

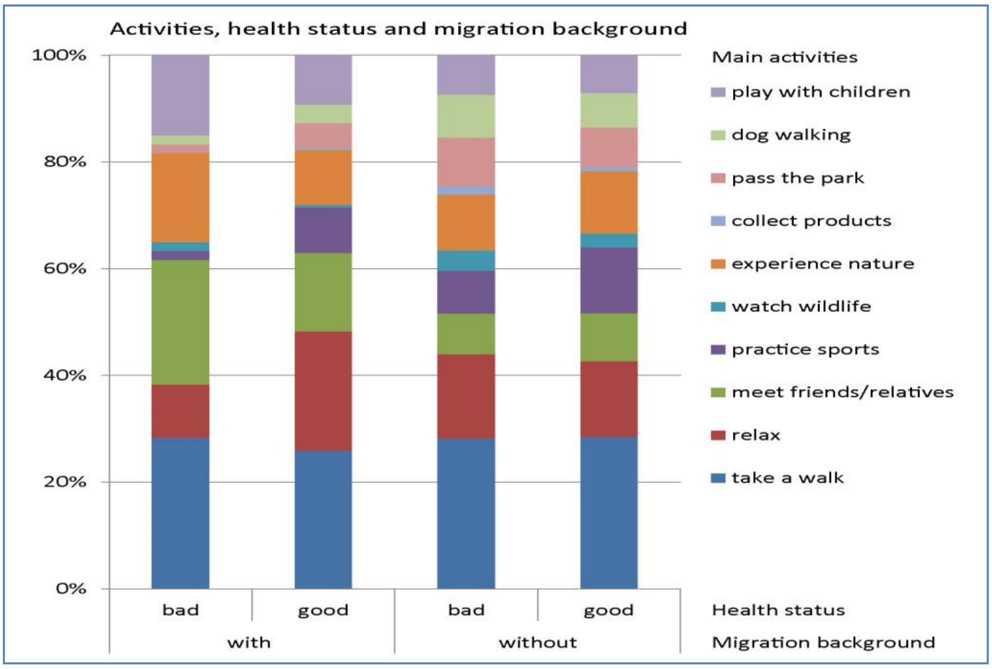


Figure 5-4: Differences in percentages of various activities performed in urban parks, and linked to the self-reported health status of the respondents and whether they indicated a migration background or not (*N* = 3,648; NA's and categories "I don't know" and "Never visit a park" not displayed).

Discussion of the results on residents' activities in green spaces

The field survey conducted in the five ULL cities is a very valuable resource for identifying linkages between the use of and activities at urban green spaces by users of different health state. Additionally, this large survey with more than 3,000 respondents distributed over five European urban areas, allows for relating these findings with further variables that describe the social and cultural backgrounds of different user groups. The overall balanced sample (regarding demographic, social and cultural variables) gives thus representative insights in park visitors' activities and interactions with urban nature and biodiversity components.

From the above presented results we conclude that there is a general pattern regarding the activities performed in urban parks, mainly independent from geographical, social and cultural influences as in most comparisons taking a walk was the most frequent activity that the respondents indicated. One assumption in this regard is that minor differences in this main activity that respondents reported for urban parks may be traced back to the different design schemes of the parks the respondents regularly use. The design schemes and the overall identity of a park may also be attributed to the specific urban development or the historical roots of park establishment in each specific city.

Beside such external influences, cultural habits may influence the users' activities as well (see e.g. the difference in main activities determined for the ULL city Bari, the southernmost city in the sample), or play in concert. Differences in more passive or active activities in parks were before attributed to the cultural context of users (Özgüner 2011). Nevertheless, our results promote that especially the linkages between geographical context, cultural and social backgrounds and the health state may shape the users' direct activity in urban parks, and thus influence the interaction with nature and biodiversity components. This was for example demonstrated for the health state, educational level and the activity to collect natural products or watch specific wildlife in parks. This is in line with findings that urban dwellers explicitly use a wide range of different vegetation in green spaces (McLain et al., 2014). At the same time, park users may show only a poor knowledge on species that can influence such activities, and which relates to their actual interest in nature (Muratet et al., 2015). Whereas Lin et al. (2014) showed that the average park user is younger and better educated than people that do not use parks, our study demonstrated that park users were very heterogeneous in terms of selected socio-cultural variables but perform similar activities.

To conclude, our results suggest that the respondent's health state also leads to minor differences in the reported main activities in urban parks, such as in combination with the age. Having this in mind, to design urban parks and managing its vegetation composition, may integrate the needs of different user group, e.g. by enabling sport activities for elderly people of the adjacent neighbourhood.

5.3.2 Distribution of the Berlin's sub-districts according to health-inequality indicators

The distribution of the sub-districts according to health inequality indicators demonstrates a spatial intra-urban pattern in Berlin. Four potential dimensions of health inequality – overweight, single parent household, natural space cover, and measles immunization – were distributed throughout the city according to a certain spatial pattern (Figure 5-5 and Figure 5-6). Sub-districts with a relatively large proportion of natural space cover also show low percentages of children being overweight or living in single parent households. Interestingly, sub-districts with higher social status seem to be those with a comparatively low percentage of children with full measles immunization. The distribution of natural space is highest in those districts with very low population densities and rather low non-German background. These somewhat mixed results demonstrate the inherent complexity in spatial relations between social and environmental factors and health outcomes including inequalities. By demonstrating the spatial patterns of various indicators (both environmental and social), a contextual interpretation may better inform us about what patterns contribute to health problems and how combined efforts could be achieved to reduce inequalities.

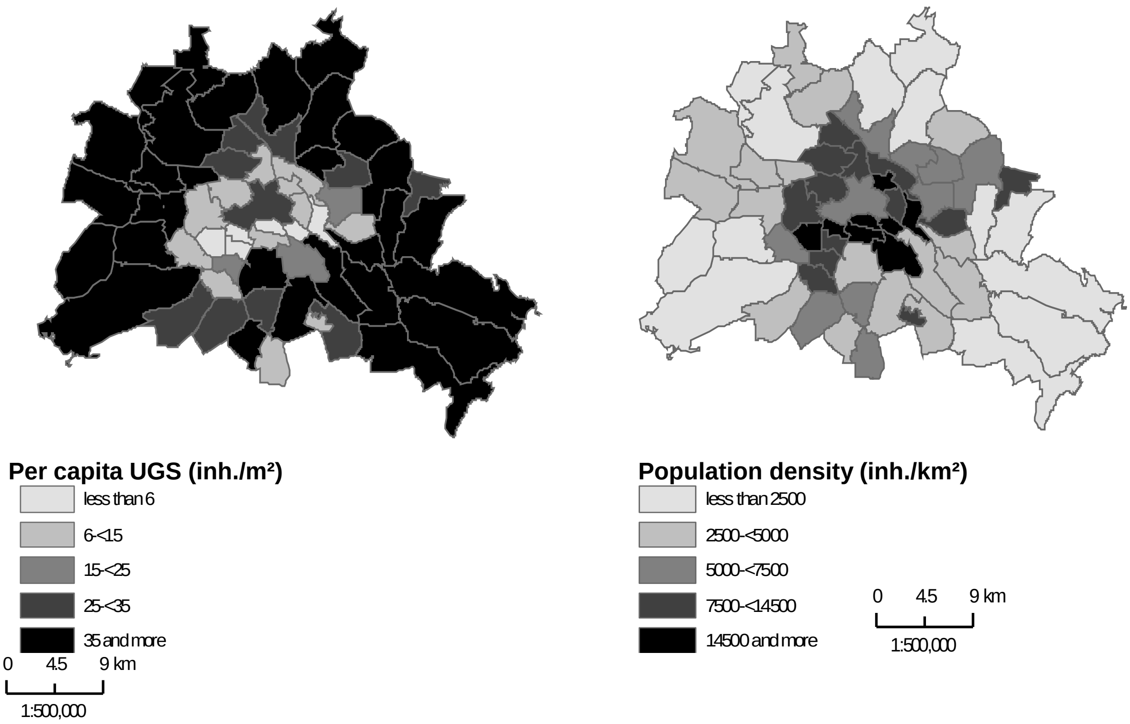


Figure 5-5: Distribution of the sub-districts according to Per capita UGS and population density.

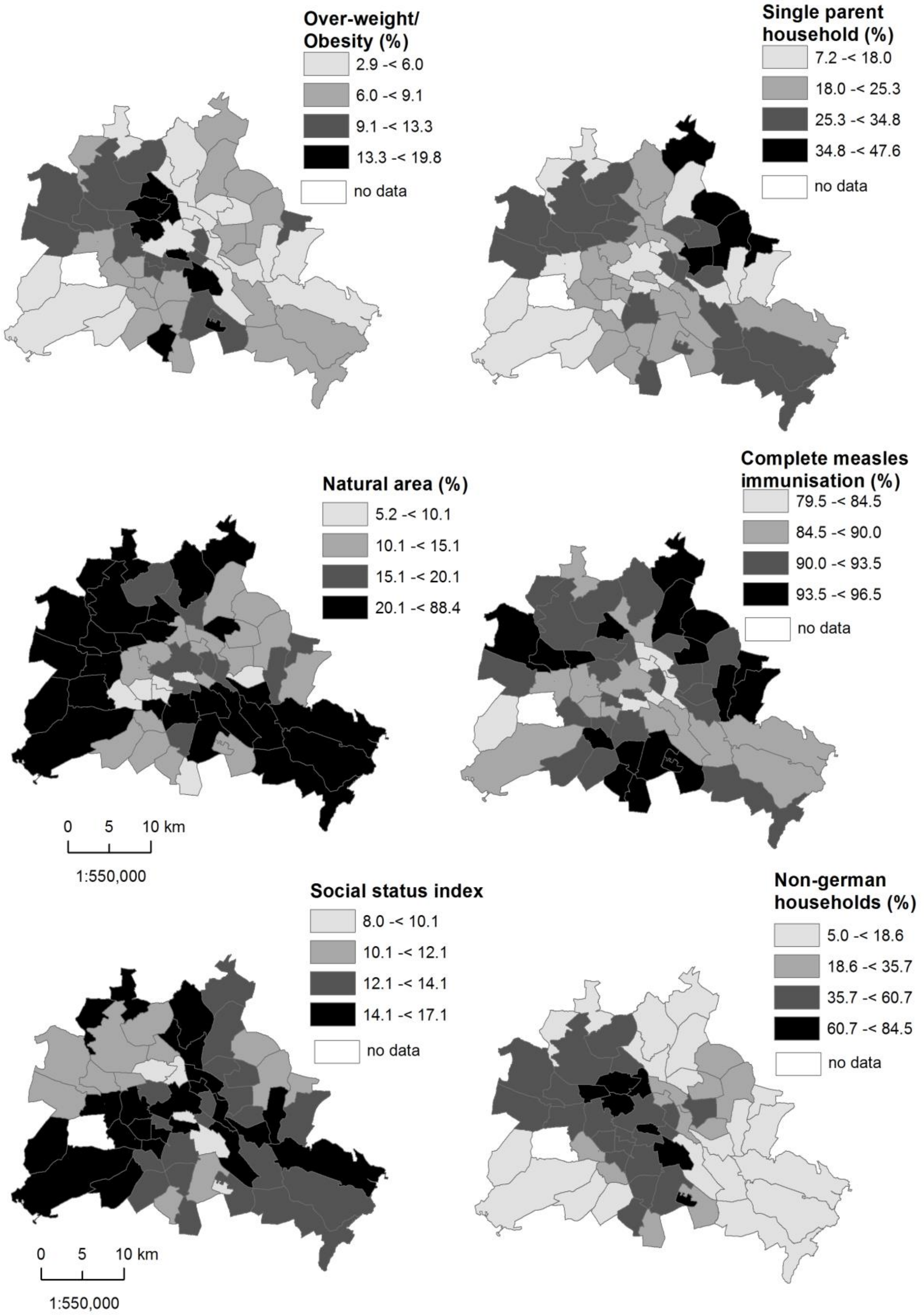


Figure 5-6: Distribution of the sub-districts according the health and social variables.

5.4 Conclusion

Our study confirms that there is a certain socio-spatial distribution of natural spaces in Berlin. In general, the maps showed that green and water areas have a clear spatial pattern that overlapped with social but also health-related patterns of overweight in children. This reflects the need for further investigation of "green" inequality indicators, especially in other cities where green spaces may be less abundant than in Berlin. This could potentially promote policy interventions and governance activities for developing healthy, natural spaces in areas where they are most needed, particularly for children.

The results from the spatial distribution of sub-districts are, however, not conclusive as to whether natural space cover or natural space per capita is the most appropriate variable to use to indicate health and inequalities. In general, this would suggest that a green or natural space indicator for health should incorporate several aspects of natural space including the percentage of coverage, per capita, and accessibility values, and if possible the quality of the area as well. Most importantly, the spatial distribution of natural space indicators should be carefully considered and incorporated into decisions regarding efficient resource allocation with a particular focus on the districts that are currently less green (or blue) or are deprived.

6 OVERALL CONCLUSIONS

To come to some overall conclusions across the different sections we can state that the findings at European scale definitely support each other and that cities in Northern Europe benefit from large green spaces (mainly forests and waters) and are at the same time less impacted by urban heat and high temperature. At the same time, Southern European cities mainly suffer from traditionally less green in their cities (this refers to both parks and forests) but at simultaneously are affected by considerable high summer temperatures and heat islands. A mean position takes Central Europe and Eastern Europe being on the one hand well-equipped with different types of UGI but at the same time also under pressure of increasing temperatures and clear heat islands. Whether or not the species diversity of the green and blue spaces in- or decreases the climate adaptation function was not able to investigate using the European Urban Atlas dataset where no information on site diversity is given. What could be assumed is that cities where green spaces and especially forests form large patches can support a wider range of forest dwelling species than very fragmented 'patchy' forest green spaces. What is more, probably ecological resilience, e.g. resistance towards alien species, is lower in small green spaces compared to large ones. But this needs definitely more empirical evidence to get proved.

At the local level, urban foraging and environmental justice and public health were studied also showing linkages in terms of where do we find which kind of patterns and which parts of the population benefit from green more than others: Areas with higher activities (densities) of urban foraging belong to those districts that exhibit better public health under firstgraders (young children starting primary school) in terms of a) access to UGI (parks, waters) and b) detectable health state (obesity, tooth state, language deficits). Thus, social segregation falls together with imbalances in green space distribution and accessibility (see here also Kabisch et al., 2016). Here, intervention could start in terms of bringing in green, that is for instance planting trees or construct new green spaces including pocket parks or make use of interim use sites, into deprived neighbourhoods on the one hand. On the other, better education on what is urban foraging and what it means in terms of personal happiness and well-being could also bring kids from inner Berlin districts to the areas where foraging takes place/happens. Thus, urban foraging could develop into a really creative tool for urban green and social intervention.

In so far, we detected a close functional linkage between geographical situation and wealth on the one hand and green space diversity (in size, edge and shape) and availability as well as adaptation potential against summer heat at pan-Euopean level and a same strong linkage between social deprivation, poor health and missing access to green space at local level (exemplified at the city/ULL of Berlin).

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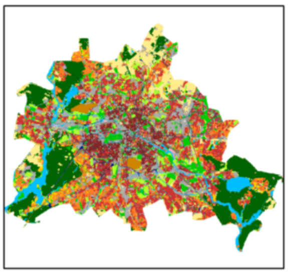
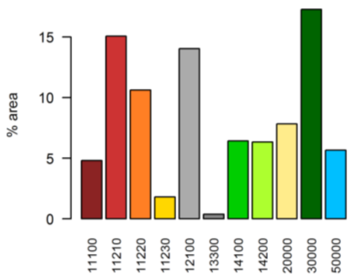
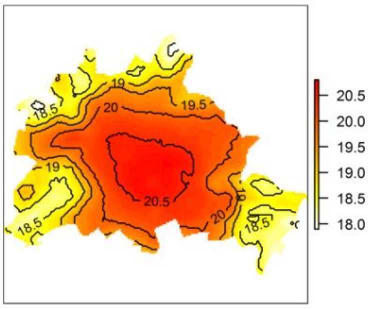
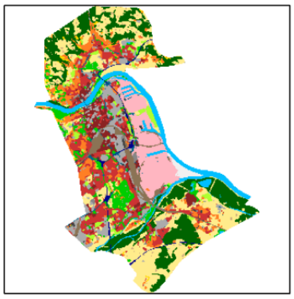
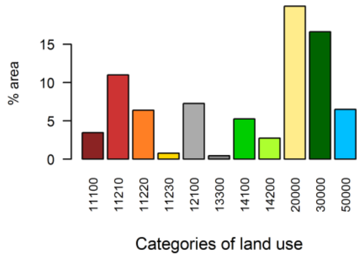
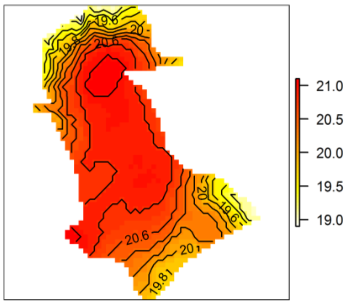
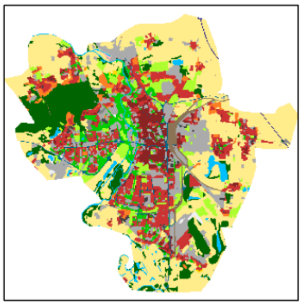
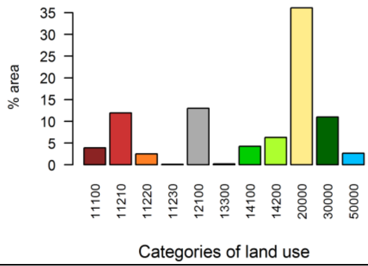
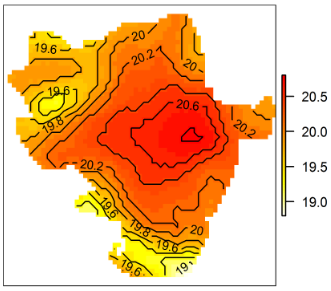
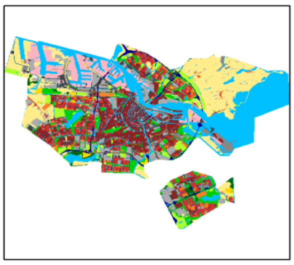
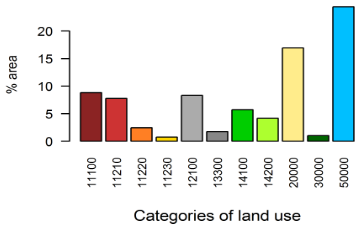
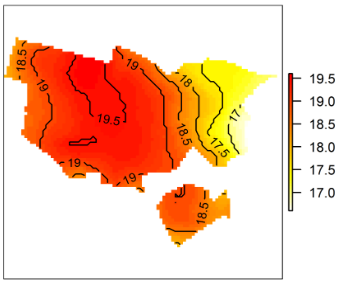
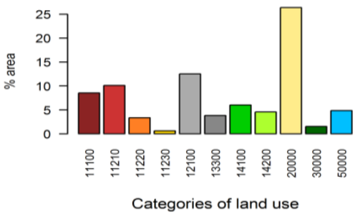
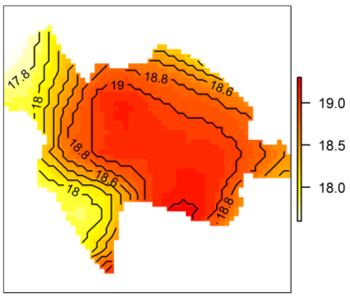
8 APPENDICES

Appendix 1: Linkages between land use, planning family, heat island effect, and predicted climate change for Tier 1b cities from the GREEN SURGE project

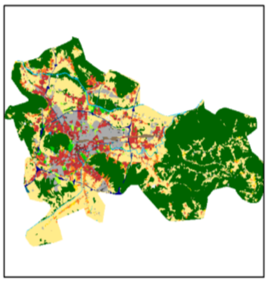
	Planning family	Land use	Heath island	Predicted climate change
	Central/ Regional economic planning			
BERLIN				Temperatures rise larger than European average Decrease in glacier extent and volume Decrease in mountain permafrost areas Increasing risk of soil erosion
LINZ				
HALLE AN DER SAALE				
AMSTERDAM				
UTRECHT				

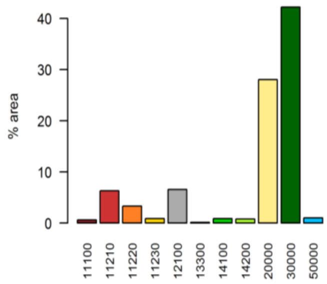
Planning family	Land use	Heath island	Predicted climate change

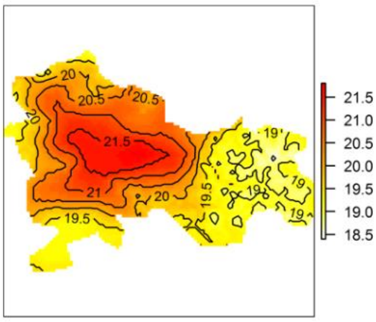
New member states in the process of change

Increase in water temperature
Increasing risk of forest fire
Increase in warm temperature extremes
Decrease in summer precipitation

LJUBLJANA







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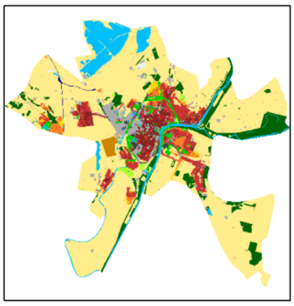

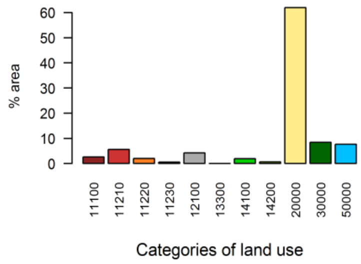

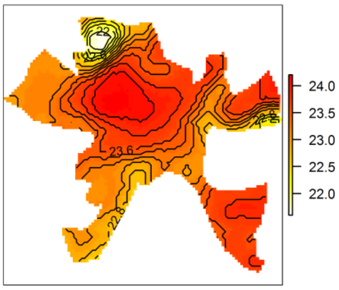

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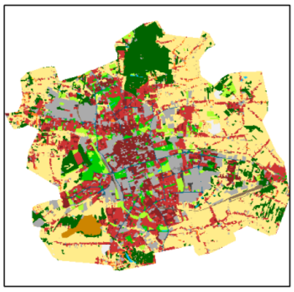
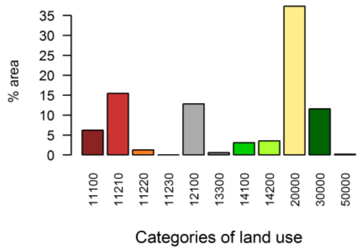
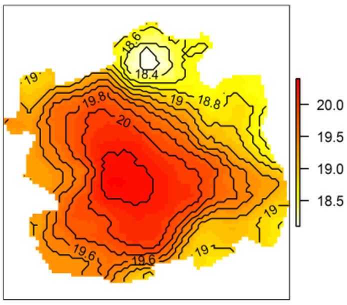
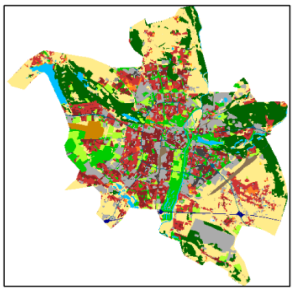
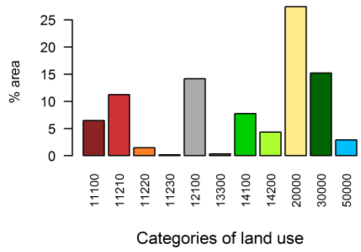


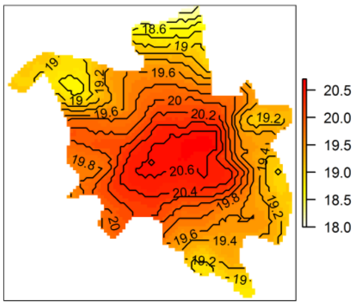




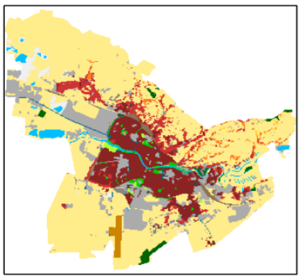
POZNAN

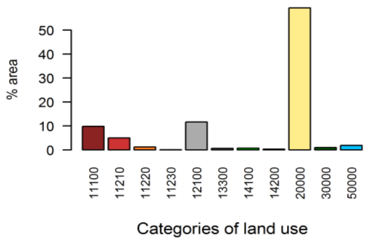


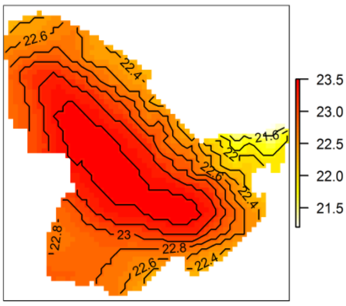




ORADEA







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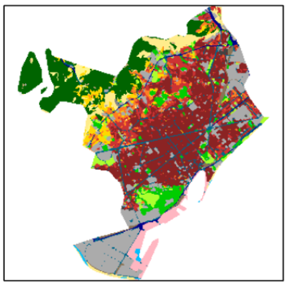
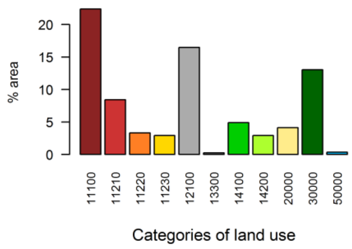
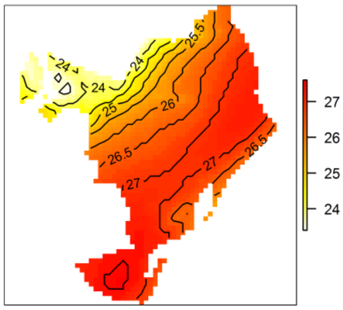
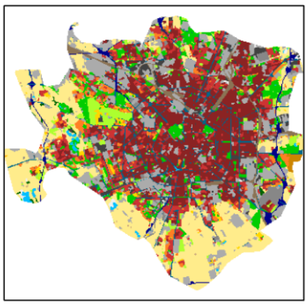
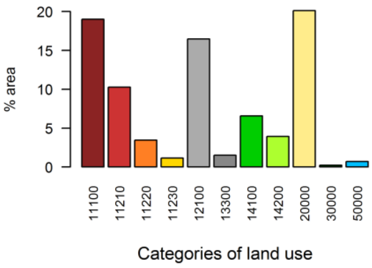
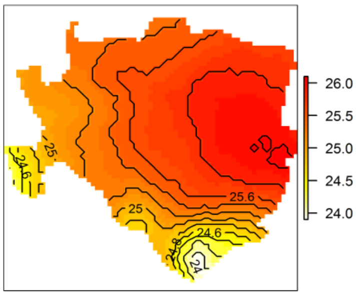
<tr><td>BARCELONA</td><td></td><td>
</td><td>
</td><td rowspan="2">Temperatures rise larger than European average
Decrease in annual precipitation
Decrease in annual river flow
Increasing risk of biodiveristy loss</td></tr>
<tr><td>MILANO</td><td></td><td>
</td><td>
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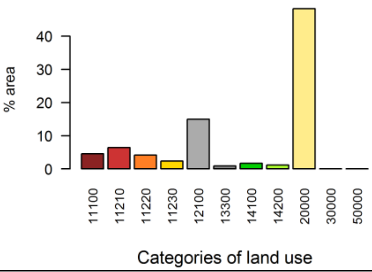
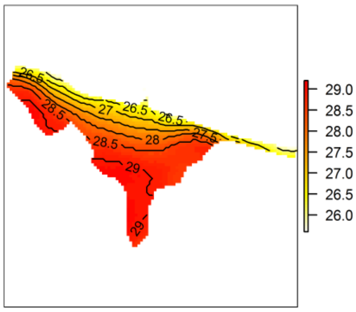
<tr><td>BARI</td><td></td><td>
</td><td>
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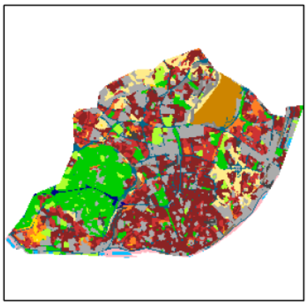
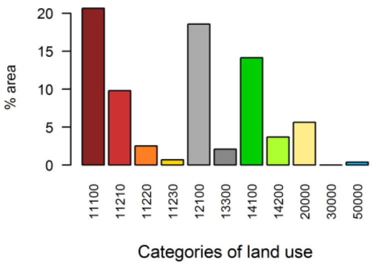
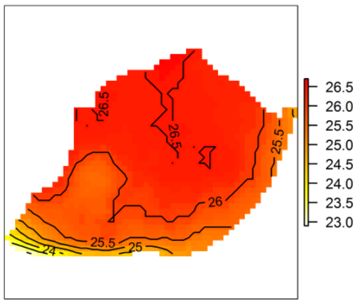
Expansion of habitats for southern disease vectors
Decrease in hydropower potential</td></tr>
<tr><td>LISBOA</td><td></td><td>
</td><td>
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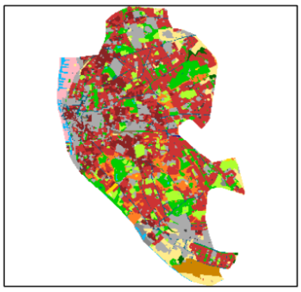
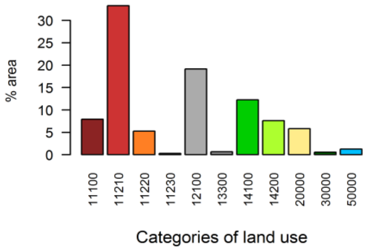
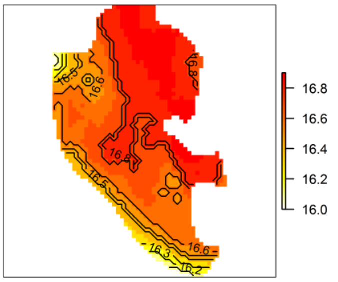
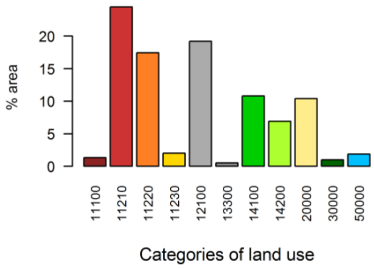
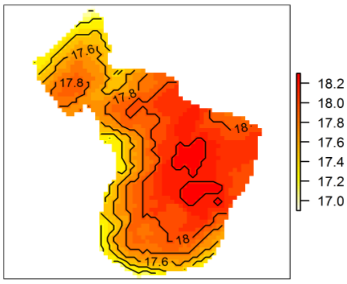
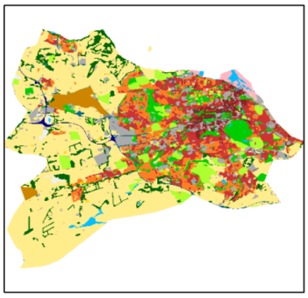
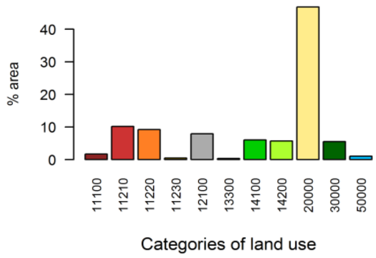
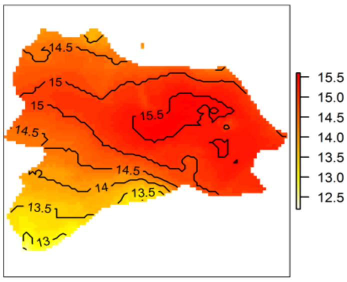
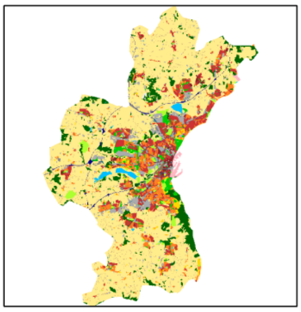
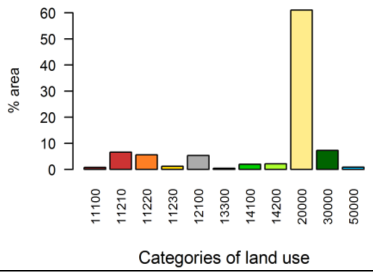
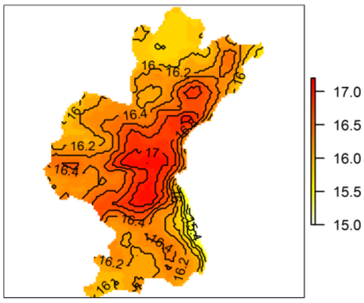
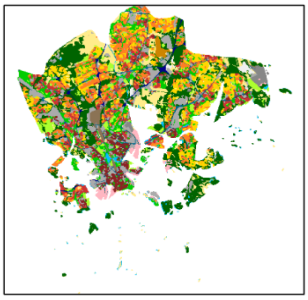
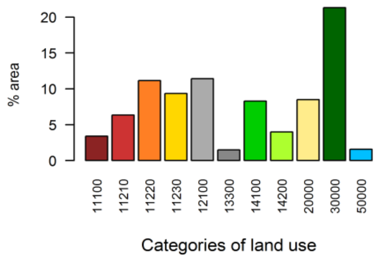
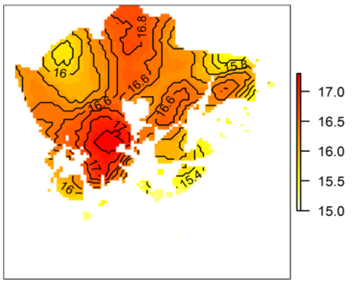
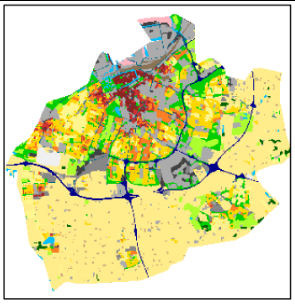
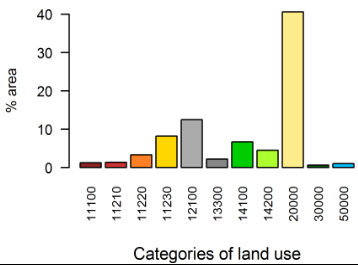
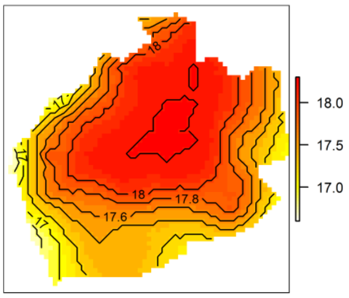
Planning family		Land use	Heath island	Predicted climate change
British planning family				
LIVERPOOL				Increase in winter precipitation Increase in river flow Northward movement of species Increasing risk of river and coastal flooding
BRISTOL				
EDINBURGH				

	Planning family	Land use	Heath island	Predicted climate change
	Nordic planning family			
AARHUS				Temperature rise much larger than global average Decrease in snow, lake and river ice cover Increase in river flows Northward movement of species Increase in hydropower potential
HELSINKI				
MALMO				

- 11100 - Continuous Urban Fabric (S.L. > 80%)
- 11210 - Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)
- 11220 - Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%)
- 11230 - Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)
- 12100 - Industrial, commercial, public, military and private units
- 13300 - Construction sites
- 14100 - Green urban areas
- 14200 - Sports and leisure facilities
- 20000 - Agricultural + Semi-natural areas + Wetlands
- 30000 - Forests
- 50000 - Water bodies