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Urban and Peri-Urban Tree Cover in European Cities: Current Distribution and Future Vulnerability Under Climate Change Scenarios

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1. Introduction

Scientific data collections and databases are exponentially growing. Modeling techniques and data analysis procedures have also been evolving rapidly in the lasts decades. Specific scientific domains such as medical and biological sciences have adopted a routine of scientific dissemination where datasets and analytical methods are visible and usable for the researchers.

This means publishing results and giving access to data and algorithms in order to allows the reproducibility (i.e. reproduce the same techniques by applying different input data) and repeatability (i.e. same technique and input data) of scientific experiments. The accessibility and possibility of sharing algorithms and programming routines is getting more important, because of the complexity of experiments. As a matter of fact, even if a methodology is explained in a very precise and detailed scientific text, the reproducibility of an experiment is highly challenging for scientists that try to implement the same method without the access to data and codes.

The global warming and climate change issues are approached by different scientific domains (climatologist, ecologists, economists as an example). This book illustrates such differentiation. The research areas of spatial ecology and ecological modeling are strongly linked to climate change applications and are continuously producing a huge amount of scientific publications and results in this domain. In comparison to biomedical studies, access to data and source codes are most of the time not available in the field of spatial ecological modelling. Recent works have been changing this routine and scientific papers in ecology are starting to include sample data and open source programming codes (Elith et al., 2008).

This chapter approaches the impact of global worming on urban greening in European cities. At the FBK foundation we highlight the importance of the accessibility of data and codes, and on the reproducibility and repeatability of our methods. The uncertainties related to predictions of global warming can be minimized or quantified only by a complete scientific transparency. Transparency is also important for the transfer of scientific knowledge to the policy macking process. The main objective of this study is to focus next to the results on the visibility and reproducibility of the method. Transparency allows further studies to improve data processing routines and produce more accurate and precise informations.

In this book chapter are analysed the impacts of global warming in urban greening. There is a wide interest in urban greening because urban greening and peri-urban forests have a strong positive effect on the physical environment of urban areas and in people life quality.

Urban greening comprises recreational and social value (Tarrant & Cordell, 2002), affect the economic value of housing (Kong et al., 2007), preserves biodiversity and wildlife corridors between urban and non-urban habitat islands (Blair, 1996; Zipper et al., 1997), reduces noise (Fang & Ling, 2003), sequester CO_2 and produce O_2 (McHale et al., 2007; Nowak & Crane, 2002; Nowak et al., 2007), reduces air pollution (Cavanagh et al., 2009; Escobedo & Nowak, 2009; McDonald et al., 2007; Yang et al., 2005), regulates the micro-climate and reduces effects of heat island in cities (Akbari et al., 2001; Shin & Lee, 2005).

Due to climate change, a degradation of air quality is expected to occurs predominantly in urban-industrial areas as well as an urban climate warming (McCarthy et al., 2010). With a proactive management strategy, vegetation greening and belts of peri-urban forests have strong potentials to mitigate the impact of global warming such as extreme heat waves. Besides the mitigation potentials of urban greening, climate change will possibly increase the vulnerability of urban vegetation. For this reason proactive planning of urban greening is important to mitigate the impact of climate change on humans and to prevent urban vegetation vulnerability.

Proactive planning of forested urban areas require an integration of ecological information such as output of niche models in a general landscape and urban sprawl planning framework. Because of the high uncertainty of ecological changes in the future and our potential choice of development strategies, the analysis of various scenarios and the possibility to compare different mitigation strategies are interesting for scientists, decision makers and informed citizens.

In the last decades scientists have proposed several ecological niche models (ECONM) (Bolliger et al., 2000; Elith et al., 2006) and developed related habitat distribution maps. Such models are empirical statistical models relating climatic conditions to the distribution of living organisms. ECONM relate current climatic conditions to the distribution of plants and predicts vegetation vulnerability under changing climatic conditions.The output prediction maps do not provide information on a certain extinction of a specie under climate change (CC), but they will rather inform us on it's suitability. We assume the more a species grows in its fitted climate the more the ecosystem will be homeostatic. This means that the ecosystem will be more stable, resistant and resilient despite natural disturbances. In the last years, ECONM have been mainly applied to the analysis of natural reserved areas for proactive planning of landscape management, biodiversity conservation and risk assessment of species extinction. There is a lack of applied studies in the context of ECONM and vulnerability of urban and peri-urban greening (UPUG). Results of such applications could help to highlight the potential impact of CC on UPUG and to provide feed- back on effects of greening to urban micro-climate, human health and well-being. Additionally, the findings could help landscape planners to select those tree species which are best adapted to specific urban areas coinciding to current and future expected climate conditions and limit UPUG management costs.

Before analysing the potential future trends of changes for UPUG, the current distribution traits need to be defined in order to be able to interpret and evaluate scenarios of future changes. This chapter presents an automatic open access and open source procedure for the analysis of 15 urban areas in Europe. Key aspects are:

1) the visualization of the current urban greening and estimations on the extent of tree cover in urban and peri-urban areas.

2) The analysis of climate change impact on two common tree species: The Mediterranean

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evergreen Holm Oak *Quercus ilex* (L.) and the Scots pine *Pinus Sylvestris*. An example analysis is applied in two different city.

2. Method

For this study the available data needs to be selected as well as the urban and peri-urban areas that will be used for the case studies. Further, the method for the data processing and its computational implementation needs to be defined.

2.1 Input data selection

At present a large variety of data on European forests, urban greening and urban development exists but frequently difficulties occur with the harmonization of input data for comparability of local scale analysis. The main source of harmonized data on European forest is provided by the Eurostat forestry statistics. However, Eurostat does not include a forest mapping survey. Remotely sensed data provide an useful information on the estimate of tree cover in European cites. Currently existing forest maps on a European extent (derived by remote sensing data) range from 1 km resolution based on Advance Very High Resolution Radiometer (Häme et al., 2001) and Spot-vegetation (Bartholome & Belward, 2005) to 180 m resolution Wide Field Sensor data (GAF, 2001), and 25 ha minimum mapping unit of CORINE Land Cover (CLC) database (Perdigao & Annoni, 1997) where forest and urbanized area data can be retrieved. Using this data will lead to a strong generalization of results including errors in the estimate. In fact, none of these data have the possibility to detect tree cover of objects smaller of 25 ha of surface. One alternative solution is the forest non forest pan European map 2000 (FNFMAP) (Pekkarinen et al., 2008). This harmonized data on a European extent is available for studying tree cover distribution of minimum of 25 m mapping units. The forest non forest map was not conceived for urban greening study purposes but it includes urban tree cover. For this study the latter dataset was chosen because its scale and extent is appropriate as well as the fact that it is an open access product and harmonized for the whole European extent. Such data peculiarity allows potential reproducibility of our method on other potential European urban zones and to eventually produce urban cover changes using the 2006 map now available at the Joint Research Centre of the European Commission web site [1].

Beside the greening component of our study we selected the Urban Morphological Zones (UMZ) (Milego, 2007; Simon et al., 2010) map as definition and geographical determination of urban areas. The UMZ are defined as a *set of urban areas laying less than 200 m apart* (Simon et al., 2010). Those urban areas are drawn by CLC land cover classes contributing to the urban topology and function: continuous urban fabric; discontinuous urban fabric; industrial or commercial units; green urban areas, port areas, airports, sport and leisure facilities. Besides the previously mentioned "core" classes, road and rail networks are also considered if they are neighbors to the core set of classes. Water courses, forests and scrub classes are also considered if they are completely within the core classes. As a result, the administrative boundary of a specific city is different and not directly comparable to what we define as city using the UMZ. The exercise of harmonizing and extracting green urban areas in Europe was already carried out by using a mosaic map derived from remotely sensed data [2]. Two resulting maps were achieved: the Green Urban Areas within Urban Morphological Zones 2000 map (GUA, 2006) and the Percentage of Green Urban Areas in Core Cities (GUA, 2011). Both results derive

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[1] http://forest.jrc.ec.europa.eu/forestmap-download

[2] Image2000: Joint Research Centre of the European Commission http://image2000.jrc.ec.europa.eu/ - The Spatial Reference for Europe, based on Landsat 7 ETM+ data

urban zones from CLC data. The latter focuses on cities with more 100.000 inhabitants (see GMES Urban Atlas GMES) while the first is not restricted to any city size. Both data are also not open access data therefore, only a low resolution map or low resolution statistics for percentage green cover can be visualized This is the main reason to use the UMZ and FNFMAP maps for this research project.

Once defined the urban tree cover distribution (refer to sub-chapter "spatial analysis and computational implementation"), the ECONM can help to understand vegetation vulnerability under climate change scenarios (Casalegno et al., 2010). ECONM are based on field data locally sampled. The harmonization of such data at continental scale is technically difficult and implies the use of rigorous scientific methodology to limit inaccuracy and imprecision. An example of integrated efforts to collect harmonized data in the forest sector on the European scale is the *forest Focus* regulation (EC, 2003). The Forest focus database was implemented in 1994 for a better understanding of the impact of air pollution and other biotic factors concerning European forest ecosystems. It is a Pan European Programme for Intensive and Continuous Monitoring of Forest Ecosystems. Results of the programme and datasets contribute to the assessment of criteria and indicators for sustainable forest management. Other results from the forest Focus regulation are ECONM models of main dominant European tree species and forest categories, which is on-line available (Casalegno et al., 2011; 2010; EFDAC, 2011).

In this application, ECONM map derived from forest focus datasets are used as the only open access prediction maps at high resolution of 1 km and continental extent for European tree species. Summarized, the CC impact assessment is build on urban and peri-urban European areas using the forest non-forest Pan European map, the Urban Morphological Zones map and the ecological niche models of tree species available at JRC - EFDAC website.

2.2 Selection of the urban study area

From the UMZ 15 city capitals in Europe were selected (Fig. 1) including : Amsterdam, Athens, Berlin, Bruxelles, Budapest, Copenhagen, Helsinki, Lisbon, London, Madrid, Paris, Rome, Stockholm, Warsaw, Vienna.
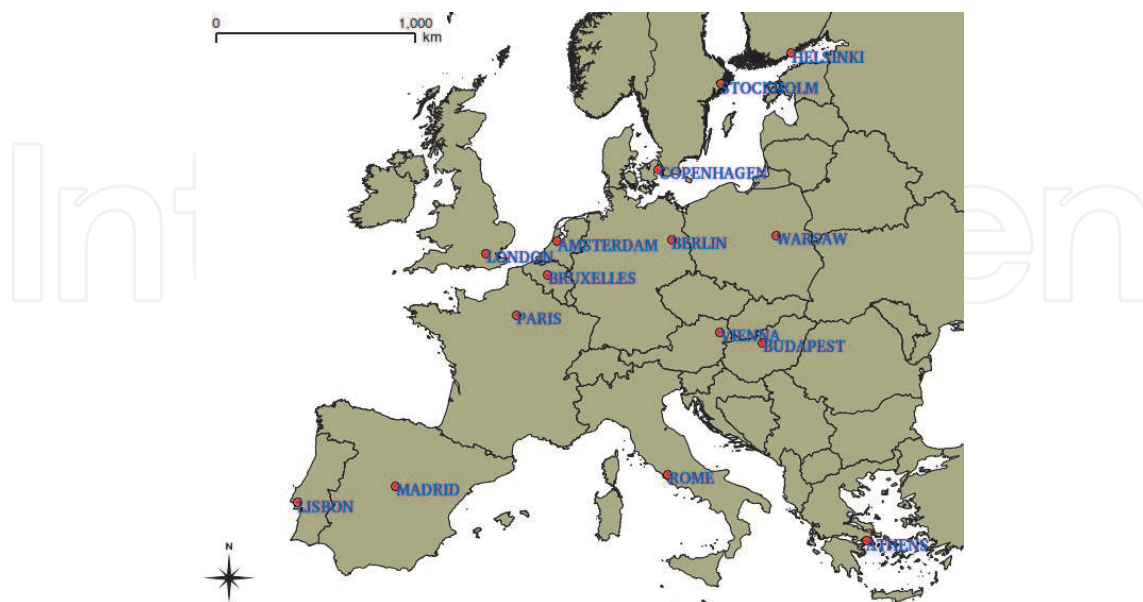

Fig. 1. Selected European capitals for the analysis

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2.3 Spatial analysis and computational implementation

The spatial analysis and data processing include following steps:

(1) Defining the extent of the study areas. For each urban study area a squared bounding box was defined including the core UMZ corresponding to each city. The squared area is larger than the core UMZ. The selected areas contain urban zones and not urbanized areas according to the UMZ classification scheme.

(2) Downloading and importing forest cover data with the same projection into a Geographic Information System project.

(3) Mapping current UPUG: The intersection between UMZ and FNFMAP produces maps of UPUG cover.

(4) Estimate for each city the proportion of the tree cover / non-tree cover within the UMZ and outside (the peri-urban area). The size of the bounding box determines the quantity of urban greening that is analyzed. Here a percentage cover is used as measure unit to allow comparisons between different cities. A table summarizing results and a figure plotting the percentage urban green cover versus the percentage peri-urban green cover are automatically produced by executing the script. This allows easy data interpretation. Since the pixel resolution of the analysis is set to 100 meters, the original output statistics are in hectares (ha). In order to simplify the data visualization the map units in ha were converted into km.

(5) Downloading and importing the ECONM habitat suitability maps of Scots pine and Holm oak into the Geographic Information System. The maps are binary classified in suitability / non-suitability of the specie. (6) Plotting the maps of current and future trends of suitability under climate change projections. For both specie the difference maps between the year 2000 and the three future projections maps (2020-2000, 2050-2000 and 2080-2000) are computed.

Difference maps contain information categorized in four classes representing suitability changes in time: Class 1: Stable suitability with no changes between the input maps. During the years the species maintain their suitability. Class 2: Gain of suitability. Pixels classified as not-suitable will be suitable. There is a climatic fitness of the species to the changing climate. Class 3: Loss of suitability. Pixels classified as suitable will be not-suitable. The climate is not suitable anymore for the growth and reproduction of the tree specie. The population is now displaced out of the optimum climatic ecological niche of the species. In these areas plants become potentially vulnerable, because the particular specie does not grow anymore under it's appropriate climate. This leads to a potentially declining resilience capacity, inability to regenerate and lower resistance to external biotic and abiotic events. An increasing vulnerability to pathogens, extreme climatic events and competition is to be expected. Class 4: Unsuitable. Pixels are classified as not-suitable in both maps. The area is not within the optimal condition in neither past nor under future climate conditions.

Data processing is carried out in Linux Ubuntu environment using the GIS software: Geographic Resources Analysis Support System (GRASS Development Team, 2010) and R software and environment for statistical computing and graphics (R Development Core Team, 2011). Both software are used in text mode allowing the scripting routines to be processed in the Linux bash shell terminal.

3. Results

After downloading all required input data, the overall computational time on a 2CPU computer and 4GB memory is relatively fast (30min). This allows the reproducibility of the research project using the selection of different city or the city extent bounding box. The analysis of other tree species is also feasible changing the ECONM suitability maps imported within the scripting routine.

3.1 Current tree cover distribution

Maps on urban and peri-urban greening within each European capital is displayed in figure 2, 3, 4. The maps visualise the extent of the urbanized areas against the peri-urban areas as well as the tree cover within both classes.

The extent of the study area for each city is available in table 1 as well as the extent of the urban and peri-urban spatial extension. The exact location of each city study area is available on-line together with the scripting codes [3].

In figure 5 are visualized the data found in table 1 to facilitate the analysis and allow immediate understanding and comparison of urban greening distribution trends.

	Total sq km	Urban sq km	Peri-urban sq km	% UPUG	% UG	% PUG
Amsterdam	1370	422	948	4.1	4.1	4.0
Athens	1583	454	1129	9.7	0.9	13.2
Berlin	2487	1002	1485	43.8	42.0	45.0
Bruxelles	1783	857	927	16.0	12.0	19.7
Budapest	2704	718	1986	20.8	2.5	27.3
Copenhagen	1352	547	806	21.0	28.5	16.0
Helsinki	1360	498	862	57.0	49.1	61.6
Lisbon	2063	491	1572	23.7	8.7	28.4
London	3521	1897	1623	9.9	4.9	15.8
Madrid	1903	524	1379	6.4	6.8	6.2
Paris	3549	1777	1771	20.8	10.8	30.8
Rome	1654	446	1208	8.4	3.5	10.2
Stockholm	2541	720	1820	70.5	57.3	75.7
Warsaw	3782	646	3135	32.8	36.5	32.0
Vienna	1685	457	1228	28.9	4.9	37.8

Table 1. Synthetic overview of urban and peri-urban tree cover estimated using The pan-European Forest non forest map (Pekkarinen et al., 2008) and the European Urban Morphological Zones (Milego, 2007; Simon et al., 2010). The resolution of the analysis is 100m. UPUG: urban and peri-urban greening; UG: urban greening; PUG: peri-urban greening.

3.2 Tree species vulnerability under climate change

Tree species suitability maps from the ECONM are generated by the *Random Forest* software package in R (Liaw & Wiener, 2002) as described in (Casalegno et al., 2010). Input of the ECONM maps is the *Worldclim* climatic database (Hijmans et al., 2005) for simulating current and future plant-climate suitability. The total number of predictions available in the ECONM maps per specie is 25. One of them correspond to the predictive model plotted for the year 2000. The other 24 ECONM maps per specie correspond to future climate scenarios: three different global circulation models and their averaged model simulating three years (2020, 2050 and 2080) under two different future development trends (A2a and B2a). A2a and B2a scenarios are detailed in the Intergovernmental Pannel on Climate Change (IPCC, 2001) Special Report on Emissions Scenarios story-line (SRES).

The three different Global Climate Models used in the *Worldclim* dataset simulations are: HADCM3 (Hadley Centre Coupled Model version 3) (Collins et al., 2001), CCCMA (Canadian Centre for Climate Modelling and Analysis) (Kim et al., 2003), CSIRO (Commonwealth
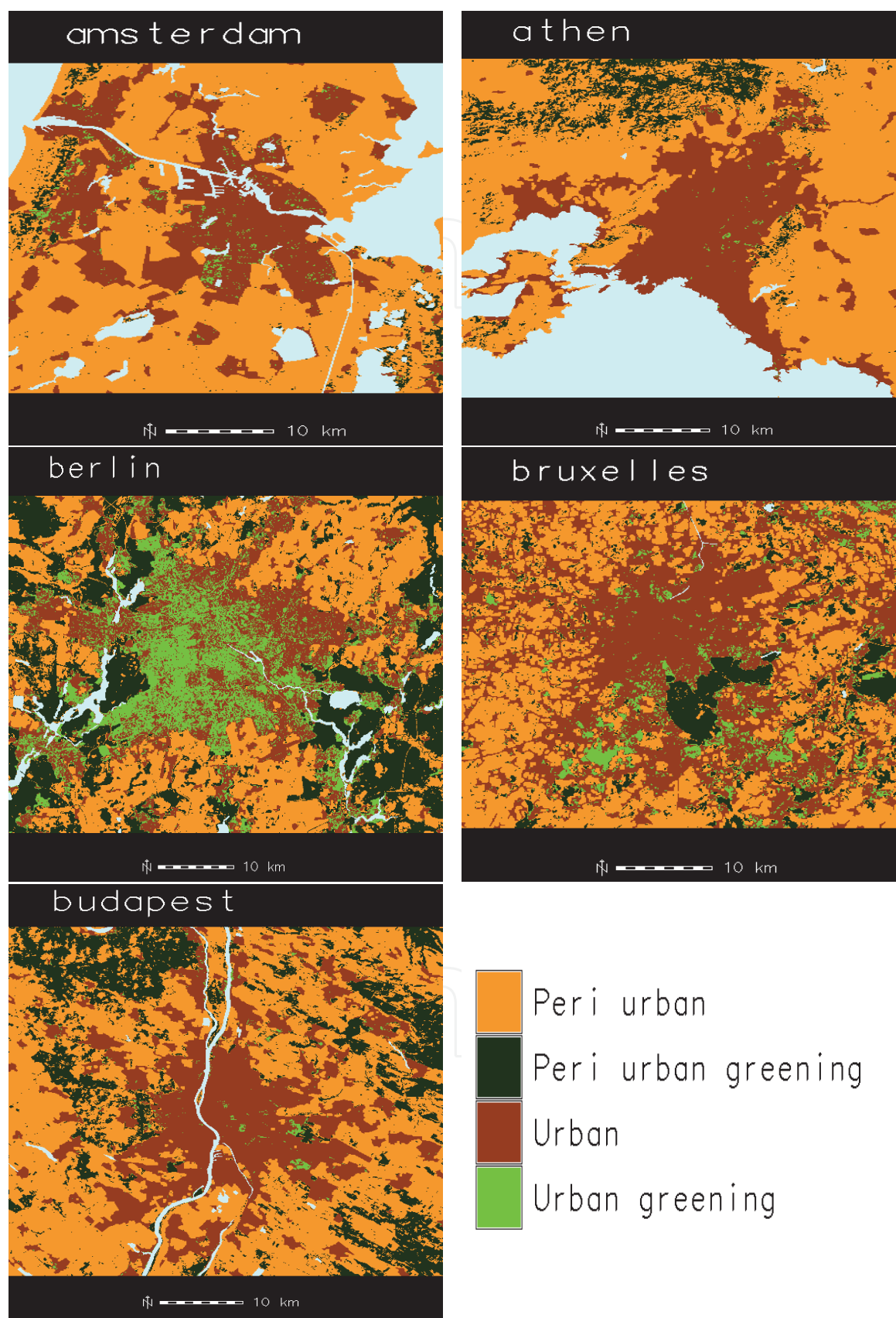
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[3] http://www.spatial-ecology.net/doku.php?id=wiki:urbanmod

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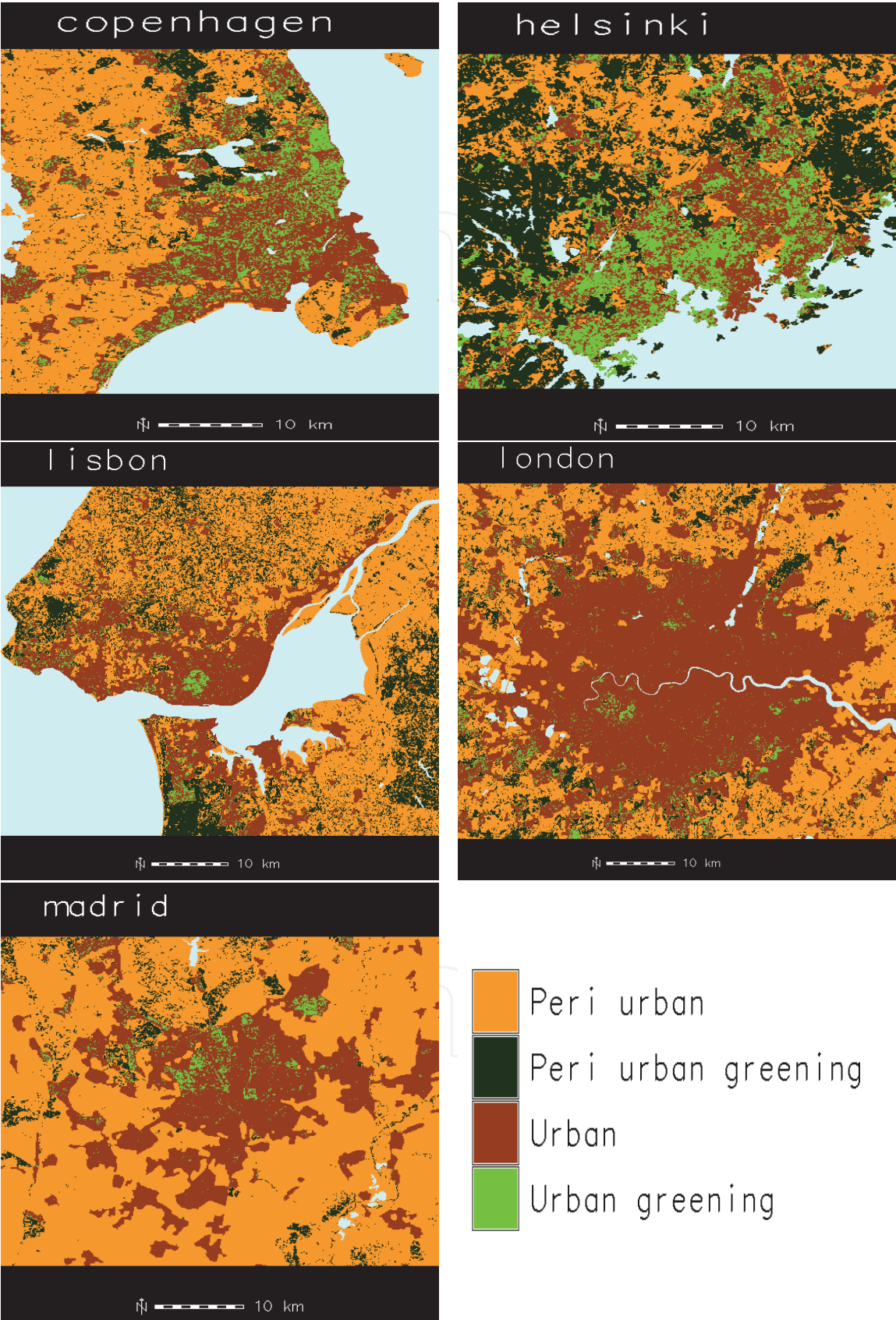Current Distribution and Future Vulnerability Under Climate Change Scenarios

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Fig. 2. Urban and peri-urban tree cover distribution in European Capitals

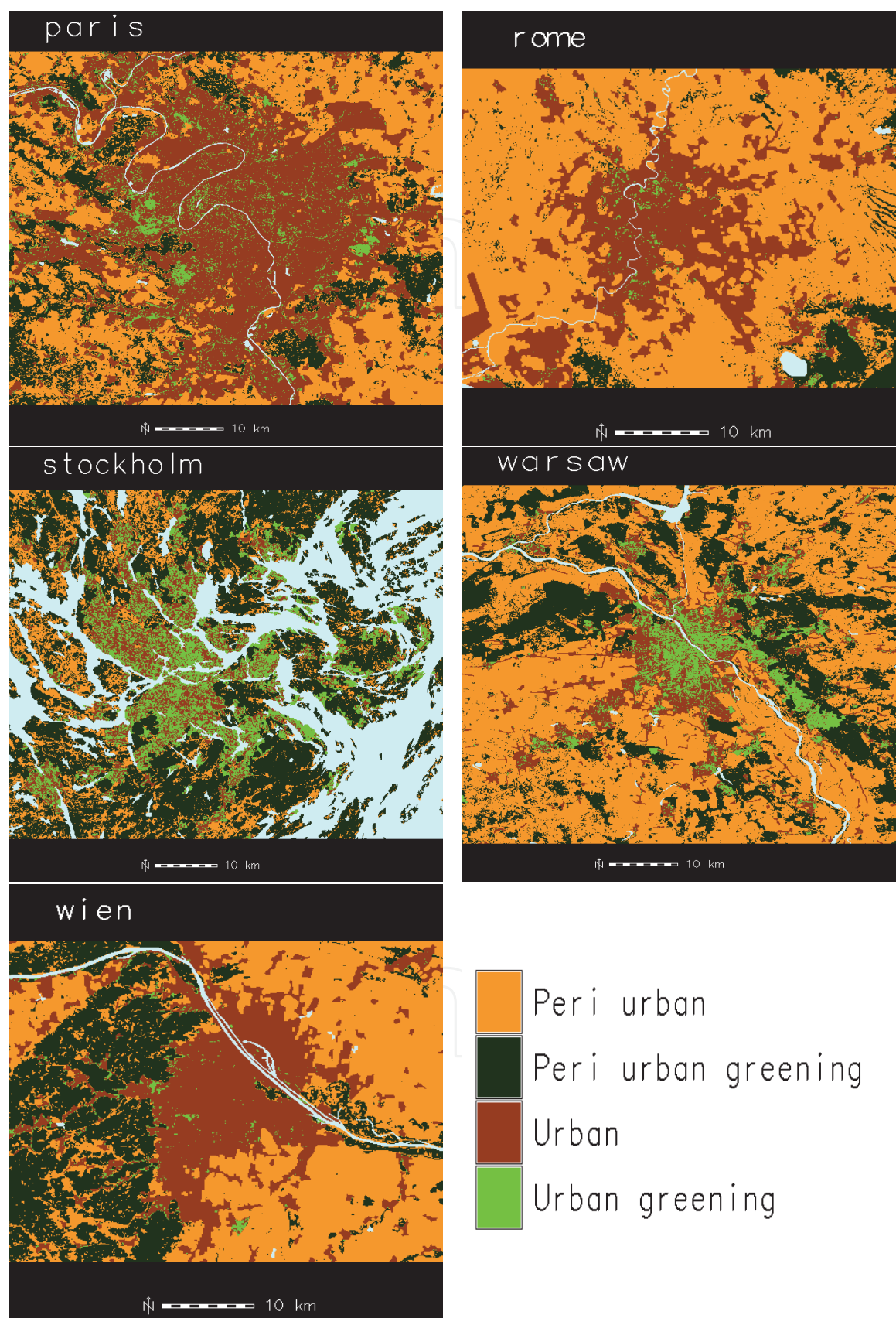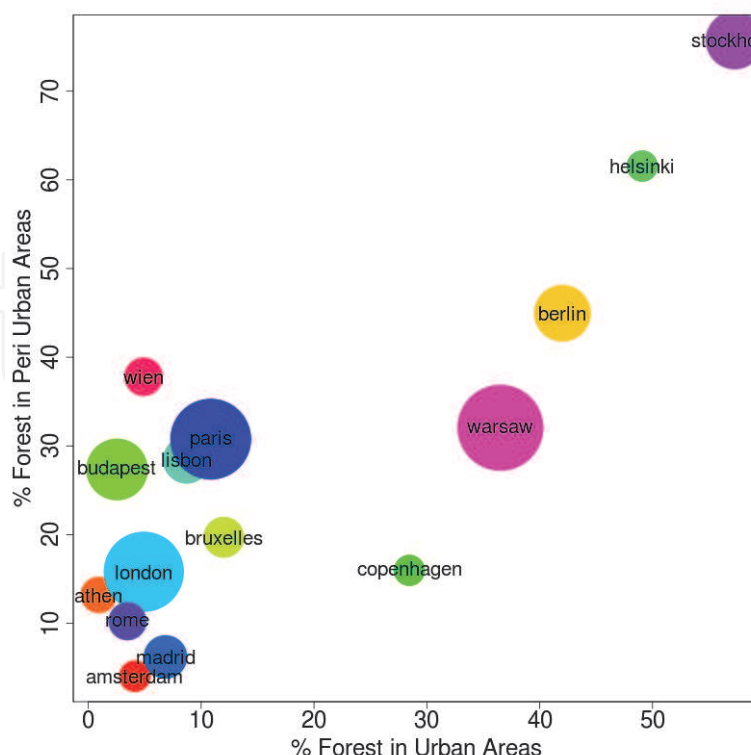Fig. 3. Urban and peri-urban tree cover distribution in European Capitals

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Fig. 4. Urban and peri-urban tree cover distribution in European Capitals

Fig. 5. Urban and peri-urban tree cover proportions in 15 selected European City capitals. The size of circles is proportional to the study area considered for the analysis.

Scientific and Industrial Research Organisation) (Gordon & O'Farrell, 1997).

The two SRES story-line (A2a B2a) included in the *Worldclim* scenarios describe the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways: A2a describe a highly heterogeneous future world with regionally oriented economies. The main driving forces are a high rate of population growth, an increase in energy use, land use changes and slow technological change. The B2a storyline produce a minor increase in the temperature for the future, it is also regionally oriented but with a general evolution towards environmental protection and social equity.

The amount of maps produced for one specie is equal to 375 (24 prediction maps x 15 Urban areas). The potential applications of such maps can be multiple. Governmental and intergovernmental pannels or biodiversity conservation centres can be interested in the analysis of the overall vulnerability of a species in UPUG environments. Local managers and decision makers could use the suitability trends of a particular species for proactive landscape planning.

Here, few maps were chosen from the large variety of maps produced: the current and future distribution of Scots Pine in Helsinki and Holm oaks in Paris, which were simulated according to the SRES A2a scenario, using the averaged global circulation climatic model.

Figure 6 and 7 shows the trends of suitability changes for the next century in Paris and Helsinki. According to the ECONM output suitability maps, Scots Pine is adapted to the climate of Helsinki in year 2000 but will lose most of its climatic habitat suitability during the next century. On the contrary, the Mediterranean specie Holm Oak is gaining suitability in the warming climate of Paris. The major increase in suitability is visible between 2000 and

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2020 ECONM maps. Difference maps between year 2000-2050 and 2000-2080 also predict an increased suitability but in different areas.
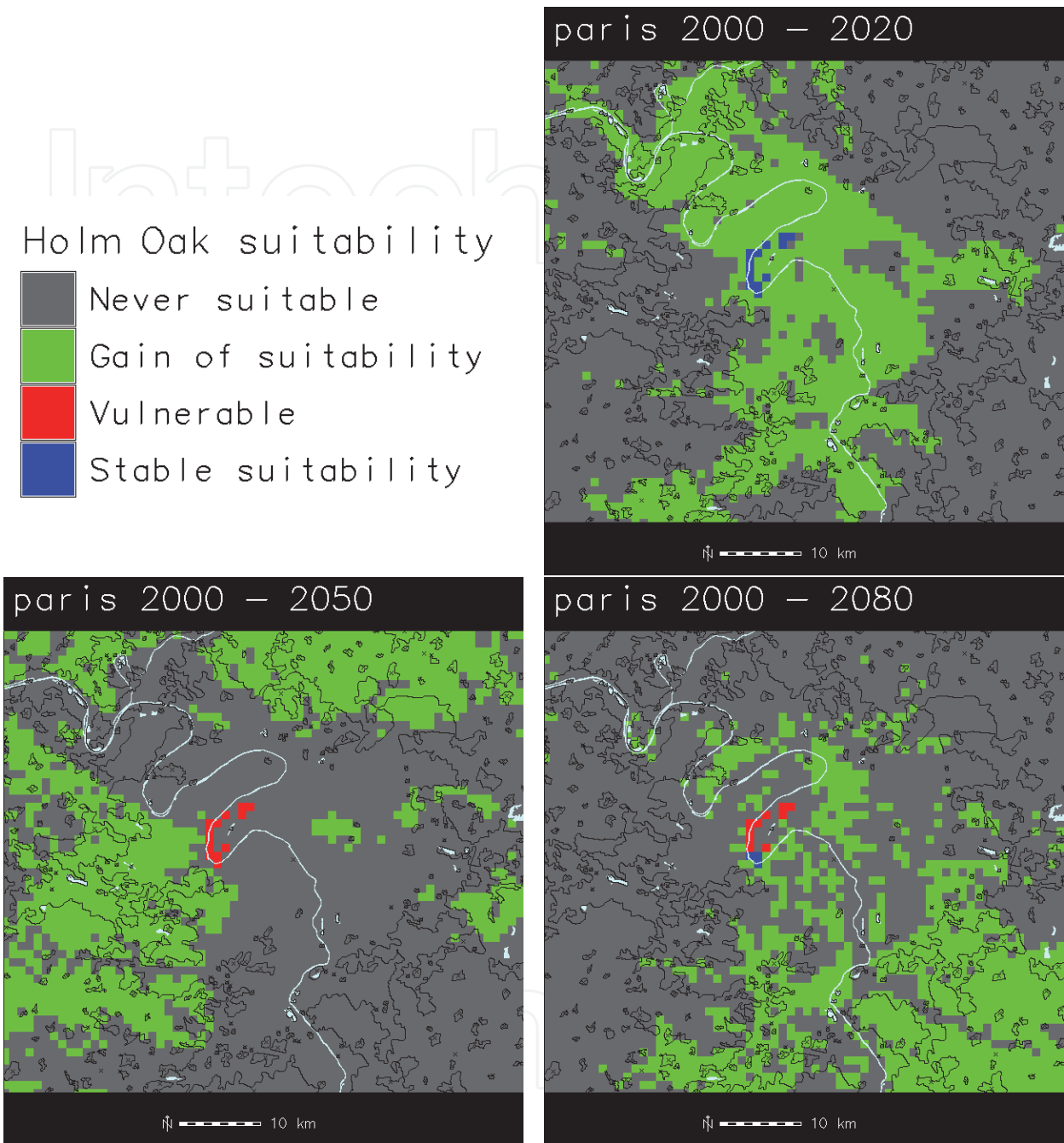

Fig. 6. Urban and peri-urban tree cover distribution in European Capitals

4. Discussion

Global change studies and analysis of climate change impact need transparency of data processing routines and their methodology. This study proposes a spatial ecological analysis of UPUG zones using open source codes and open access data. The main objective is the reproducibility and repeatability to target and improve the understanding of high uncertainties of studies on future projections and predictive model. This is important for
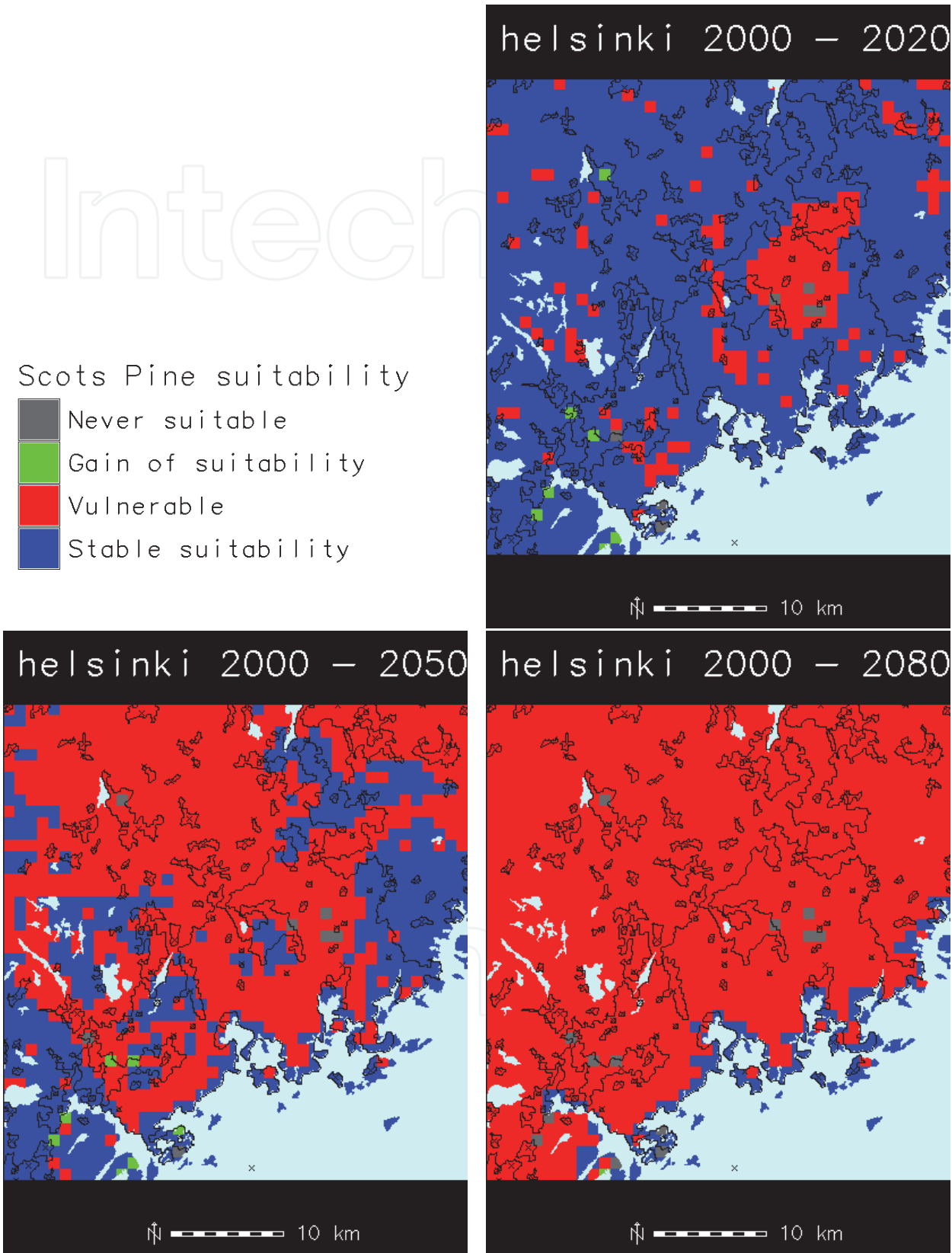
Fig. 7. Urban and peri-urban tree cover distribution in European Capitals

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improving our knowledge on the impact of climate change and the capacity to react and eventually mitigate the consequences.

Regional data may be more accurate and of higher resolution compared to the data applied in this project. However, the local data is facing the problem that level of accuracy and detail is varying for different regions. Local data are frequently not freely available and divers sources of information are used to produce them standing upon different definitions. In this study the UPUG maps are based on the same tree cover definition allowing inter and intra-city comparison. Therefore, local data are not appropriate in applications like the one which is proposed here targeting international comparison for policy and reporting purposes.

Besides the subject matter of data accuracy, harmonization and accessibility the major proposal of the present data analysis study is to share the underlying scripting routines. We believe open source codes should be compulsory in spatial ecological science and in climate change applications. The scripting routines produced for this application are available to be used, improved and reused. Whichever future climate data or improved vegetation map will be available in future, the script can be changed and adapted for reproducing the analysis. Tables and figures are directly produced by the coding routines, changing parameters such as the number of cities or the extent of the bounding box area will directly modify graphs and reproduce maps and tables. Another benefit of the scripting routine is the potential to use them in virtual machines for cloud computing or in stand alone computation for cluster processing when computational time is a limiting factor in research.

One drawback of this application is the "black box" represented by the ECONM and their input data used for modelling and mapping species suitability, due to the fact that the *forest Focus* database is not open access yet. In order to open the "black box" for more transparency and shared knowledge, we strongly recommend to rebuilt a set of ecological niche models for tree species using as inputs open access database such as the Global Biodiversity Information Facility [4].

This study demonstrates two examples of future trends projections: the increased vulnerability of Scots pine in Helsinki and the increased suitability area of the Mediterranean oak in Paris. In many cases the trends of changes are not so pronounced as in the described example. More details such as probability maps instead of or in addition to the binary suitability maps would help to interpret the results and to understand model limits. As an example we could be able to clarify the discrepancy of future projections found for the Holm oak in Paris. Instead of the different trends of suitability changes in time according to sub-areas of Paris (figure 6), probability map could eventually highlight a common trend of suitability increase with different probability of increase according to city sub-areas.

5. Conclusion

Due to the negative future prospects for the urban environment caused by global warming, there is a need to monitor and manage pro-actively urban greening and peri-urban forests. They have strong potential in mitigating the impact of climate change. Vegetation is necessary for urban environmental sustainability, human health and well-being.

When investigating complex systems such as the urban ecosystem, predictive modeling and spatial ecological analysis like the one presented in this chapter are some elements of many that are required to simulate the dynamics of urban ecosystems in space and time. This knowledge is prior and can be used for promoting urban sustainability and managing urban greening.

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[4] http://www.gbif.org

The exponential increase in data availability concerning urban areas, urban greening, climate and human health has to be followed by an improved ability to make full usage of those data. We believe this can be done by increasing the transparency of scientific applications and by the use of open access data and open source codes as proposed in this application. This will exponentially improve quality and accuracy of scientific applications allowing a better transfer from knowledge to policy and implementation.

6. Acknowledgments

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