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Review

Edible green infrastructure: An approach and review of provisioning ecosystem services and disservices in urban environments

Alessio Russo[a,*], Francisco J. Escobedo[b], Giuseppe T. Cirella[c,d], Stefan Zerbe[e]

[a] Laboratory of Urban and Landscape Design, School of Arts, Culture and Sports, Far Eastern Federal University, 690922 Vladivostok, Russia
[b] Functional and Ecosystem Ecology Unit, Biology Program, Facultad de Ciencias Naturales y Matemáticas, Universidad del Rosario, Kr 26 No 63B-48, Bogotá DC, Colombia
[c] Institute of Earth Sciences, Department of Regional Policy and Political Geography, Saint Petersburg State University, 199034 Saint Petersburg, Russia
[d] Polo Centre of Sustainability, Imperia, Italy
[e] Faculty of Science and Technology, Free University of Bozen-Bolzano, Piazza Università 5, 39100 Bolzano, Italy

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ABSTRACT

Recently published green infrastructure, nature-based solutions, and ecosystem disservices (ED) literature have focused primarily on the supply of urban *regulating* and *cultural* ecosystem services (ES). Other literature on urban and peri-urban agriculture has mostly studied the role of localized, intensive agricultural practices in providing food to inhabitants. The aim of this review is to raise awareness and stress the knowledge gap on the importance of urban *provisioning* ES, particularly when implementing an edible green infrastructure (EGI) approach as it can offer improved resilience and quality of life in cities. We compiled and systematically analyzed studies on urban ES and ED related to a number of EGI typologies. Our systematic review of the relevant literature via an EGI framework, identified more than 80 peer-reviewed publications that focused on ES and food production in urban areas. An EGI approach can contribute socially, economically, and environmentally to urban sustainability and food security. However, such benefits must be weighed against ED trade-offs, including: potential health risks caused by human exposure to heavy metals and organic chemical contaminants often present in urban surroundings. We conclude with recommendations and guidelines for incorporating EGI into urban planning and design, and discuss novel areas for future research.

1. Introduction

The world's population is rapidly increasing and will top 9.7 billion by 2050 (United Nations, 2015). By 2025, two thirds of the world's population will be concentrated in urban areas, increasing the importance of providing not only environmental quality and livable spaces but food security and resilient food systems (Haberman et al., 2014). This advanced rate of urbanization has coincided with global environmental degradation, increased consumption of natural resources, habitat loss, and overall ecosystem change (Daily, 1995; McDonald et al., 2013; McNeill, 2000). A cause-and-effect reproach from escalating global population brings to the forefront the need to re-examine how urban spaces are developed, used, and urban inhabitants fed (Ackerman et al., 2014). Recent research has focused on the use of *regulating* and *cultural* ecosystem services (ES) and ecosystem disservices (ED), green infrastructure (GI) and nature-based solutions (NBS) for improving upon environmental, social, and economic conditions in cities (Haase et al., 2014). This literature has rarely focused on systems integration for food cultivation and the benefits of *provisioning* ES in relation to urban areas (Cameron et al., 2012). Below, we expand upon the historical traditions of urban agriculture by examining rarely incorporated studies on GI, ES, and NBS (Lin et al., 2015; Lovell, 2010).

Our review provides background justification and scope into integrating commonly used GI, ES, ED, and urban agriculture concepts. We then explore the relevant literature to better characterize different types of edible green infrastructure (EGI) and their related ES and ED. We further our research by discussing recommendations for promoting the design, planning, and management of sustainable EGI. At present, GI and ES are promoted as concepts that have the potential to improve environmental planning in urban areas (Hansen and Pauleit, 2014). More recently, NBS is an approach that improves upon the livability and resilience of cities in retrospect to climate change. Although these concepts are apparently used interchangeably, below we refer to urban GI as hybrid infrastructure of green and built systems (e.g. urban forests, wetlands, parks, green roofs, and walls that together can contribute to ecosystem resilience) and human benefits through their

* Corresponding author.
E-mail addresses: alessio.landscape@gmail.com, russo.a@dvfu.ru (A. Russo).

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ecological processes or ES (Demuzere et al., 2014; Russo et al., 2016). These benefits or ES are also referred to as NBS when GI is incorporated into urban management, planning, design, and sociopolitical practices and policies for climate change mitigation and adaptation. Indeed, urban GI has been found to contribute positively to outdoor and indoor environments (Russo et al., 2016; Wang et al., 2014), while providing many relevant ES − including important health benefits (Coutts and Hahn, 2015). As such, GI delivers measurable ES and benefits that are fundamental to the concept of a sustainable city (Ahern et al., 2014).

Urban and peri-urban agriculture and forestry (UPAF), on the other hand have been studied and can be considered a set of experiences and practices for implementing the GI approach in and around cities (Eigenbrod and Gruda, 2015; Escobedo et al., 2011). UPAF systems focus on agro-forestry production and agro-ecological practices (e.g. production of vegetables, mushrooms, fruits, crops, aromatic and medicinal herbs, and ornamental plants) as well as the raising of animals (e.g. livestock and aquaculture) in and around urban areas (FAO, 2016). Whereas GI, as stated earlier, is closely related to ES and human wellbeing, with particular focus on *regulating*, *cultural*, and *supporting* services such as biodiversity and nature conservation (Breuste et al., 2015; Tzoulas et al., 2007). Very few studies have integrated UPAF as part of GI and ES frameworks (Coronel et al., 2015; Di Leo et al., 2016). To our knowledge, studies on UPAF have focused mostly on issues relating to livelihoods, poverty reduction, environmental pollution, health risks, and urban policy (Lwasa et al., 2014).

Studies have documented that urban soils often have increased levels of potentially toxic elements (PTEs) such as Zn, Pb, Zi, and Cu that are of primary concern in food production in cities, mostly due to their potential long-term effects to human and animal health (Lu et al., 2016). The balance between food supply and its demand correlates with sustainability and environmental health, while maintaining the factor of human health, fundamental to future challenges and long-term goals (Boye and Arcand, 2013). In this paper, we define EGI as a sustainable planned network of edible food components and structures within the urban ecosystem which are managed and designed to provide primarily *provisioning* – as opposed to highly studied urban "*cultural*" (e.g. recreation, increased property premiums, and aesthetics) and "*regulating*" (e.g. air and water pollution removal, temperature regulation, and flood regulation) – ES. To this end, EGI can include allotment gardens, rooftop gardening, edible landscaping, and urban forests. It can also include non-timber forest products in unmanaged and remnant peri-urban landscapes (McLain et al., 2014). The EGI concept does however emphasize UPAF practices that focus on sustainable techniques that yield food, while protecting the environment and its associating human communities. Note, the scope of this research does not include intensive urban-agricultural practices such as commercial farming, biomass feedstock, aquaculture, and livestock in urban areas (Eigenbrod and Gruda, 2015).

In developing this review, we found it necessary to examine facets of the urban landscape, specifically, food supply. For example, a city's footprint requires vast areas and transportation networks to deliver the necessary food products that urbanites have largely become depend upon, this includes: large amounts of food, complex and extended food delivery systems, and associated energy use often supplied great distances from the end consumer (Deelstra and Girardet, 2000). The results are emission of greenhouse gasses (Grewal and Grewal, 2012) and negative socioeconomic impacts. But, to our knowledge, few cities produce a sufficient supply of the food they consume, and thus depend largely on distant areas to meet demand (Eigenbrod and Gruda, 2015; Gerster-Bentaya, 2013). Low income urban dwellers are particularly vulnerable to adverse food price shocks, as they are largely net food buyers and depend mostly on accessible markets for their food supplies, thus, more localized agriculture supplies may play a substantial role in reducing urban poverty and food security issues (Zezza and Tasciotti, 2010). The aim is to raise awareness and specify a gap in the knowledge-base of urban *provisioning* ES, particularly when implemented using an EGI approach. Specifically, the objectives of this review are to: (1) identify different typologies of urban EGI, (2) synthesize findings on ES and ED of EGI from relevant literature, and (3) provide indicators and technical guidelines regarding the design, planning, and management of sustainable EGI.

As pointed out, most of the GI and ES literature has focused on *cultural* and *regulating* urban ES with only scant references to their food providing components and related co-benefits (i.e. *provisioning* ES) (Escobedo et al., 2011; Haase et al., 2014). Given the need for improved urban living spaces, food security, climate change mitigation, socio-economic equity, and sustainable resource use, we propose that the EGI approach can indeed provide both a lens and set of practices to address mismatches in ES provision, food security, poverty alleviation, and issues of inequality in urban areas.

2. Methodology

A systematic literature search was conducted using the following electronic journal databases: Science Direct, Web of Knowledge, Scopus, ProQuest, Sage, Directory of Open Access Journals, Google Scholar, and Google. We specifically searched for the following English language keywords including "urban agriculture benefits", "green roof + food", "urban + provisioning ecosystem services", "edible green wall", "urban forestry food production", "school gardens", "edible forest garden", "historic gardens", "edible botanic gardens", "food + botanic gardens", "edible community gardens", "allotment garden", "urban soil contaminants", "edible green walls", "ecosystem disservices + urban agriculture", and "botanic gardens ecosystem services". Once the literature was compiled, publications were systematically analyzed so as to identify those that presented specific findings on urban ES, NBS, and ED related to EGI, as previously defined, using strategic and critical reading methods (Matarese, 2013; Renear and Palmer, 2009).

From this original compilation of the literature we then identified and analyzed the identified literature and relevant information regarding different urban EGI components (e.g. green roofs, urban forest, and domestic gardens) which were then summarized and presented in the results and discussion sections. As part of the systematic review process, we also identified past and existing terminology related to GI and UPAF and we synthesize and updated it so as to provide a way forward with the EGI framework. In addition, we identified the related ES and ED indicators and metrics related to these EGI components. Overall, we identified more than 6700 articles, reviews, and grey literature in our initial literature review. To better focus our review, we filtered out articles published before 1989 and omitted articles on *cultural* ES or those that did not discuss the nexus between ES and food production in urban and peri-urban areas, leaving us with approximately 175 publications that included literature published in the form of books and technical reports.

Once these were filtered, we compiled and discussed findings and their implications for development of management and planning guidelines for city-based food production and policy uptake in different cities worldwide. We conclude with specific recommendations and guidelines for incorporating EGI into urban planning and design. Note that, in this review, all chemical element names are referenced by their element symbols.

3. Results

After initial filtering out of non-relevant publications, we identified approximately 80 peer-reviewed publications that were related to our definition of EGI. The geographical distribution of EGI-related studies varied according to different typologies. For example, approximately, 70% of the studies relating to ES of "edible urban forests and edible urban greening" were from the USA. Conversely, there was only one review paper on "edible forest gardens" in which one co-author was from an American institution while 50% of the studies were from peri-