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Supplying urban ecosystem services through multifunctional green infrastructure in the United States

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Abstract This paper summarizes a strategy for supplying ecosystem services in urban areas through a participatory planning process targeting multifunctional green infrastructure. We draw from the literature on landscape multifunctionality, which has primarily been applied to agricultural settings, and propose opportunities to develop urban green infrastructure that could contribute to the sustainable social and ecological health of the city. Thinking in terms of system resilience, strategies might focus on the potential for green infrastructure to allow for adaptation and even transformation in the face of future challenges such as climate change, food insecurity, and limited resources. Because planning for multiple functions can be difficult when many diverse stakeholders are involved, we explored decision support tools that could be applied to green infrastructure planning in the early stages, to engage the public and encourage action toward implementing a preferred solution. Several specific ecosystem services that could be relevant for evaluating current and future urban green spaces include: plant biodiversity, food production, microclimate control, soil infiltration, carbon sequestration, visual quality, recreation, and social capital. Integrating such ecosystem services into small-scale greening projects could allow for creativity and local empowerment that would inspire broader transformation of green infrastructure at the city level. Those cities committing to such an approach by supporting greening projects are likely to benefit in the long run through the value of ecosystem services for urban residents and the broader public.

Keywords Social–ecological systems · Resilience · Transformation · Multifunctionality · Green infrastructure

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Introduction

Urban ecosystems are becoming increasingly important as contributors to both the problems and potential solutions to the environmental issues we will face in the coming years. In particular, the loss of agricultural and 'natural' landscapes will place greater pressure on urban green spaces to provide the important ecological, production, and cultural functions that were available from rural areas in the past. Urban green spaces, for example, will have a critical role to play in conserving biodiversity, protecting water resources, improving microclimate, sequestering carbon, and even supplying a portion of the fresh food consumed by urban dwellers. At the same time, these spaces must continue to meet the traditional cultural needs of nearby residents by encouraging recreational activities, embodying the aesthetic preferences of the community, educating people about nature, and preserving historic landscape features. These various functions, which provide the 'ecosystem services' that benefit humans directly or indirectly, will need to be considered simultaneously and to be balanced to meet the needs and preferences of local residents as well as society as a whole.

We propose that the challenge to optimize functions of urban green space might be undertaken using a multifunctional landscape framework for sustainable planning of green infrastructure. While the multifunctional landscape approach is increasingly applied to agroecosystems, few examples exist for planning urban ecosystems. This approach offers several key benefits for designing and planning sustainable cities including: the incorporation of cultural functions that contribute to learning and public enjoyment of the environment (Carey et al. 2003); an embedded framework for evaluating the success of landscape plans (Lovell and Johnston 2009b); and an emphasis on land owners and users as primary stakeholders (Otte et al. 2007).

Despite growing evidence that society will benefit from ecosystem services and biodiversity provided by multifunctional green infrastructure, many cities struggle to find the resources and coordination capacity to implement comprehensive agendas across the city. We argue for a commitment to multifunctional green infrastructure that will pay off in the long run through the value of ecosystem services for urban residents and the broader public. This paper reviews the current state of relevant literature, describes decision support tools that could be applied to green infrastructure, and offers strategies for engaging the community in the planning process. Two key research concepts in landscape ecology highlighted by (Wu 2013a) are addressed—"landscape sustainability" and "ecosystem services in changing landscapes". The paper also covers topics of "integrating humans and their activities into landscape ecology" and "optimization of landscape pattern", as recommended by (Wu and Hobbs 2002). Definitions of relevant terms as they relate to this paper are provided in Table 1.

Background

Our proposal for the development of sustainable approaches for planning urban ecosystems draws from recent literature across several fields including urban ecology, sustainable landscape planning, resilience thinking, multifunctional landscapes, and green infrastructure. The synthesis of this material provides a framework for building healthy and sustainable social–ecological urban systems. Table 1 provides definitions for key terms that form the basis of this synthesis.

Landscape ecology in urban ecosystems

With rapidly expanding urbanization, cities have become an important frontier for ecosystem science.

Table 1 Definitions of key terms as they are used in this paper

Term	Definition
Landscape sustainability	Capacity of the landscape to consistently provide long-term, landscape-specific ecosystem services essential for maintaining and improving human well-being (Wu 2013b)
Ecosystem services	Benefits humans derive from ecosystems (Millennium Ecosystem Assessment 2005)
Landscape services	Benefits humans derive from the landscape, worked out as a structure–function-value chain to inform landscape development (Termorshuizen and Opdam 2009)
Multifunctional landscape	Landscapes that provide a range of beneficial functions across production, ecological, and cultural dimensions, considering the needs and preferences of the owners and users (Otte et al. 2007; Lovell et al. 2010)
Urban green space	An undeveloped piece of land located within the context of a city and open to the public
Green infrastructure	A strategically planned and managed network of natural lands, working landscapes, and open spaces that provide a range of diverse benefits (www.conservationfund.org)
Community greening	Community-based efforts to transform underutilized sites into valuable green spaces such as community gardens (Tidball and Krasny 2009)

Urban ecosystems are complex, heterogeneous, and dynamic systems requiring a landscape ecology perspective (Breuste et al. 2008) for investigating the interrelationship between spatial structure of the landscape and ecological functions or processes (Forman and Godron 1986). The study of the pattern of landscape mosaics and their component parts (patches, corridors, and matrix) is useful for understanding the future health of these highly managed ecosystems (Leitao and Ahern 2002; Forman 2008). In cities, the landscape mosaic consists of "built" matrix containing corridors and patches that are small and fragmented, often existing as parks, cemeteries, schoolyards, and residential yards, as well as vacant lots and other interstitial spaces (Goddard et al. 2010). Even the habitat patches and green spaces of cities are often highly managed systems, heavily influenced by human activity, where ecological functions are often highly interconnected with cultural functions. Urban ecology is an emerging field that seeks to study this complex structure and function of urban ecosystems, recognizing the important interactions of human and natural processes (Breuste et al. 2008). Urban ecology is expected to become increasingly important in future years, as urbanization contributes to global environmental change in a number of significant ways: changing land use and land cover to more impervious surface, contributing to climate change through greenhouse gas (GHG) emissions, modifying hydrologic systems to more "engineered" systems, reducing biodiversity for many biotic communities, and altering biogeochemical cycles including nutrients and metals (Grimm et al. 2008).

Until recently, ecological sciences have focused on cities as the source of environmental problems, at odds and competing with so-called natural areas. In most cases, cities draw in valuable resources (e.g. food, fuel, water) and export the undesirable waste products including greenhouse gases. While this situation may be true in a broad accounting of resources, opportunities exist to find solutions that would close some of these loops at a smaller scale. Highlighting the role of urban ecology, Grimm et al. (2008) summarize the idea well:

> "Cities are concentrated centers of production, consumption, and waste disposal that drive land change and a host of global environmental problems…Thus, our hope is that cities also concentrate the industry and creativity that have resided in urban centers throughout much of human history, making them hot spots for solutions as well as problems. Urban ecology has a pivotal role to play in finding those solutions and navigating a sustainable urban future."

Sustainable landscape planning

The concept of sustainability is increasingly discussed in the context of landscape ecology, for the potential to address the complex relationships and the fragile balance between humans and their environment. Cities might be viewed as a possible sustainable solution for the growing global population, because of the efficiencies created when dense populations are accommodated on a relatively small land area. They are the most cost-effective solution for providing transportation, potable water, sanitation services, electricity, and other social services (Wu 2013b). Creating more sustainable cities, however, remains a daunting challenge as we seek to identify strategies for measuring success and appropriate metrics to serve as sustainability indicators. Furthermore, because of the interconnections between cities and the surrounding landscape near and far, sustainable solutions will require the consideration of the ecology of the landscape even beyond the political boundaries of the city (Wu 2010). In fact, urban sustainability is considered essential to the health of the greater landscape and the planet as a whole (Wu 2013b).

Landscape designers have an important role to play in delivering these sustainable solutions, by connecting science to practice and ultimately to policy (Nassauer and Opdam 2008; Swaffield 2013). Challenges arise, however, as scientists, policy-makers, designers, landowners, and other stakeholders struggle to communicate effectively and find a scale appropriate to take action (Ahern 2013; Dramstad and Fjellstad 2013). To deal with this problem, better methods are needed for visualizing, communicating, and comparing different sustainable design alternatives with land owners and managers (Dramstad and Fjellstad 2013). Social sustainability is particularly important to the long-term success of designed landscapes. The human connection to the landscape will be strengthened by efforts to: (1) integrate diverse public preferences,

(2) educate people on sustainability through nature interactions, (3) recognize the importance of the people's intimate and personal connections to the landscape, and (4) improve human health and well-being (Selman 2008). Thinking of a city as an "ecosystem" with humans as one component, as promoted by Ann Whiston Spirn in the seminal book, *The Granite Garden: Urban Nature and Human Design*, offers a basis for urban planning that addresses the complex interactions between societal needs and environmental health (Spirn 1984).

Cities as social–ecological systems

The ecosystem concept continues to evolve as it relates to the urban context. Recent literature focusing on resilience and transformability could be particularly relevant for planning cities to be more sustainable, with increased core biological and social diversity providing the buffering capacity necessary to withstand a shock to the urban ecosystem, and even to move beyond the disturbance into a more desirable future state (Folke 2006). Social–ecological resilience has been defined as "the capacity of a social–ecological system (SES) to continually change and adapt yet remain within critical thresholds" (Folke et al. 2010). A resilient system is one that can persist following disturbance (Holling 1973), while a vulnerable system could suffer dramatic negative consequences under the same perturbation (Folke 2006). The original work in resilience emphasized the *adaptability* of a system, or "the capacity to adjust responses to changing external drivers and internal processes and thereby allow for development along the current trajectory" (Folke et al. 2010). Recently, however, there has been a shift to consider opportunities for positive change that may not exist along the "current trajectory". The term *transformability* is being used to describe this "capacity to cross thresholds into new development trajectories" (Folke et al. 2010). This type of thinking could have important implications for planning sustainable cities. Instead of viewing disturbances (e.g. flooding, climate change, economic crises) as tests of the resilience of a system, they could actually be considered as opportunities to realign resources and organizational structures by drawing from the innovation and knowledge concentrated in the impacted area. *For disinvested inner city neighborhoods in particular, the transformation of the existing SES may be a more desirable goal than the conservation of the current developmental trajectory.*

Tidball and Krasny (2009) propose that urban community greening in particular can play an important role in resilience by supporting self-organization and creating constructive positive feedback loops. Self-organization creates a situation in which local residents are empowered to manage their own resources. Positive feedback loops occur as communities acquire new knowledge and skills to improve their environment and optimize ecosystem services, leading to adaptive learning. The collective management of these 'urban commons' can promote diverse learning streams and environmental stewardship (Colding and Barthel 2013). Urban community greening might actually serve as a community-based tool to promote resilience through innovation, adaptive management, and social learning. Examples include community forestry projects, community gardens and farms, and living memorial gardens that all require active participation and investment by local residents in the initiation of projects and the planning and maintenance of the spaces (unlike a city's formal parks). Ecologically, these landscapes support a high degree of biological diversity and spatial heterogeneity with many small, distributed patches (Tidball and Krasny 2009). Socially, they support human diversity, by engaging community members from a variety of cultural and ethnic backgrounds (Colding and Barthel 2013). They further support the retention and transmission of ecological knowledge and practices among community members, strengthening the resilience of the system (Barthel et al. 2010). In the case of many community or allotment gardens, the spaces even have a productive component that could contribute to food security and agricultural knowledge. As a place-based approach, community greening can ultimately serve as a platform for organizing residents for action and learning that could improve their capacity to transform and improve under conditions of uncertainty and change within their own communities (Tidball and Krasny 2009; Krasny and Tidball 2012).

Community greening projects also can lead to social and ecological transformation at higher levels, with implications for the equitable distribution of resources, including ecosystem services. Community gardens, for example, can serve as sites for political mobilization and resistance to marginalization and neighborhood disinvestment, where disadvantaged groups resist dominant paradigms of land use planning, urban development, and urban design at the city level (Baker 2004). Community-initiated green infrastructure projects such as community gardens and farms may empower local residents, help to build community capacity, and begin to repair the social fabric in disinvested neighborhoods in cities such as Detroit (White 2011). They are not, however, a substitute for a comprehensive economic revitalization plan for these neighborhoods. Instead, they can complement such initiatives.

Landscape multifunctionality

Landscape multifunctionality can serve as a framework for the co-transformation of the social and ecological dimensions of the system in ways that benefit humans—including disadvantaged social groups—and the environment. Ecosystem multifunctionality has long been recognized as a condition for sustainability in unmanaged systems (De Groot 2006), and recently the interest in multifunctional landscapes has expanded to intensively-managed ecosystems (Brandt and Vejre 2004; Zander et al. 2007). Managed ecosystems, like natural systems, can provide important functions that represent "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (De Groot 1992). Selman (2008, 2009) emphasizes the importance of multifunctionality as a fundamental property of sustainable development, particularly as we see a blurring of the urban–rural dichotomy. When applied to a landscape, the concept of multifunctionality is more tangible than "sustainability", although the goals for ecosystem health often overlap between the two frameworks. Landscape multifunctionality consists of three key dimensions – cultural, ecological, and production functions. Cultural functions, which represent the social realm of sustainability, include recreation, visual quality, cultural heritage, education, and other benefits directly experienced by humans. Ecological functions represent the environmental realm of sustainability and include climate regulation, carbon sequestration, water infiltration, biodiversity conservation, nutrient cycling, and other benefits for environmental health. Production functions are related to the economic realm of sustainability, as these functions typically have some market value through their agricultural products including food, animal feed, fiber, biofuel, and medicinal resources. The performance of a multifunctional landscape improves as different functions are supported through a diverse set of landscape features; the stacking of functions across the three dimensions allows for a wide range of successful solutions (Lovell and Johnston 2009b; Lovell et al. 2010) (Fig. 1).

The concept of multifunctionality is distinguished by four primary characteristics: (1) the functions interact beyond just shared location, (2) the interactivity is positive and synergistic, (3) the landscape can provide products and services beyond cultural associations, and (4) rural and urban regions are considered together as a continuous matrix (Selman 2009). By merging the traditional rural–urban divide, the concept of multifunctionality is particularly germane to planning for urban ecosystems. The multifunctional landscape approach could in fact contribute to the development of urban ecosystems in several important ways. First, by respecting and supporting the cultural functions offered by landscapes, humans are valued as an integral part of the ecosystem. Secondly, the approach encourages the incorporation of new functions often not considered for urban ecosystems, such as food production and agrobiodiversity (Lovell 2010). A third advantage of landscape multifunctionality is the development of a framework for evaluating landscape designs—those from the past, in the present, or for the future—based on specific goals or targets for improving landscape performance (Lovell and Johnston 2009b). One of the most significant contributions of the landscape multifunctionality approach is the emphasis on the land owner and users as primary stakeholders, suggesting the need to strongly consider

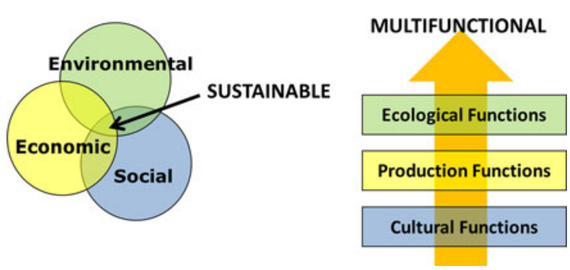


Fig. 1 Comparison of the concept of sustainable with that of multifunctional. Sustainable is often represented by the overlapping of environmental, economic, and social pillars, whereas multifunctionality can be envisioned as the stacking of ecological, production, and cultural functions to achieve greater overall performance

their preferences and desires in planning (Otte et al. 2007). This aspect is particularly important (but also complicated) in urban ecosystems, where green spaces are highly managed, humans live in close proximity to one another, and the "land owner" may be the city government expected to represent the interests of the broader public.

Finally, and particularly relevant for the discussion here, the development of multifunctional landscapes can serve as an adaptive strategy to address unknown future conditions including climate change, water scarcity, food insecurity, and limited economic resources. These conditions are expected to heavily impact urban environments, and certain vulnerable populations will be at extremely high risk of negative consequences to their health and well-being (Shonkoff et al. 2011; Lissner et al. 2012). Ecosystems could be made more resilient to the disturbances associated with these conditions if greater complexity and biodiversity were built into the system through a multifunctional landscape approach (Fischer et al. 2006; Folke et al. 2010). With respect to climate change, multifunctional landscapes play a role both in adapting to new environmental conditions and in mitigating the problem. Adaptations include reducing flooding, intercepting and storing rainfall, absorbing solar radiation, and cooling urban microclimates (Mell 2009). Multifunctional landscapes can contribute to mitigation by sequestering carbon in above- and below-ground vegetation, reducing energy required for cooling, and reducing vehicle emissions by supporting alternative transportation such as bike paths (Landscape Institute 2009). In urban areas, multifunctional landscape design strategies should be adjusted to allow for continued function and ecosystem services provision under changing conditions (O'Farrell and Anderson 2010), while also incorporating strategies to reduce greenhouse gases.

Green infrastructure

For a city, the multifunctional landscape approach might best be applied through "green infrastructure" planning. Green infrastructure can be defined as a network of green spaces planned and managed as an integrated system to provide synergistic benefits through multifunctionality (Landscape Institute 2009). The concept is typically used in reference to the "planned" open space existing on public land including parks, forest preserves, greenways, alleyways, and roadside right-of-way zones. Mell (2009) suggests that green infrastructure can promote urban sustainability by providing flexible development options that can be retrofitted into the existing fabric of the city, including those interstitial spaces that have little value otherwise. This strategy, however, would require a transition toward policies that promote a holistic approach to urban planning that would recognize and connect multiple social-ecological systems (SESs) (Mell 2009). Principles from urban ecology, sustainable development, and landscape multifunctionality could guide this holistic development of green infrastructure, to create spaces that promote connectivity, accessibility, physical activity, learning, social cohesion, and other desirable functions (Mell 2009).

Green infrastructure programs, however, have been criticized for a narrow focus on storm water management that ignores opportunities for multifunctionality (Newell et al. 2013), for limited success in institutionalization (Young and McPherson 2013), and for neglecting private spaces and their owners or managers for expanding open space benefits (Young and McPherson 2013). We propose the concept of green infrastructure should be expanded to include unplanned open space in both the public and private realms, considering a wide variety of ecosystem services beyond storm water management, and drawing on input from diverse stakeholder groups. The domestic garden, for example, has been found to play an important role in the provision of ecosystem services in a city (Cameron et al. 2012). Vacant lots have also been proposed as a contributor to green infrastructure that could improve the health of the city—encouraging new markets for fresh food, supporting social interaction, and improving human health through physical activity and access to healthy food (Schilling and Logan 2008). While food production on vacant lots will not replace the businesses and industries that were once a foundation of now disinvested neighborhoods, Folke et al. (2010) suggest that such small scale efforts can enable resilience or lead to transformation at a larger scale, with isolated projects inspiring broader efforts that diffuse through the city. Consequently, a focus on small, manageable systems may be the most productive approach to navigating transitions (Folke et al. 2010). A city-wide effort to support small-scale transformation would require coordinated planning goals and policies, capital to rehabilitate underutilized spaces, and community empowerment to envision creative and unique landscape designs that meet local needs.

Planning for multiple functions

Implementing a strong multifunctional green infrastructure plan requires a multi-scale approach. At the scale of the whole city, urban planning can play a key role in establishing strategies to conserve existing habitats, develop new green spaces, and connect isolated fragments (Lovell and Johnston 2009a). Urban ecologists recommend planning cities to enhance heterogeneity and ecological functions, while maintaining and restoring remnant ecological processes that support ecosystem services (Cadenasso and Pickett 2008). Landscape heterogeneity (diversity of habitats) has been proposed as one of the most promising metrics for assessing landscape quality across human and natural systems, for predicting biodiversity (Jorgensen and Gobster 2010), for increasing ecosystem function and resilience (Fischer et al. 2006), and for improving visual quality (Dramstad et al. 2001) and landscape preference (Poudyal et al. 2009). At the scale of individual sites such as urban parks, landscapes can be designed to support specific ecosystem services that benefit the local community, fully integrating social sciences and ecology (Breuste et al. 2008; Lovell and Johnston 2009b). Urban patches, even those as small as individual residential yards, can also contribute to biological diversity in the city by supporting native vegetation and species richness (Werner 2011). Despite the growing evidence that society will benefit from ecosystem services and biodiversity provided by multifunctional green infrastructure, we often lack the empirical data, tools, and guiding principles to design these landscapes to perform well across a range of different functions. We know, for example, very little about the ecology of a feature as ubiquitous as the urban backyard (Cook et al. 2012).

Decision support tools

A number of resources are available to support decision-making related to green infrastructure development. The Sustainable Sites Initiative (SITES) is a useful source of materials and tools for sustainable development and management of individual open spaces of varying scales (http://www.sustainablesites.org/). Online resources include descriptions of ecosystem services impacted by site design and management, a collection of pilot projects, and a handbook of "Guidelines and Performance Benchmarks". The handbook includes a rating system of credits earned for sustainable practices, which could be used to compare sites or alternative designs for a single site. A wide range of other tools have been developed or adapted for landscape design and urban planning at various scales, including Life Cycle Assessment (LCA), the Multifunctional Landscape Assessment Tool (MLAT), and the Urban Forest Effects Model (UFORE), each of which serves a different purpose but could contribute to the early stages of green infrastructure planning.

LCA may be used to evaluate or compare the environmental impacts (e.g. energy and material inputs and outputs) of distinct green spaces. LCA seeks to account for a broad range of categories such as water, energy use, greenhouse effect, toxicity, resource extraction, and land use based on international standards (ISO 14040 and 14044). A more focused LCA—the Carbon Footprint calculation—targets only CO_2 and other greenhouse gas emissions, facilitating the evaluation of something as complex as a landscape (Cucek et al. 2012). The approach can be used to compare landscape design and management alternatives, weighing the implications of diverse activities such as tree planting or removal, fertilizer use, and irrigation (Smith et al. 2012; Ingram 2013). Carbon Footprint analysis, for example, has been applied to urban agriculture in an effort to compare GHG emissions from a local farm versus a commodity food production system, considering a variety of fresh market crops (Kulak et al. 2012). Examples of more refined tools developed for landscape design and management include the Farm Carbon Assessment Tool (FCAT) (http://www.soilassociation.org/lowcarbon) for improving farming practices and the Climate Leadership in Parks (CLIP) Tool (http://www.nps.gov/climatefriendlyparks/CLIPtool/index.html) for inventorying greenhouse gas emissions in U.S. National Parks based on activities such as purchased electricity, landfill waste, fertilizer application, forest management, and oil and natural gas activities. One weakness of LCA and particularly Carbon Footprint assessment is a lack of consideration of cultural values and social justice issues, although some attempts have been made to include these dimensions as part of the broader LCA in an effort to better align with sustainability goals (Cucek et al. 2012).

Another tool appropriate for the assessment and planning of green infrastructure is the MLAT originally developed by Lovell et al. (2010) to evaluate the design of agroecosystems. The tool is intended to help landowners and planners make informed decisions about land use that take into consideration the multifunctionality of the current system and the potential future functions. The inputs include the area of each habitat type, its functional attributes, and ratings of each attribute based on user perception and expert assessment depending on the site-specific context. Figure 2 shows an example of how the MLAT could be applied to a small urban neighborhood park. The accuracy of the results can be extended by providing empirical data beyond subjective ratings, to quantify the benefits (ecosystem services) of each green space to indicate overall performance. In addition, a weighting of the relative value of different ecosystem services can be incorporated based on input from landowners, nearby residents, and experts (Lovell 2010). The MLAT is limited in its ability to capture multiple spatial and temporal scales simultaneously; however, multiple "runs" of the assessment could demonstrate differences in time and space dimensions.

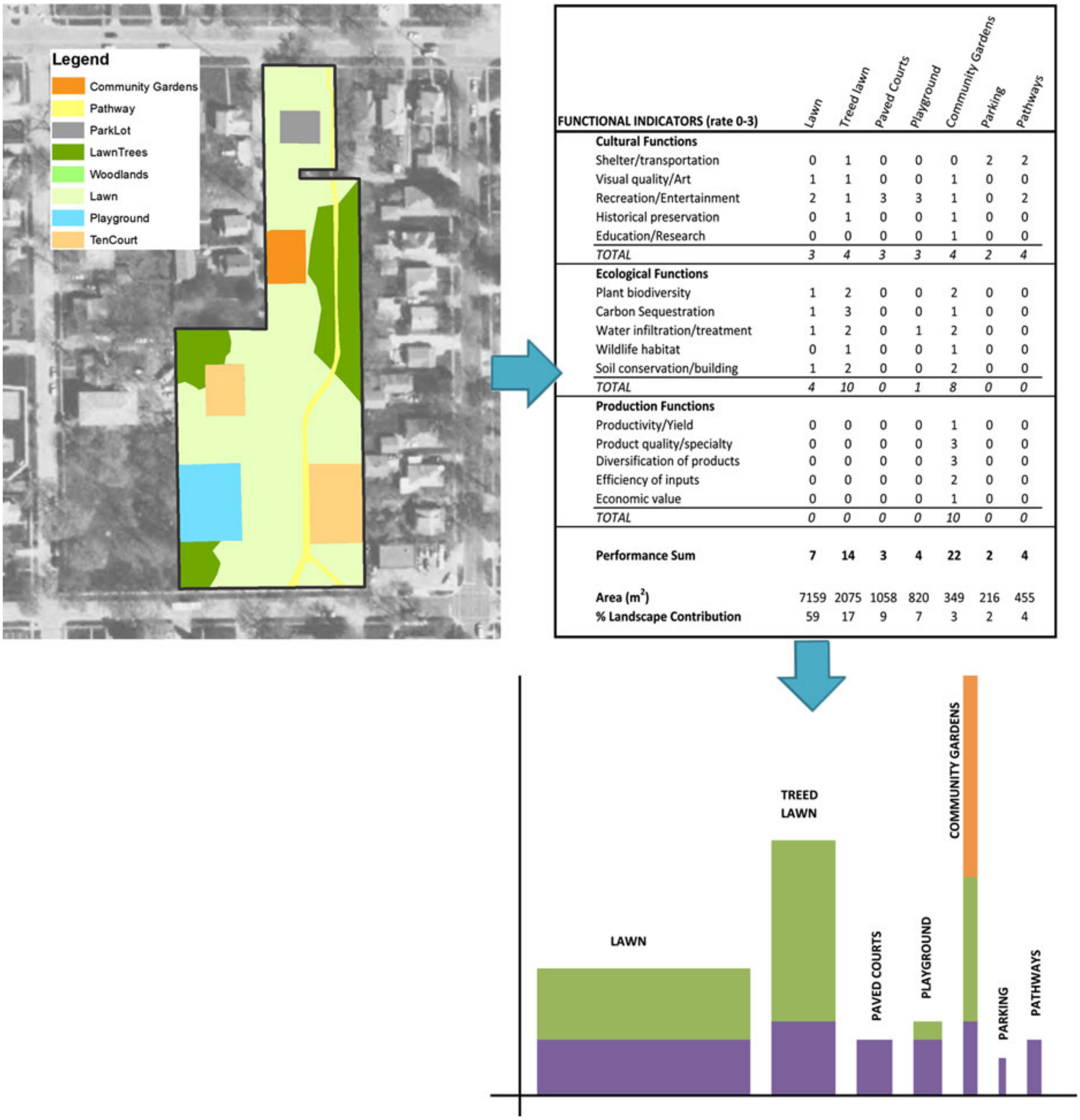
Determining the appropriate ecosystem services to include in the MLAT or other planning tools is critical to quality of the output. In Table 2, we identify and describe a broad set of services that have been recognized in recent years as providing value in urban areas around the globe. These ecosystem services were also selected for the relative simplicity of measurement at a raw level, as a good starting point for considering multiple functions simultaneously. Urbanization has been shown to impact these services, so the context of the urban setting is particularly important. Local experts and stakeholders, however, should be involved in determining the specific ecosystem services to target, as well as their relative importance (weighting) based on the local context of the ecosystem. Such a place-based approach "provides the context in which the problems can be recognized and articulated, and within which different values can be understood, conflicts resolved and choices made" (Potschin and Haines-Young 2013).

At a larger scale, the UFORE can assist in green space planning, specifically for urban forests (http://www.nrs.fs.fed.us/tools/ufore/). This freely available software was developed to assess forest structure and functions, and the tool can be used to plan tree establishment to support desired functions. The assessment of urban forest structure is conducted through aerial and ground-based (random sampling) measurements to determine area of tree cover, number of trees, species composition, tree biomass, and other relevant factors (Nowak et al. 2008). Participatory approaches involving non-professional citizens in the inventory process may be used to supplement sampling by providing data on tree structure from photogrammetric measurement (Abd-Elrahman et al. 2010). From the assessment data, UFORE can calculate functions provided by local urban forests, such as air pollution removal, carbon sequestration, volatile organic compounds (VOC) emissions, and energy conservation for nearby buildings (Nowak et al. 2008). One limitation is that the tool is designed for woody plant cover, so it does not account for other types of vegetation and cover. This tool also focuses heavily on ecological functions, mostly neglecting cultural and production functions.

All of these tools have the potential to contribute to the planning of multifunctional green infrastructure, particularly in the early stages. No single tool used in isolation, however, will provide the level of sophistication required for large-scale urban planning. Therefore, using a combination of tools that are based on a common theoretical framework is likely to be the best strategy (Gil and Duarte 2012), connected with an iterative process involving input and response from the community (see next section). Later stages of the planning process will require more advanced tools for modeling and testing potential investment or policy choices, by forecasting land use changes and impacts on ecosystem services (Deal and Pallathucheril 2009).

Engaging the community in a participatory planning process

Planning for multifunctional green infrastructure must engage the community—including diverse groups—if the outcomes are to be socially sustainable. Historically, the urban landscape, including urban green spaces such as Central Park in New York City (Gandy 2003), has been shaped and re-shaped by geometries of power favoring the political and economic interests of privileged groups, the reproduction of capitalist relations of production, and the accumulation of



FUNCTIONAL INDICATORS (rate 0-3)	Lawn	Treed lawn	Paved Courts	Playground	Community Gardens	Parking	Pathways
Cultural Functions							
Shelter/transportation	0	1	0	0	0	2	2
Visual quality/Art	1	1	0	0	1	0	0
Recreation/Entertainment	2	1	3	3	1	0	2
Historical preservation	0	1	0	0	1	0	0
Education/Research	0	0	0	0	1	0	0
TOTAL	*3*	*4*	*3*	*3*	*4*	*2*	*4*
Ecological Functions							
Plant biodiversity	1	2	0	0	2	0	0
Carbon Sequestration	1	3	0	0	1	0	0
Water infiltration/treatment	1	2	0	1	2	0	0
Wildlife habitat	0	1	0	0	1	0	0
Soil conservation/building	1	2	0	0	2	0	0
TOTAL	*4*	*10*	*0*	*1*	*8*	*0*	*0*
Production Functions							
Productivity/Yield	0	0	0	0	1	0	0
Product quality/specialty	0	0	0	0	3	0	0
Diversification of products	0	0	0	0	3	0	0
Efficiency of inputs	0	0	0	0	2	0	0
Economic value	0	0	0	0	1	0	0
TOTAL	*0*	*0*	*0*	*0*	*10*	*0*	*0*
Performance Sum	**7**	**14**	**3**	**4**	**22**	**2**	**4**
Area (m^2)	7159	2075	1058	820	349	216	455
% Landscape Contribution	59	17	9	7	3	2	4

Fig. 2 Multifunctional Landscape Assessment Tool (MLAT) applied to a neighborhood park including: (*a*) the map of landscape features in GIS; (*b*) the worksheet for rating different functional indicators for each landscape feature; and (*c*) the output displaying multifunctionality of the park with *bar width* proportionate to spatial extent of each landscape feature and *bar height* indicating the performance across cultural (*purple*), ecological (*green*), and production (*orange*) dimensions. (Color figure online)

private capital (Keil and Graham 1998; Gandy 2003; Hagerman 2007). The uneven development of the urban environment has been the focus of different strains of critical urban theory, particularly urban political ecology, which seek to excavate the historically contingent and politically mediated processes of urban environmental change and to identify "alternative, radically emancipatory forms of urbanism that are latent, yet systemically suppressed, within contemporary cities" (Brenner 2009).

An emerging literature critiques contemporary urban green infrastructure projects as reinforcing the

Table 2 Urban ecosystem services and their measurement strategies as they might be applied in evaluating the performance of a green space

Ecosystem Service	Metric	Methodology
Plant Biodiversity	*Species Richness* or total number of taxa; *Plant Diversity* or *Evenness* indices—account for abundance of species (e.g. Shannon Diversity Index)	Along a transect or random sampling plots (often with subplots for herbaceous plants), determine presence and abundance of taxa and characterize native and invasive species (Boutin et al. 2002; Barrico et al. 2012).
Production	*Yields* of individual crops per area; *Market value* of yield	Harvest, weigh or count units, and record yields. Calculate value based on market prices (Vitiello and Nairn 2009).
Microclimate control	*Air temperature*, *solar radiation*, *relative humidity*, and *wind velocity*	Gather data from weather stations located in different zones of land use to compare conditions continuously throughout year (Mahmoud 2011).
Soil Infiltration	*Infiltration capacity* and *soil compaction*	Estimate relative infiltration rates using an infiltrometer. Compaction estimates based on readings from cone penetrometer (Gregory et al. 2006).
Carbon sequestration	Above ground *biomass* and *carbon balance* including emissions from maintenance and decomposition	For biomass, sample trees and measure diameter at breast height (DBH). For carbon balance, calculate emissions from site practices based on fuel used by equipment and estimate vegetation carbon based on type, life span, growth at maturity (Nowak 2002; Townsend-Small and Czimczik 2010).
Visual Quality	*Preference ratings* for different scenes	Traditional approach uses photo-questionnaires with visual simulations of settings with varying qualities (Kaplan and Kaplan 1989). New approaches allow modeling of virtual landscapes (Tyrvainen et al. 2006).
Physical Activity	*Activity level* with self-reporting of type, intensity and duration; estimate *metabolic equivalent of task* (MET) based on observation of activities	For self-reporting, conduct surveys of green space users or local residents. For estimating MET units, activities are documented through observation (Cohen et al. 2011) or tracking (Fjortoft and Sageie 2000) and activity level determined from averages in the Compendium of Physical Activities (https://sites.google.com/site/compendiumofphysicalactivities/).
Social Capital	*Social networks* from self-reported ratings; *Social interactions* through observation	Survey residents/visitors for self-reported social activities and networks (Fan et al. 2011). Ethnographic observation of interactions between individuals (Bagley and Hillyard 2011).

political and economic interests of urban elites and the state, which are often one and the same. Pudup (2008), for example, argues that contemporary community gardens should generally be construed not as sites of community resistance to marginalization, but as garden projects organized by "non-state and quasi-state actors who deliberately organize gardens to achieve a desired transformation of individuals in place of collective resistance and/or mobilization" (Pudup 2008). Gardening as a form of social control and assimilation, however, has a long history, from its promotion among the working classes as a form of labor discipline in Victorian England (Gaskell 1980), to the incorporation of school and community gardening into programs of assimilation for African American, Native American, and immigrant communities in the United States in the nineteenth and twentieth centuries (Lawson 2005).

At larger scales, contemporary green infrastructure projects, such as the greenways and restored waterfronts associated with urban redevelopment, have been characterized as token green interventions into the fabric of the postindustrial city. Nature is repackaged and symbolically re-inserted into the city as part of the discursive and material construction of the "sustainable" or "liveable" city. These interventions erase or rework the city's industrial past (and associated working class populations) and construct landscapes of consumption in the place of spaces of production. Politically, they divert public attention away from the expenditure of public monies to promote private development and from the negative consequences of urban "renewal," such as the displacement of marginalized populations from redeveloped land (Hagerman 2007). Working class natures, even those that support the green infrastructure goals of public agencies, such as squat gardens and farms on vacant land, may be displaced by middle class natures perceived to be more legitimate by urban planners (Domene and Sauri 2007).

In a truly democratic participatory process for urban green infrastructure planning, all participants—including ecologists, planners, designers, and users—must be cognizant of and acknowledge existing geometries of power, the potential mobilization of "green" planning discourse in the service of urban elites, and the vulnerability of the process to the uneven distribution of power. In this context, the decision support tools described earlier have the potential to empower marginalized groups and local communities in the production of urban environments that embody their ideals, values, and aspirations. Ideally, local green infrastructure projects are initiated by community members, and participatory planning is used to identify and represent the interests of individuals and groups often neglected in the planning process (Tress and Tress 2003), leading to socially just alternatives (Tippett 2004). Engaging the community in planning and design encourages commitment from citizens, increases satisfaction with results, builds trust, and creates more realistic outcomes, while also allowing ecologists, planners, and designers access to community expertise and local knowledge and community members access to professional expertise (Al-Kodmany 1999; McCall and Minang 2005). A bottom-up approach, in which communities initiate (and are encouraged to initiate) projects, helps to ensure that planning "solutions" are not imposed from above. Community involvement in the planning process from problem identification through landscape design and management can further result in more successful and durable green interventions in the urban landscape. At the same time, the development of a broad, city-level framework for green infrastructure planning (also using a participatory process) will help to ensure that projects at the neighborhood scale contribute to an integrated city-scale system with synergistic benefits.

Various approaches have been developed to help support community engagement. Planners may facilitate the development of community-initiated projects through initial outreach and community networking activities followed by design workshops in which planners, design professionals, and other "experts" help stakeholders realize their visions for their community (Semenza et al. 2007) or discover new visions. Alternative future scenarios can be developed based on expert analysis and/or community input and used to represent plausible landscape futures and associated implications resulting from different drivers of change, such as new land use policies (Steinitz et al. 2003; Tress and Tress 2003; Shearer 2005). These scenarios are used to inspire and inform decision-makers of the opportunities and impacts of different alternatives through spatially specific models (Santelmann et al. 2004). Visualization techniques including photorealistic designs (Tress and Tress 2003; Nassauer and Corry 2004) and 3-D models (Lewis and Sheppard 2006) have been used effectively in combination with scenario descriptions to communicate proposed landscape changes to stakeholders and to solicit input on alternative landscape scenarios (Tress and Tress 2003).

Although many studies show positive benefits of participatory approaches to urban planning, special care must be taken to offer a transparent and truly participatory democratic process that includes input from less powerful neighborhoods and residents, as the participatory planning process has been criticized in some cases for supporting elite views and reinforcing relations of power. Advocacy groups promoting specific urban planning goals may be composed primarily of members of privileged social groups with the time, resources, and vocabulary to articulate their ideas to decision-makers (Carr 2012). Engaging underrepresented populations in participatory planning can be difficult. Traditional, passive strategies for engaging the general public, such as posting notices of public planning meetings—even in the native languages of underrepresented stakeholder groups—are insufficient. Language barriers, apathy, a lack of familiarity with government institutions (particularly the public planning process), prior negative interactions with such institutions, and a lack of time to attend public meetings can all be barriers to participation for members of disadvantaged or minority communities (Howard et al. 1994; King et al. 1998; Oshun et al. 2011). Planners must actively engage stakeholders through innovative strategies such as the use of planning outreach liaisons to ensure meaningful participation and a democratic outcome (Oshun et al. 2011).

Discussion

In this paper, we proposed a strategy for supplying ecosystem services in urban areas through a participatory planning process targeting multifunctional green infrastructure. We reviewed and synthesized literature from urban ecology, resilience thinking, multifunctional landscapes, and green infrastructure to make a case for viewing urban green spaces—not only formal parks and nature preserves, but also interstitial spaces such as vacant lots, right-of-way zones, and green roofs—as having potential to contribute to the social and ecological health of the city. Because planning for multiple functions can be a major task when many diverse social groups are involved, we explored decision support tools that could be applied to green infrastructure planning to engage the public and encourage action toward implementing a preferred solution. Strategies for engaging underrepresented populations were reviewed as an important component of a planning process to support healthy SESs.

Contributions

This paper broadens the conversation on SESs, by considering the potential for multifunctional green infrastructure to contribute to greater resilience in the face of an unpredictable future challenged by climate variability, food security, and availability and equitable distribution of resources. The concept of "transformability" suggests that the disturbances related to this unpredictable future could actually serve as opportunities to realign resources and organizational structures by drawing from the innovation and knowledge concentrated in urban areas. Tidball and Krasny (2009) suggest that community greening could serve as a community-based tool to promote resilience through innovation, adaptive management, and social learning. We expanded this idea to consider how the entire system of green infrastructure of a city might be designed and planned to support a broad set of ecosystem services that could enable transformation and empower communities.

This paper offers specific tools that can be used for decision-making during the planning process. Building on previous work on urban ecosystem services (c.f. Bolund and Hunhammar 1999; Lovell and Johnston 2009b), we propose a set of ecosystem services appropriate for many urban ecosystems around the world. These ecosystem services, which cover ecological, production, and social dimensions, might be used as indicators of sustainability of existing sites or as design targets for future sites. In the case of comparing existing sites, we offer the quantifiable metrics and associated methods for measuring current performance. For planning future sites, the alternative scenarios might be characterized and compared using rankings, with the decision support tools discussed earlier (Lovell et al. 2010).

Finally, this paper makes a case for a participatory planning process at multiple scales, from the neighborhood to the city and region, to guide decision-making on green infrastructure. Such a multiscalar approach could be used to identify and represent the interests of all stakeholders–including those from marginalized or historically underrepresented groups—in the green infrastructure planning process, potentially leading to more equitable and sustainable outcomes with broad-based public support. Local scale participatory planning must occur within a city-level framework that is also developed through a participatory process, to ensure that local projects synergistically contribute to an integrated city-scale system. We argue that, when appropriate, this approach to planning could and should be complemented by a community-based strategy of green infrastructure *management*, as a form of civic environmentalism promoting social cohesion and empowerment, ecopsychological health, and the development of an environmental ethos among community members (Leigh 2005). Participatory planning and community-based resource management are not, however, a panacea. Planners and other decision-makers must be cognizant of residents' differential access to social resources and the vulnerability of planning for and managing green infrastructure to unequal power geometries.

Implications

Our work has important implications for urban planners, landscape architects and designers, community organizers, and researchers. For urban planners, we offered several themes that could help guide a more holistic urban planning process to prepare for an unpredictable future: (1) to develop multifunctional green infrastructure by integrating a broad set of ecosystem services, (2) to use the concept of "transformation" to guide the planning process for a more resilient system, and (3) to legitimately involve all stakeholder groups in decision-making, with special consideration for engaging underrepresented groups. The implications for landscape architects and designers are related to the complexity of transforming sites, while considering the broader costs and benefits beyond the site. Simple themes such as conserving biodiversity, establishing ecological connectivity, and planning for multifunctionality can guide the design approaches (Ahern 2013). We hope the material provided in this paper will help in developing specific goals and objectives that will lead to sustainable solutions. For community organizers, we suggest that urban green space could serve as a visible platform for action and social and ecological transformation toward a better and more sustainable future. And for researchers (as we are), this work may be a guide for interdisciplinary evaluation of a complex urban ecosystem, considering multiple functions simultaneously.

Limitations

One limitation of the framework for multifunctional green infrastructure is the difficulty in accounting for the negative externalities, or disservices (those negative for human well-being), from urban green spaces. Ecosystem disservices can have an important impact on the way green spaces are perceived, used, and managed (Lyytimaki and Sipila 2009). Potential disservices from urban green spaces include: establishment of invasive species that threaten other ecosystem services, spread of allergens or toxins in plants, wildlife animals transmitting diseases, physical damage to built infrastructure by decomposition or tree roots, depletion of water resources due to irrigation, nutrient runoff from fertilization, or spread of contaminants through soil and plant material (Lyytimaki and Sipila 2009; Escobedo et al. 2011; Pataki et al. 2011). Some researchers have attempted to capture ecosystem services and disservices together through landscape assessments (De Groot 2006; Dobbs et al. 2011), but it has been difficult to expand beyond narrow market economics which do not adequately address cultural functions. Overall, we need to recognize that the net effectiveness of green spaces in providing ecosystem services may not be as great as expected, once a full accounting of costs and benefits are considered, and much uncertainty still exists in the magnitude of effectiveness of many ecosystem services (Pataki et al. 2011; Roy et al. 2012).

Another limitation is the potential for trade-offs among ecosystem services, particularly in urban areas with intensive human activities. In an analysis of the Beijing area, two types of ecosystem service bundles—the "natural" bundle (carbon storage, soil retention, and habitat conservation) and the "artificial" bundle (production and population support)—were found to represent the tradeoffs in the landscape (Wu et al. 2013b). Other researchers have also documented interactions between different ecosystem services, uncovering situations of both synergies and tradeoffs, depending on the services and the context. While the identification and assessment of complex relationships among multiple ecosystem services will require integrated social–ecological approaches, the appropriate management of these relationships could improve the resilience of urban ecosystems (Bennett et al. 2009).

In addition, the success of this approach is limited by the true potential of urban green infrastructure to contribute to certain ecosystem services at a meaningful level or extent. Focusing narrowly on carbon sequestration by urban forests, or food production from urban gardens, might lead to the conclusion that the contributions are miniscule and insignificant compared with those of vast old-growth forests or contemporary agricultural systems. Considering multiple ecosystem services simultaneously, however, will help community members, investors, and decision-makers come to some agreement on the best land use for a specific site. Even so, we must recognize that a city-wide transition to a more sustainable, efficient, and healthy state will indeed require major commitment from urban governments, and the results will take time to be revealed. Certainly, those cities that strategically plan for greater efficiency will be much more competitive in the future (Troy 2012).

Moving forward

What needs to be done to move a multifunctional green infrastructure forward? First, we need to gather the data that will convince community members, land owners, investors, and decision-makers that this strategy is worth-while and deserves a long-term commitment. Valuation of ecosystem services and disservices through cost-benefit analysis could help cities to justify the investment in multifunctional green infrastructure in the eyes of the public (Vandermeulen et al. 2011). Engaging the public throughout the process will lead to a greater understanding and acceptance in the new directions of tax revenue spending that could build a more resilient system able to transform in a positive direction even when faced with disturbance.

Second, when large-scale commitment is absent or failing, individual "early-adopters" can take the leap and implement innovative solutions on their own, even if the technologies have not been fully proven. These innovative technologies may then diffuse outward, transforming the urban landscape. Several landscape ecologists have proposed the idea of "adaptive design" for exploring innovative and creative practices through small-scale, "safe-to-fail" design experiments. Such an approach would allow cites to become living laboratories, in which new ideas are tested and monitored with a specific goal of improving future design (Felson and Pickett 2005; Ahern 2013). Some systems might be designed by urban planners and landscape ecologists, while others might emerge more organically as communities work together on greening efforts to improve their own neighborhoods. In both cases, opportunities exist to assess the performance of the systems over time, as they adapt and transform in the face of a changing climate and increasing disturbances.

Conclusions

We hope this paper will contribute to the broader discussion on the sustainability of urban ecosystems. We clearly face a critical need to develop the infrastructure that will simultaneously support humans and nature in an uncertain future threatened by a changing climate, food insecurity, water shortages, and energy limitations. In particular, we should explore those opportunities to build on the innovation capacity of cities to develop a multifunctional green infrastructure that could allow communities to adapt and even to *transform* to a more desirable development trajectory. Appropriate planning tools and a shared language will help to translate across multiple scales, and in many cases, the small-scale, grass roots projects might guide transformation on a broader scale. Governmental agencies could play a role in establishing the green infrastructure to support smaller, manageable systems and to empower local communities to transform their SES through action on the landscape. Participation in planning for and managing green infrastructure must be broad and truly representative to help guarantee that environmental change benefits all social groups, including historically disadvantaged and underrepresented populations. Innovative strategies for identifying and engaging potential stakeholders in the planning process and for encouraging communities to initiate green infrastructure projects can help to ensure a democratic and just outcome.

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