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Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure

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ABSTRACT

In order to develop climate resilient urban areas and reduce emissions, several opportunities exist starting from conscious planning and design of green (and blue) spaces in these landscapes. Green urban infrastructure has been regarded as beneficial, e.g. by balancing water flows, providing thermal comfort. This article explores the existing evidence on the contribution of green spaces to climate change mitigation and adaptation services. We suggest a framework of ecosystem services for systematizing the evidence on the provision of bio-physical benefits (e.g. CO_2 sequestration) as well as social and psychological benefits (e.g. improved health) that enable coping with (adaptation) or reducing the adverse effects (mitigation) of climate change. The multi-functional and multi-scale nature of green urban infrastructure complicates the categorization of services and benefits, since in reality the interactions between various benefits are manifold and appear on different scales. We will show the relevance of the benefits from green urban infrastructures on three spatial scales (i.e. city, neighborhood and site specific scales). We will further report on co-benefits and trade-offs between the various services indicating that a benefit could in turn be detrimental in relation to other functions. The manuscript identifies avenues for further research on the role of green urban infrastructure, in different types of cities, climates and social contexts. Our systematic understanding of the bio-physical and social processes defining various services allows targeting stressors that may hamper the provision of green urban infrastructure services in individual behavior as well as in wider planning and environmental management in urban areas.

1. Introduction

Urban areas are facing increasing challenges from climate change, for example, floods, droughts, heat waves and other threats to human comfort and environmental justice. In addressing ways to deal with these challenges, growing attention has been paid to the potential role of green and blue spaces, often approached with the concept of green (and blue) infrastructure (GUI). Green urban infrastructure can be interpreted as a hybrid infrastructure of green spaces and built systems, e.g. forests, wetlands, parks, green roofs and walls that together can contribute to ecosystem resilience and human benefits through ecosystem services (Naumann et al., 2010; Pauleit et al., 2011; European Environment Agency, 2012). Although GUI cannot fully replace natural areas, it is regarded as beneficial, e.g. as it can provide habitats for diverse biota and thereby help protect terrestrial and aquatic ecosystems (Ignatieva et al., 2011). However, a more integrated approach highlights the need for a holistic view of functions from nature conservation to social benefits, including

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benefits for coping with climate change, for citizens from regional to city (neighborhood) and site specific scales (Naumann et al., 2010; Niemelä et al., 2010; Pauleit et al., 2011).

Green urban infrastructure has been indicated as promising for reducing the adverse effects of climate change in urban areas, for example, by balancing water flows to alleviate flooding, providing thermal comfort by shading vegetation, and supporting coping capacities by providing people with opportunities to grow food for themselves (e.g. Krasny and Tidball, 2009; Cameron et al., 2012; Farrugia et al., 2013). Green urban infrastructure has also gained attention as a resource for mitigating climate change, e.g. its biomass can function as carbon storage (e.g. Davies et al., 2011). In scientific debates on climate change mitigation and adaptation, green urban infrastructure has often been described in terms of policy and governance (Naumann et al., 2010), but less holistically based on empirical evidence of benefits and trade-offs. The services and benefits of green urban infrastructure to climate change mitigation and adaptation have been studied (Gill et al., 2007; Lafortezza et al., 2009), and conceptual frameworks have been developed for addressing services and benefits in multi-scalar contexts (Faehnle et al., 2014; Scholes et al., 2013). Improved knowledge on the scales at which these services function and the benefits are delivered can link these processes to the appropriate level of decision-making, municipal or state authorities or individual level (Sternlieb et al., 2013; Wyborn and Pixler, 2013).

This review synthesizes empirical evidence on the contribution of green urban infrastructure to climate change mitigation and adaptation services and benefits. For this purpose, we propose a framework of ecosystem services and identify a set of green urban infrastructure services and benefits reported in the literature. We will address the production of the services, benefits, and potential co-benefits as well as elaborate on trade-offs at various spatial scales. The article concludes with identifying knowledge gaps worth exploring in future research.

2. Evidence on services and benefits provided by GUI

In order to draw together the empirical evidence on the contribution of green urban infrastructure from a climate change mitigation and adaptation perspective, we have developed a framework for the analysis of the benefits (Fig. 1). Ecosystem services can be defined as the contribution of ecosystems to human well-being, based on ecological phenomena (Fisher et al., 2009). Services are the production of benefits that are of value to the people (Chan et al., 2012). For example, carbon storage and sequestration (service) contributes to decreased CO_2 emissions (benefit), and regulation of climate (service) contributes to human thermal comfort, which can be a benefit (Fig. 1).

Several authors (James et al., 2009; Heidrich et al., 2013; Villarroel Walker et al., 2014) have highlighted the need for more integrated approaches to analyze the physical and social benefits of urban ecosystems and climate change mitigation and adaptation. Addressing this call, the empirical evidence on the role of green urban infrastructure in such a context is described (Fig. 1). Categorization of services and benefits is challenging because of the multi-scalar and multi-functional nature of green urban infrastructure and the multiplicity of interactions between the various phenomena. For example, thermal comfort and improved air quality (physical benefits) contribute to human health and quality of life (health and restorative benefits), but the latter also depend on many other issues. An aesthetically pleasant floodplain provides flood protection by regulating water flows (service), enables recreation (health and restorative benefit), but may also offer practical knowledge (educational benefit) for climate change adaptation. We will discuss a set of services and benefits that are reported in literature as essential for climate change mitigation and adaptation. This list is not exhaustive and others exist, e.g. food security benefits of urban agriculture are excluded. However, we categorize the key services and benefits that reflect the role of green urban infrastructure in the context of climate change mitigation and adaptation.

2.1. Physical benefits

2.1.1. CO_2 reduction

Green urban infrastructure contributes to climate change mitigation as it directly removes CO_2 from the atmosphere via photosynthetic uptake during the day and releases CO_2 at night via

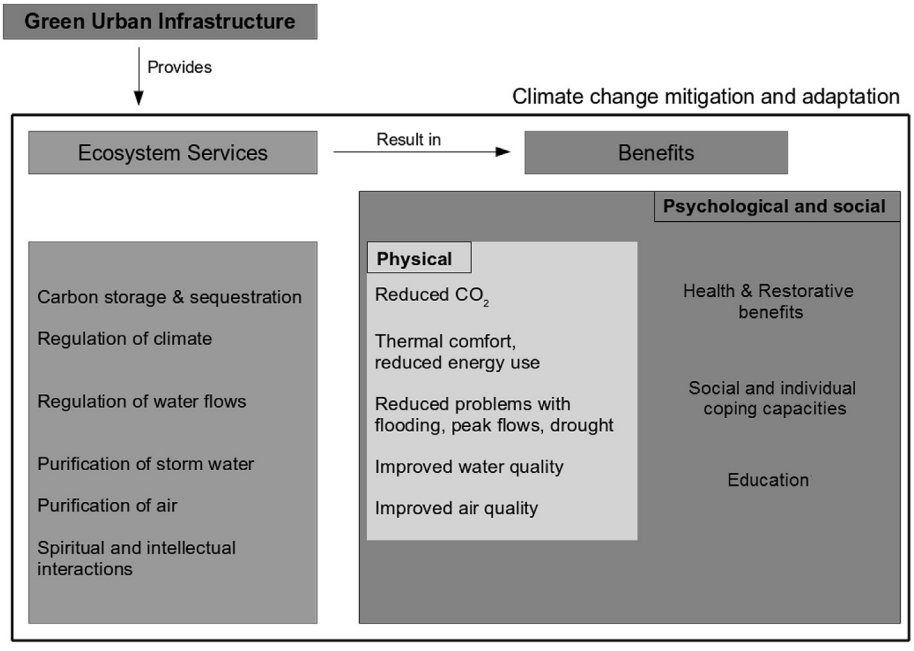

Fig. 1. Green urban infrastructure services and benefits within a climate change mitigation and adaptation framework.