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Research Paper

Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit

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HIGHLIGHTS

- Green infrastructure in Detroit is not being sited to maximize ecosystem services.
- A Green Infrastructure Spatial Planning (GISP) model is developed and applied to Detroit.
- The GISP model provides an integrated, stakeholder-driven approach to maximize ecosystem services.
- The model reveals tradeoffs, synergies and hotspots for future green infrastructure.
- The model and planning approach can be readily deployed for other cities.

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ABSTRACT

Cities are expanding green infrastructure to enhance resilience and ecosystem services. Although green infrastructure is promoted for its multifunctionality, projects are typically sited based on a particular benefit, such as stormwater abatement, rather than a suite of socio-economic and environmental benefits. This stems in part from the lack of stakeholder-informed, city-scale approaches to systematically identify ecosystem service tradeoffs, synergies, and 'hotspots' associated with green infrastructure and its siting. To address this gap, we introduce the Green Infrastructure Spatial Planning (GISP) model, a GIS-based multi-criteria approach that integrates six benefits: 1) stormwater management; 2) social vulnerability; 3) green space; 4) air quality; 5) urban heat island amelioration; and 6) landscape connectivity. Stakeholders then weight priorities to identify hotspots where green infrastructure benefits are needed most. Applying the GISP model to Detroit, we compared the results with the locations of current green infrastructure projects. The analysis provides initial evidence that green infrastructure is not being sited in high priority areas for stormwater abatement, let alone for ameliorating urban heat island effects, improving air quality, or increasing habitat connectivity. However, as the Detroit GISP model reveals, it could be developed in locations that simultaneously abate stormwater, urban heat island, and air pollution. Tradeoffs exist between siting to maximize stormwater management versus landscape connectivity. The GISP model provides an inclusive, replicable approach for planning future green infrastructure so that it maximizes social and ecological resilience. More broadly, it represents a spatial planning approach for evaluating competing and complementary ecosystem service priorities for a particular landscape.

1. Introduction

For decades cities and communities have grappled with how to strategically balance often competing economic, environmental, and social justice goals (Campbell, 1996). Now there is increasing pressure to plan not just for sustainability but also for 'resilience', or the ability to cope with disturbances or changes (Ahern, 2011; Davoudi et al. 2012). As with sustainability, planning for resilience is contested and political (Chelleri, Waters, Olazabal, & Minucci, 2015).

A major strategy for enhancing the sustainability and resilience of cities and communities is the expansion of green infrastructure (Lennon & Scott, 2014). Green infrastructure refers to the development of urban green spaces, such as parks, rain gardens, and greenways, that provide a variety of social and ecological benefits, from improved public health to stormwater abatement (Jim, Yo, & Byrne, 2015; Young, 2011). These benefits are often classified using

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the ecosystem services framework, which includes four major categories of services: provisioning, regulating, supporting, and cultural (Ahern, 2007; Andersson et al., 2014; Elmqvist, Gomez-Baggethun, & Langemeyer, 2016). Researchers, government agencies, and organizations are actively promoting the expansion of green infrastructure. Cities such as Detroit, New York City, and London have ambitious policies to implement it on a large scale (Berkooz, 2011; Mell, 2016).

Despite its growing popularity, there are challenges associated with expanding green infrastructure, which are emblematic of the broader politics of resilience planning (Meerow & Newell, 2016). Although often promoted on the basis of its *multifunctionality*, green infrastructure is frequently researched and implemented from the perspective of a single benefit, usually stormwater abatement (Kremer et al., 2016; Newell et al., 2013). We lack integrated planning models that evaluate synergies and tradeoffs among the social and ecological benefits of green infrastructure. This is problematic because green infrastructure benefits are highly localized, thus siting decisions have significant implications for local environmental and social justice (Hansen & Pauleit, 2014).

To address this research gap, this paper introduces a spatial planning approach to identify tradeoffs and synergies associated with ecosystem services provided by green infrastructure, and to identify priority areas where green infrastructure can be strategically placed to leverage co-benefits. We introduce the Green Infrastructure Spatial Planning (GISP) model, which combines GIS-based multi-criteria evaluation of six benefit criteria (stormwater management, social vulnerability, access to green space, air quality, urban heat island, and landscape connectivity) and expert stakeholder-driven weighting. This model is designed to facilitate spatial planning at a citywide scale, which would then be followed by detailed suitability assessments at smaller spatial scales. Initially applied to Detroit, Michigan, the GISP model is designed to be generalizable and applicable for other cities and communities.

Detroit is a post-industrial city facing numerous resilience challenges including a weak economic base, high poverty and vacancy rates, and aging infrastructure (Gallagher, 2010; Schilling & Logan, 2008). Yet Detroit's extensive vacant land also presents an opportunity for urban transformation, and green infrastructure is a primary redevelopment strategy (Berkooz, 2011; Nassauer & Raskin, 2014). But are green infrastructure projects in Detroit being strategically planned and sited in areas where ecosystem service benefits are maximized and needed most? What are the spatial tradeoffs and synergies associated with these benefits? We use the GISP model to answer these questions, comparing the modeled 'hotspots' with the locations of green infrastructure projects across Detroit.

The structure of this paper is as follows: The next section provides background for the GISP model by summarizing the spatial planning approach, the ecosystem services provided by green infrastructure, the relationship between green infrastructure and resilience, and the planning challenges associated with green infrastructure, including in the Detroit context. Section 3 introduces the GISP model methodology and the data sources used to apply it to Detroit. Section 4 presents the results, including analysis of synergies, tradeoffs, hotspots, and the comparison between modeled priority areas and locations of current green infrastructure projects in Detroit. In Section 5, we reflect on the implications of these results and discuss strengths and limitations of the GISP modeling approach, and suggest ways to further improve it. The paper concludes by stressing the need for strategic and integrated green infrastructure planning in Detroit and beyond, and offers the GISP model as a promising spatial planning approach to evaluate often competing ecosystem service priorities and to identify strategic locations where co-benefits can be maximized for a particular landscape.

2. The spatial planning of green infrastructure for resilience

Cities can enhance their sustainability or resilience through spatial land-use planning. The European Commission (1997, p. 24) broadly defines spatial planning as approaches "used largely by the public sector to influence the future distribution of activities in space." Some spatial planning takes an "ecosystem approach," in which effective management of land and water provides a suite of *ecosystem services* for the benefit of humans and the natural environment (Wilson & Piper, 2010, p. 42). The expansion of green infrastructure in cities has emerged as a popular strategy to operationalize this ecosystem-based approach to spatial land-use planning (Lennon and Scott, 2014).

Commonly defined as the "interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations" (Benedict & McMahon, 2002, p. 12), green infrastructure has emerged as a complement to, and even a situational replacement of, more centralized 'gray infrastructure' (e.g. water pipes, pumps, and sewers) in large part because of its potential to enhance resilience for society and the natural environment. Scholars and practitioners argue that green infrastructure fosters urban resilience by increasing diversity, flexibility, redundancy, modularization, and decentralization (Ahern, 2011; Godschalk, 2003; Wardekker, de Jong, Knoop, & van der Sluijs, 2010; Wilkinson, 2011).

The relationship between green infrastructure and these resilience characteristics is often focused on stormwater management (Ahern, 2013). In particular, green infrastructure has the potential to reduce dependence on centralized stormwater infrastructure, based on the rationale that decentralized systems are more modular, provide functional redundancy, and are therefore less vulnerable to catastrophic failures (Ahern, 2011). Green infrastructure is also more flexible than massive buried pipes and pumps (Mell, 2016; Palmer, Liu, Matthews, & Mumba, 2015; Casal-Campos et al., 2015), which may be especially important given the changing and uncertain climate (Foster, Lowe, & Winkelman, 2011; Mell, 2016). During heavy precipitation events, green infrastructure can help alleviate flooding and pressure on aging or undersized sewer systems (Voskamp & Van de Ven, 2015). In cities with combined sewer systems, this can reduce the likelihood of combined sewer system overflows (CSOs), which in the United States alone purportedly cause 850 billion gallons of pollution annually (Carson, Marasco, Culligan, & McGillis, 2013). In this respect, green infrastructure can improve water quality by reducing harmful outflows. In coastal areas, wetland and mangrove green infrastructure can act as natural buffers against storm surges, thereby mitigating flooding (Danielsen et al., 2005). A meta-analysis found that green infrastructure reduced both overall stormwater runoff and water pollution levels (Jaffe, Zellner, Minor, Gonzalez-Meler et al., 2010, p. 8).

2.1. Green infrastructure and ecosystem services

Green infrastructure's utility as a resilience strategy goes beyond its ability to abate stormwater, for fundamental to green infrastructure's appeal is its *multifunctionality* (Kabisch et al., 2016; Madureira & Andresen, 2013; Sandström, 2002). The literature has extensively catalogued these multiple benefits as provisioning, regulating, supporting, and cultural *ecosystem services* (Ahern, 2007; Andersson et al., 2014; Elmqvist et al., 2016; Tzoulas et al., 2007). Besides stormwater abatement, this literature commonly cites five additional ecosystem service benefits: 1) improved air quality; 2) urban heat island mitigation; 3) improved communities and reduced social vulnerability; 4) greater access to green space; and 5) increased landscape connectivity (Table 1). These ecosystem