Ecosystem Services 26 (2017) 225–235

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Estimating the cooling capacity of green infrastructures to support urban planning

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ARTICLE INFO

Article history:
Received 21 February 2017
Received in revised form 24 June 2017
Accepted 27 June 2017
Available online 7 July 2017

Keywords:
Green Urban Infrastructures
Ecosystem-based adaptation
Ecosystem services
Climate adaptation

ABSTRACT

Heatwaves are threatening human wellbeing in our cities, but Green Urban Infrastructures (GUI) can contribute to reduce temperatures and the associated health risks, by virtue of their cooling capacity. GUI present different typologies and consequently different key components, such as soil cover, tree canopy cover and shape, which determines their capacity to provide cooling. The aim of this study is to propose an approach to estimate the cooling capacity provided by GUI in order to generate useful information for urban planners. The methods are based on the review of the literature to identify the functions of GUI that are involved in providing cooling, and the components of GUI that determine those functions, and then to combine them to provide an overall assessment of the cooling capacity. The approach was used to assess 50 different typologies of GUI, which are result of different combinations of the components that influence the cooling, for three climatic regions. An illustrative case study in the city of Amsterdam show the applicability of the approach. This work provides a contribution in the panorama of Ecosystem Service assessment tools to support the mainstreaming of Ecosystem-based measures (such as the creation of GUI) in the planning practice.

1. Introduction

Heatwaves have caused the most human fatalities among the natural disasters that occur in postindustrial societies: nearly 95% of recorded human deaths from natural hazards (Poumadere et al., 2005). During the summer of 2003, for example, the heatwave in Central and Western Europe was estimated to have caused up to 70,000 excess deaths over a four-month period (EEA, 2012). A study in Germany (Hübler et al., 2008) showed evidence of the fact that heat-related hospitalization costs increased sixfold in that period, not including the cost of ambulance treatment, and that heat also reduced the work performance, resulting in an estimated output loss of between 0.1% and 0.5% of GDP. Climate change is expected to increase heat island effect and the consequent rise of temperatures in cities during the summer in many regions of the world (Koomen and Diogo, 2015).

Against this harsh reality, it becomes imperative to increase the resilience of cities to heatwaves and extreme temperatures (Ogato et al., 2017). Among the variety of strategies and approaches, ecosystem-based Adaptation has proved to provide flexible, cost effective and broadly applicable alternatives for reducing the impacts of climate change (Munang et al., 2013a). Ecosystem-based adaptation is defined as the use of biodiversity and ecosystem services to help people to adapt to the adverse effects of climate change (CBD, 2008). It represents an alternative approach to more traditional grey infrastructures and often proved to be cost-effective and able to provide a range of co-benefits, such as opportunities for recreation, biodiversity conservation and water regulation (Demuzere et al., 2014; Naumann et al., 2011; Vignola et al., 2009; Munang et al., 2013b,c).

Among the most common ecosystem-based adaptation measures in cities are the creation and enhancement of Green Urban Infrastructures (GUI) (Munroe et al., 2012; Geneletti and Zardo, 2016). GUI can be described as hybrid infrastructures of green spaces and built systems, such as urban forests and wetlands, parks, green roofs and walls, that together can contribute to increase city resilience and human benefits through the provision of ecosystem services (Naumann et al., 2011; Pauleit et al., 2011; EEA, 2012). Thus, GUI contribute to reduce high temperatures in cities and the associated health risks, by virtue of their cooling capacity (Lafortezza et al., 2013; Escobedo et al., 2015). This ecosystem service, which belongs to the "micro and regional climate regulation" class of the CICES classification system (CICES v. 4.3, Potschin et al., 2016) refers to the capacity of ecosystems to modify temperature, humidity and wind fields.

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http://dx.doi.org/10.1016/j.ecoser.2017.06.016
2212-0416/

Smith et al. (2013) defines micro and regional climate regulation as the capacity of GUI to provide shelter from extreme weather, either cold or hot weather. In this paper, we focus on the cooling capacity of GUI, i.e. their capacity to mitigate high temperature in the summer (McPhearson, 1997). GUI can lower temperatures in cities by almost 6 °C (Souch and Souch, 1993). In particular, the creation and restoration of GUI aimed at maximizing their cooling capacity can reduce energy costs in summer and limits the exposure of city dwellers to increased mortality induced by higher temperatures (Koomen and Diogo, 2015).

Urban plans are among the most important governance tools that can help to integrate and mainstream EbA measures in cities (Kremer et al., 2013), in particular through the creation and restoration of GUI. The enhancement of green areas represents a typical objective that planners pursue to improve the urban space for a variety of purposes that go beyond adaptation to extreme temperatures (e.g., providing recreation opportunities, improving air quality) (Tzoulas et al., 2007). However, a recent review showed that, even though there is in general good awareness of the potential role of GUI to address climate change challenges, their treatment in plans at the urban level often lacks sufficient baseline information (Geneletti and Zardo, 2016). The review concluded that a better knowledge base, including information on spatial pattern of ecosystem services flow at the local scale would allow to better target the design and implementation of GUI. Assessments of the flow of ecosystem services at local scales are often missing, given that many climate change impact and vulnerability studies provide results at larger scales, limiting their usefulness for developing adaptation strategies at the urban scale (Vignola et al., 2009). In addition, in the ecosystem services literature, the services provided by GUI are mostly assessed at large spatial scales (regional or national), which cannot capture the differences in different types and structures of GUI (Norton et al., 2015), since they mainly rely on coarser land use information (De Groot et al., 2010). GUI may be very different in nature, including typologies such as parks, gardens, forests, green roofs and walls, and rivers (Naumann et al., 2011; Pauleit et al., 2011; EEA, 2012). These typologies may differ in key components, such as soil cover, tree canopy cover, size and shape. Hence, they provide different ecosystem services, with different capacity (Bolund and Hunhammar, 1999; Bowler et al., 2010; De Groot et al., 2010; Chang et al., 2007). There is lack of information on GUI relevant for planning and decision-making at the urban scale (Larondelle and Haase, 2013), which requires more research in this area (Munang et al., 2013a; Braat and De Groot, 2012).

The aim of this study is to contribute to fill this gap by proposing an approach to estimate the cooling capacity provided by GUI that can be used to support urban planning. Evidence exists about the need for urban planners to effectively include the design and enhancement GUI into the planning practice as a measure to cool cities and combat urban heat islands. Yet, to our knowledge, no study specifically addressed this need by providing guidance for GUI planning and design. This paper attempts to contribute to add an important missing piece to the whole of the urban ecosystem services discussion.

More specifically, we focus on three specific objectives: i) identify how different components of a GUI correspond to functions relevant for cooling; ii) assess the cooling capacity of different typologies of GUI; iii) apply the approach to an illustrative case study -we tested the applicability of our methodology by applying it to the city of Amsterdam.

Section 2 presents the rationale of the proposed approach and describes its four main steps and the case study application. Section 3 illustrates our results, consisting in the assessment of the cooling capacity of different typologies of GUI (Section 4) and the findings related to the applicability for a case study. In Section 4, we discuss our findings, and in Section 5 we draw some conclusions on the approach and its potential contribution to urban planning.

2. Methods

Ecosystem functions, defined as the "capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly" (De Groot et al., 2010), are determined by the structure of an ecosystem, i.e., how its components (e.g., land cover, size, geometry, tree species) are composed and combined (De Groot et al., 2010). Our approach follows the Cascade Model (Haines-Young and Potschin, 2009), which explicitly identifies the general links between structure, functions and ES provisioning of an ecosystem. We first identify the ecosystem functions of GUI involved in the cooling capacity and then the components associated to these functions (Section 2.1). Secondly, we investigate how to compute the contribution of each function to the cooling capacity of a GUI (Section 2.2 and 2.3), and how to combine it to obtain an overall assessment of the cooling capacity assessment (Section 2.4). Finally, we compile an inventory of GUI typologies, resulting from a variety of combinations of the components involved in the functions. For each typology, we assess the cooling capacity in a scale from 0 to 100 and then in terms of temperature decrease in °C (Section 2.5) (Fig. 1).

The approach is based on an extensive analysis of the literature, covering mainly the fields of ES and urban forests -in particular, Sections 2.1, 2.2., 2.3 and 2.4 that aim at identifying functions, components and understanding how to combine and consider them to provide an overall cooling capacity value for a specific GUI. For Section 2.5, we first built up an inventory of the 50 GUI presenting different combinations of the components –based on the findings of the previous sections-, and then we used EU and FAO datasets and field literature to determine the cooling capacity of a GUI in three different climatic regions: Atlantic region, Continental region and Mediterranean region. We classified climatic regions (adopting the classification scheme for climate regions by ETC/BD (2006) into three categories- namely, cool temperate moist (Atlantic), warm temperate moist (Continental), warm temperate dry (Mediterranean). The regions are defined by a set of rules based on: annual mean daily temperature, total annual precipitation, total annual potential evapotranspiration (PET), and elevation. Section 2.6 present the application of our approach to the city of Amsterdam.

2.1. Identification of ecosystem functions and components

Shading, evapotranspiration (ETA) and wind are the three ecosystem functions that determine the cooling capacity of GUI (Oke, 1988; Taha et al., 1991; Akbari et al., 1992; McPhearson, 1997; Bolund and Hunhammar, 1999; Dobbs et al., 2011; EEA, 2012; Smith et al., 2013; Gomez and Barton, 2013; McPhearson et al., 2013; Larondelle and Haase, 2013). More specifically, vegetation regulates the urban microclimate in three ways: (i) by intercepting incoming solar radiation (shading); (ii) through the process of evapotranspiration and (iii) by altering air movement and heat exchange. Shading and evapotranspiration contribute most to the cooling effect (Skelhorn et al., 2014). Additionally, considering the contribution of wind to cooling capacity assessments is particularly complex because it largely depends upon very local conditions that are not dependent on ecosystem functions and the components of GUI (e.g. presence of buildings, directions of streets, ...) which require analysis at micro-scale of the shape of the open space and buildings (Bowler et al., 2010). For these reasons, this