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SOME ASPECTS OF INDICATOR DEVELOPMENT FOR MAPPING MICROCLIMATE REGULATION ECOSYSTEM SERVICE OF URBAN TREE STANDS

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Summary: In the light of the changing climate the urban heat island effect delineates important tasks for researchers and for urban planners. One choice of the adaptation possibilities is to preserve and extend urban green surfaces. The quantitative assessment of the ecosystem services of green surfaces is required to meet policy objectives. In our study, we summarize the available experiences concerning the evaluation and indication of climate regulation based on results from the literature. This is followed by a brief summary of the micro- and local-scale climatic effects of urban trees, with particular regard to the modification of the factors which affect human thermal comfort. Finally we make some suggestions concerning the mapping of urban green surfaces from the aspect of human thermal comfort with regard to indicator-development aspects.

Key words: urban heat island, ecosystem services, indicators, trees, microclimate regulation

1. INTRODUCTION

In the light of the changing climate the urban heat island effect marks important tasks for researchers and for urban planners. Because of the increasing number of urban citizens, proper adaptation features need to be worked out. Of these features the most important are the protection and the increasing coverage of urban trees and green places, because the vegetation affects the microclimatic conditions and thus human thermal comfort. These positive properties of green areas can be interpreted as ecosystem services, together with e.g. carbon sequestration, energy saving and the recreational value of parks (Gómez-Baggethun and Barton 2013). This environmental assessment methodology in addition to the many scientific results of the various regional-scale planning processes is also expected to significantly determine the future. According to the European Commission communication of „Green Infrastructure – Enhancing Europe's Natural Capital" in 2013, the various national and international regional development programs have to serve the development of a Green Infrastructure. This document highlights urban green areas as highly important elements of the Green Infrastructure. The assessment and mapping of ecosystem services are in most cases carried out by developing indicators, which describe the processes well. Accordingly, indicators have been developed concerning the climate regulation of urban tree vegetation, in different urban evaluations. Dobbs et al. (2011) set a general framework to work out indicators for urban ecosystem services. They assessed 11 (primarily regulating) services and 3 disservices based on available or on easily obtainable spatial data for other cities as well.

The 'maintenance of favourable climate' service, which has primary importance in terms of our topic, was indicated with the cooling effect of the trees, which was calculated through the effect by tree cover in each land multiplied by m^2 of plot trees cover in ˚C. Some socio-economic indicators were also part of this analysis, which were compared to the full range of services. They also mentioned the limited usage of the indicators in different geographical regions because the biomass growth and climatic factors strongly affect the services, and they depend on the geographical location (Dobbs et al. 2011). Similarly to the previous study Bastian et al. (2012) described different urban places with the temperature reduction and its spatial extrapolation using the tree crown area. The specific of this work is that he included the climate control service in the ecosystem properties-potentials-services system, and by relatively easily obtainable spatial data, he could evaluate land use change scenarios with regard to the prevalence of a particular service. The work of Breuste et al. (2013) was also based on relationships with land use forms, where the data of parks and other land use types were created on the basis of remotely sensed data. Mean annual temperature was calculated on a large time scale, based on a dataset of nearly five decades.

Table 1 Characteristics of studies that have indicated climate regulation (temperature modification) in urban ecosystem service assessments

Citation	Urban area	Indicating method
Dobbs et al. (2011)	Gainesville (Florida, USA)	Temperature reduction effect by tree cover in each land multiplied by m^2 of plot trees cover in °C
Bastian et al. (2012)	Leipzig (Germany)	Shading potential (based on temperature measurements in shaded and non-shaded places) extrapolated to the whole city, using an urban tree GIS data layer
Breuste et al. (2013)	Karachi (Pakistan)	Temperature reduction effect of different urban green spaces, in relation to land use pattern/characteristics of built-up areas
McPherson et al. (2012)	New York City (USA)	Decreasing temperature (calculated based on latent enthalpy hours/cooling degree days ratio), multiplied with the percent of the total lot covered by coarse vegetation
Schwarz et al. (2011)	Leipzig (Germany)	Combined use of land surface emissivity (based on a case study-specific look up table) and evapotranspiration potential (based on empirical estimations and site specific calculations)

McPherson et al. (2012) also treated this specific service as temperature regulation, but the quantification of the indicator was based on the ratio of latent enthalpy hours (LEH) to cooling degree days (CDD) in the city. Based on the particularity of the urban climate, they defined the rate of temperature decrease from the spatial data of the tree canopy cover. Local climate regulation prevails in an integrated manner through several modified climatic factors, and according to this, Schwarz et al. (2011) developed indicators for urban-scale evaluations. One of the most important factors, which help in defining the temperature influencing effect of the different land uses, is land surface thermal emission. He developed this indicator with land use-specific look-up tables from remotely sensed data. Latent heat also plays an important role in affecting the air temperature. He indicated this with an evapotranspiration potential parameter, because evapotranspiration is in a linear relationship with latent heat. The quantification of land use class was based on empirical estimations, taking local environmental conditions into consideration. In this article urban planning policies and their effect to climate regulation were defined with two different indicators. The result was that in most cases the value of the two indicators moved together, but in certain land use types showed significant differences, so if these indicators are used together it becomes possible to more exactly define the extent and spatial pattern of local climate regulation. We summarized the results in Table 1.

The above examples of different-scale evaluations have given spatial indicators for urban trees, or in broader aspect to other land use types, for defining climate regulation using air temperature decrease as an indicator base unit. Air temperature is an important factor for human thermal comfort (as a welfare factor, in the ecosystem services framework); however it is affected by several climatic parameters. Human bioclimatology is the discipline which deals with this. It uses the results to clarify the theoretical basis and to make different regional-scale analysis, and specific models to typify the thermal comfort in numbers (Gulyás et al. 2006, Gulyás and Matzarakis 2009). It's a fundamental law, that besides air temperature, relative humidity, wind speed, and the mean radiant temperature (T_{mrt}) also play an important role, influence the urban environment and have a significant spatial variability because of the heterogeneous urban environment. The above factors are affected by urban trees in a complex way, but the goal is not an accurate process-based modelling, only indicating an ecosystem service or function. Using together the models applied by human bioclimatology and the GIS methods with which we can define the location and ecological characterization of urban vegetation it is possible to work out indicators which will better describe human thermal comfort, and serve as a good basis for urban planning.

Based on the above our objectives are the follows:

- to give a brief summary of the micro- and local-scale climatic effects of urban trees based on the results of the recent literature, with particular regard to the modification and the spatial assessment opportunities of the factors, which affect human thermal comfort.
- to provide methodological proposals for developing indicators better describing human thermal comfort and its spatial pattern in the frames of the generally used system of ecosystem properties-functions-services.

2. CLIMATE REGULATION EFFECTS OF URBAN TREES

2.1. Temperature decreasing and shading in micro scale

One of the most important effect of urban trees on the modification of urban human comfort especially in hot summer days is the shading effect. Shading, the alteration of radiation energy balance, has two basic human bioclimatic impacts. Firstly, reducing the short wave radiation input the temperature increase of shaded surfaces is reduced and additionally the air temperature close to the surface remains lower. Secondly, reduced direct radiation impact of a body reduces the impact of the physiological load. These two effects together result in the significant increase of human comfort situation during sunny days (Ali-Toudert and Mayer 2007, Lee et al. 2013) Numerous comparative measurements showed in the last decade that arboreal vegetation – as a consequence of the above – reduces the air temperature (especially at daytime) at micro-scale (Table 2).

The mean near-surface air temperature in the shade (T_{air}) is less by 0.8-1.7°C than the ambient air temperature (min 0.4, max. 4.5°C, depending on the background climate, measurement method, type of surface cover, etc.). Most of the field measurements were carried out in summer (with warm-hot ambient temperature) at daytime. This decrease seems subtle, compared to the 25-35°C air temperature. In such a hot summer the impact of direct radiation on human comfort has emphasized importance that can be described by mean radiant temperature (T_{mrt}) value. T_{mrt} is the most important parameter in the human energy balance during summer conditions, since most human biometeorological thermal indices have special interest in this parameter (Hodder and Parson 2007, Thorsson et al. 2007, Kántor et al. 2013). Our studies show that the T_{mrt} (obtained from human bioclimate models or globe thermometer) differs in higher extent than (16-34.1°C) the air temperature between open and shaded (by single trees or small trees group) areas. This fundamentally affects the energy balance of the body and thus the degree of physiological stress (Shashua-Bar et al. 2010).

Table 2 Characteristics of studies that have indicated micro-scale temperature (near-surface layer) and radiation modification between open spaces and under tree (shown only the summer daytime data) * no data, **simulated environment

city	ΔT_{air} (°C) max/mean	ΔT_{mrt} (°C) max/mean	details	citation
Freiburg (Germany)	2.2 / 0.9	34.1 / 20.1	summer, daytime, small group of trees (deciduous)	Streiling and Matzarakis (2003)
	1.7 / n.d.*	29.3 / n.d.	summer, day- and nighttime, small group (dec.)	Lee et al. (2013)
Lisbon (Portugal)	4.5 / 1.7	33 / 26	summer, winter daytime small group and single (dec.)	Andrade and Vieira (2007)
Saitama** (Japan)	1.9 / 0.8	24 / n.d.	summer, daytime single trees along the road (coniferous)	Park et al. (2012)
Szeged (Hungary)	2.1 / 1.6	31.4 / 22	summer, daytime single tree (dec.)	Gulyás et al. (2006)
Taipei City (Taiwan)	2.5 / 1.4	n.d. / n.d.	summer, daytime small group of trees (dec.)	Lin and Lin (2010)
Tel-Aviv (Israel)	3.1 / 1.6	29.2 / n.d.	summert, winter, day- and nighttime (dec. con.)	Cohen et al. (2012)

The canopy of a tree can (i) reflect, (ii) absorb or (iii) transmit a certain percentage of the incoming solar radiation (Kotzen 2003, Hunter Block et al. 2012). At the local scale, the question is whether there is woody vegetation, or not. If there is, tree planting density, canopy coverage level and extension of the shaded area can be observed in the area (see in Section 2.3.). At micro-level the individual tree characteristics (e.g. species, age, size, canopy structure, etc.) and the differences of their transmissivity arising from these factors are more important. Some of these individual parameters differ between species thus for precise microclimatic characterization and more precise characterization of the ecosystem services their study may produce valuable information for city planning purposes and the decision makers. Lin and Lin (2010) examined the temperature decreasing effect of only 12 species. In Dimoudi and Nikolopoulou (2003) the light transmission of tree canopies was used for calculation only as a standard value. In other studies transmission was calculated from measured global and diffuse radiation data (Cantón et al. 1994, Shahidan et al. 2010, Konarska et al. 2013). Every study, including our unpublished data show that canopy transmission shows huge differences (depending on the density of crown, angle of sunbeam, etc.) reaching 4-30% in summer and 40-80% (deciduous trees) in winter (Shashua-Bar et al. 2010, Konarska et al. 2013).

The shading of trees has a positive effect on not only the outdoor thermal comfort; the shading of exposed walls of buildings (especially W and S oriented) reduces the warming up of interiors. In a hot climate, trees planted around buildings (the species corresponding to the right place) can positively influence the energy balance and reduce cooling energy requirements of particular buildings through sheltering windows, walls, and rooftops from strong direct solar radiation and radiation reflected from the surroundings (Nakaohkubo and Hoyano 2011, Berry et al. 2013).

Previously, only few studies addressed the micro-scale examination of temperature differences between shaded and non-shaded surfaces. These papers mainly focused on the comparison of thermal relations of surfaces covered with asphalt or grass (Ca et al. 1998, Spronken-Smith et al. 2000). Another study compared the tree canopy surface temperature values of different species but did not examine the relationship between the air and surface (under the trees) temperature (Meier and Scherer 2012). Land surface temperature can be examined using remote sensing techniques, thus it is usually studied at a larger (e.g. local) scale.

2.2. Evapotranspiration

Another important process as trees contribute to the reduction of negative effects of the urban heat island is evapotranspiration (ET), which is the sum of evaporation (movement of water to the air from different surfaces such as the soil, canopy interception, and water surfaces) and transpiration (conversion of water within the leaf to water vapor, which is then released to the atmosphere through the stomata, thus cooling the leaf and the surrounding local microclimate (Hunter Block et al. 2012). This mechanism plays an important role in the water cycle, and as such, it contributes to the provision of ecosystem services by the trees (Georgi and Dimitriou 2010).

The rate of evapotranspiration depends on various features of the local weather and climatological conditions (which are given in the Penman-Monteith equation, the general formula for ET calculations) and the characteristics of the vegetation. The latter are important from the point of view of ecosystem service indicating. One general vegetation attribute used in evapotranspiration calculations is the leaf area index, which is used in assessments on different spatial scales (Lee and Park 2008, Georgi and Dimitriou 2010). It should be noted that there are several morpho-anatomical and physiological features (leaf structure, stomata control, etc.) of the plants that characterize the complex phenomenon of evapotranspirative cooling, which should ideally be incorporated in exact referring indicators of the trees (Hunter Block et al. 2012). Though, knowing that LAI can be treated as an integrated indicator for different ecosystem services and that measurement methods of it are well-developed also for urban assessments, it will probably be considered as a general indicator of evapotranspiration and latent heat flux in most assessments in the future as well. Another important vegetation parameter in evapotranspiration calculations is the species-specific crop factor (K_c) which is an experimental ratio and its exact determination should be carried out specifically for the geographical region. In the multiparametric model for park cooling island by Vidrih and Medved (2013), LAI was used as general indicator in the thermal model (through the index of LAI_{sp} for integrative representation of trees and grass), with the evaporative heat flux incorporated. For the direct measurement of evapotranspiration (and thus for validation of other methods) there are several field-based techniques; the one which can be considered the most frequent is the eddy correlation method (Oke 1987).

Remote sensing methods provide useful assessment opportunities for calculating evapotranspiration in urban green spaces or other wider areas, enabling the analysis of spatial variations. In remote sensing approaches, spectral information is used mainly for defining empirical relationships to predict a parameter for the calculations (e.g. crop coefficients, surface temperature) (Nouri et al. 2013). These methods can probably form a good basis for ecosystem service assessments as well, when evapotranspiration is directly handled as an indicator in spatial assessments.

2.3. Local scale effects of green spaces

The previous overviewed climatic effects prevail in bigger urban green spaces in the phenomenon of Park Cool Island (PCI). In urban scale studies, in the past few years several studies examined its different aspects (Bowler et al. 2010). The generally measured parameters in PCI studies are air temperature and relative humidity, but there examples also for radiation measurements and bioclimate index calculations (Oliveira et al. 2011).

The influence of green areas in the urban environment depends on a wide variety of factors, such as size and vegetation structure, season and time of the day, sky obstruction, and weather conditions in the built-up and green areas, and the climatic zone where the green area is located (Oliveira et al. 2011). These connections can be analysed in targeted models to estimate the PCI intensity or indicators of the effect. Feyisa et al. (2014) investigated statistical relationships between different characteristics of the vegetation of parks (species group, NDVI, size and shape parameters, etc.) and some chosen characteristics of the PCI (mean hourly temperatures inside the park, park cooling distance, etc.) The multiple linear regression found many valuable informations on the effects of the studied parameters, though it should be noted that these (and every kinds of) statistical models have to be developed for every cases. For this reason, they are useful primarily in the baseline study phase for indicator development and other decision making-oriented works.

Another modelling approach was introduced by Vidrih and Medved (2013), who developed a multiparametric CFD model for estimating the cooling effect. The heat fluxes were calculated for the tree and grass layers separately. One of the parameters of the vegetation was the leaf area index, for which a constant value was given in the case of the grass layer, and a species-specific growth curve was used for the trees. Another was transmissivity, which was calculated based on the actual LAI value (for the tree layer). The model was well-verified with field temperature measurements; this fact highlights the usefulness of these types of indicating the vegetation structure.

The surface temperature (and thus the differences between parks and built-up areas) can be detected using remote sensing techniques, based on data of the thermal band of multispectral imagery. For these types of analyses the most often used datasets are from Landsat and ASTER sensors (Cao et al. 2010, Ren et al. 2013). From an ecosystem service aspect, the surface temperature does not represent the total effect of urban trees and green spaces on human thermal comfort, and the spatial resolution of the above-mentioned data is irrelevant in micro-scale studies. But, owing to the widely available data, remote sensing based PCI studies can have an important role in urban scale assessments.

3. METHODOLOGICAL ASPECTS OF ECOSYSTEM SERVICE INDICATOR SELECTION

As the above-mentioned examples show, a numerical link can be established between the determinable and measurable parameters of urban trees and tree stands and human heat stress as a direct indicator of the well-being of citizens. All the parameters which determine human comfort are only available from point-like calculations; therefore integrated heat stress maps have so far only been created by interpolating micro-scale calculations or point-like data (Égerházi et al. 2013, Takács 2013). However when the task is to choose and develop suitable indicators for the climate regulation effect of urban tree stands, or in a wider context, urban ecosystems, all the steps of the cascade model (Potschin and Haines-Young 2011) elaborated to represent the supply side of the ecosystem services can be expressed.

Several frameworks have been worked out recently for the indicator development (Dobbs et al. 2011, Bastian et al. 2012, van Oudenhoven et al. 2012). It is common in these frameworks that indicator development should be carried out in a hierarchical order (Fig. 1), where different yet quantitatively related indicators characterize the ecosystem properties, ecosystem functions (the latter is called ecosystem capacity by Bastian et al. (2012) and the utilization-based ecosystem services. In bioclimate-based evaluations the property-indicator can be the leaf area, or leaf area index, which characterizes foliage density which describes the shading effect as well as the whole biomass independently from the built-up environment or the land use. For a function indicator (in order to express the potential service supply) we suggest a shading-index possibly taking into account the effect of the buildings since human-made structures also affect the amount of ecosystem services, besides the ecosystem characteristics. One of the most important components of thermal human comfort is radiant temperature, which can be well modelled at the local scale (Lindberg and Grimmond 2011). Service indicators should be chosen possibly with regard to their further usage. In the case of urban green places, which are visited by the urban citizens with recreational purposes, this is possible since in such places the bioclimatic conditions are statistically related to the usage of the visitors (Égerházi and Kántor 2011). This system is similar to the framework where indicators are classified as either state or performance indicators (de Groot et al. 2010). Ecosystem property indices can be used as state indicators while performance indicators describe the rate of service supply.

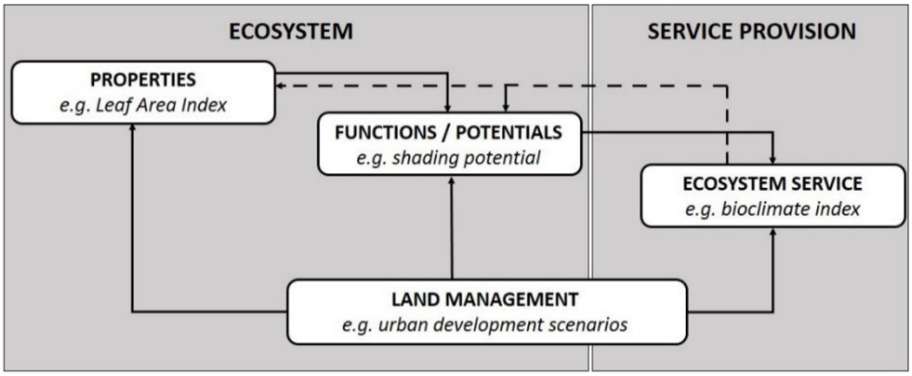

Fig. 1 Possible bioclimate-oriented indicators for mapping microclimate regulation of urban trees, in the framework by van Oudenhoven et al. (2012) for defining links between ecosystem and service provision, and based on Bastian et al. (2012)

The criteria of suitable ecosystem service indicators (van Oudenhoven et al. 2012), can be easily fulfilled in this indicator system. Temporal extensibility is possible, with the use of solid data (tree crown and building databases, meteorological data) which are available or can be calculated for most of the cities. Therefore bioclimate-based indicators can form the basis of the evaluation if considering data availability. These data types also define the local climate zones, so they can serve as a basis for aggregation e.g. by creating transfer functions for each zone (already used for the mapping of other services) therefore a given indicator can be considered scalable (McPherson et al. 2013). In the evaluation and mapping of ecosystem services the use of aggregated indicators is always an option, and through these, it is possible to visualize ecosystem service bundles (UNEP-WCMC 2011, for example: in fast evaluations, mapping different services). Leaf area index, or canopy projection area (CPA), which represents the amount of biomass, can serve as indicators for several climatological services of urban tree stands. In several studies which involve the mapping and modelling of ecosystem services, it arises that the chosen indicator must be sensitive to land management (Petz and van Oudenhoven 2012), because such decisions significantly influence the state of the ecosystem, and the amount of the available services. It also makes it possible to analyze the amount of ecosystem services in different management intensity scenarios. In the case of urban green areas, land management not only means the usage of the service providing unit (e.g. the tree stand), but also the proportion of built-up areas which affects the amount of the services too. According to our previous statements socio-economic scenarios which are realized in the changing of land management intensity, will be different urban scenarios.

4. CONCLUSIONS

In the above literature review we highlighted the need to develop suitable spatial indicators describing the micro-climate regulation role of urban trees, which significantly affects human thermal comfort. If the mapping of this ecosystem service is intended the indicators need to be selected according to the complex nature of the phenomenon. For the shading effect of the trees there are several quantitative models with bioclimatological indices and for the mean radiant temperature there is an existing model which allows medium-scale mapping. At the same time, these works also highlight the species- and individual-specific variability of parameters which affect the shading effect (e.g. transmissivity). This requires further detailed field examinations in different geographical areas, and cities with frequent urban tree species, representing the age, structure and condition of the urban trees and the seasonal variability as well as possible. Another important task is to fit these factors into city- or district-scale evaluations. The evapotranspirational effect of the trees and larger green places appears in the bioclimatological measurements, but for the calculation of the latent heat flux, and meso-scale urban climate modelling it is necessary to choose and define the appropriate indicator (leaf area index) precisely, and relevant methodological background investigation is needed as well. In many studies the researchers use remotely sensed data to examine the climatic effects of large urban green places. The study of the intensity and extension of Park Cool Islands needs specific data types and knowledge, but for a certain parameter (surface temperature) it is possible to obtain reliable data on large areas. The urban climate phenomenon and the condition of green surfaces can be significantly different in various geographical regions, partly due to the differences in the vegetation; so many more studies are needed to be carried out in several places in order to work out appropriate indicators for this task.

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