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The value of urban ecosystem services in New York City: A spatially explicit multicriteria analysis of landscape scale valuation scenarios

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ABSTRACT

Mapping, modeling, and valuing urban ecosystem services are important for integrating the ecosystem services concept in urban planning and decision-making. However, decision-support tools able to consider multiple ecosystem services in the urban setting using complex and heterogeneous data are still in early development. Here, we use New York City (NYC) as a case study to evaluate and analyze how the value of multiple ecosystem services of urban green infrastructure shifts with shifting governance priorities. We first examined the spatial distribution of five ecosystem services – storm water absorption, carbon storage, air pollution removal, local climate regulation, and recreation – to create the first multiple ecosystem services evaluation of all green infrastructure in NYC. Then, combining an urban ecosystem services landscape approach with spatial multicriteria analysis weighting scenarios, we examine the distribution of these ecosystem services in the city. We contrast the current NYC policy preference – which is focused on heavy investment in stormwater absorption – with a valuation approach that also accounts for other ecosystem services. We find substantial differences in the spatial distribution of priority areas for green infrastructure for the valuation scenarios. Among the scenarios we examined for NYC, we find that a scenario in which only stormwater absorption is prioritized leads to the most unevenly distributed ES values. By contrast, we find least variation in ES values where stormwater absorption, local climate regulation, carbon storage, air pollution removal, and recreational potential are all weighted equally.

We suggest that green infrastructure planning strategies should include all landscape components that contribute to the production of ecosystem services and consider how planning priority alternatives generate different ecosystem services values.

1. Introduction

In the four decades since the introduction of the concept of ecosystem services (ES) as a way to capture human society's dependence on the natural environment, rapid developments in the field have transformed it from a theoretical and conceptual framework into a policy-supporting, accounting and evaluation tool (e.g., Burkhard et al., 2012a,b; Ehrlich et al., 2012). More recently, the study of urban ES is emerging as an important research frontier for the incorporation of the benefits of ecosystems for urban health and well-being (Kremer et al., 2015) and as a tool for improving urban sustainability (Elqmvist et al., 2013) and resilience (McPhearson et al., 2015, 2016). However, major challenges remain in assessing and valuing individual urban ES, as well as in understanding the spatial distribution, tradeoffs and synergies of multiple services at the citywide scale (Haase et al., 2014). In this paper, we conduct a citywide assessment of multiple urban ES of green infrastructure in New York City (NYC) and examine how alternative policy and planning priorities in the city could affect the distribution of ES values across the landscape.

1.1. Policy and planning priorities for ecosystem services in NYC

NYC has emerged as a leader for incorporating ecosystem services into urban planning and policy (Hansen et al., 2015). Over the past decade the City has steadily increased its attention to the lack of adequate stormwater absorption in the city, which, due to

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its historical combined treatment of waste and stormwater, results in tens of billions of gallons of combined sewage and stormwater to overflow annually into adjacent waterways, negatively affecting aquatic ecosystems and recreation opportunities in the city (Cohen and Ackerman, 2011). As part of a cost-benefit analysis of grey versus green infrastructure for increasing stormwater retention, NYC created the Green Infrastructure Plan (2010), which allocates a total of US$2.4 billion over 20 years designed to control 10% of stormwater absorption using green infrastructure to reduce combined sewage overflows by approximately 1.5 billion gallons per year (New York City Department of Environmental Protection 2010; McPhearson et al., 2013a).

The NYC Green Infrastructure Plan has been heralded globally as an innovative example for cities to incorporate ecosystem services into urban decision-making. However, while other ES such as local climate regulation and recreation are addressed in multiple city publications and plans (McPhearson et al., 2014; Hansen et al., 2015), this major investment in green infrastructure was designed to improve a single ecosystem service, stormwater absorption, highlighting the potential missed opportunities of planning and designing new green infrastructure to simultaneously provide many other important ecosystem services for urban resident health and well being. We examine how decision-making for a single ES priority affects the value of ecosystem services across the urban landscape in NYC and compare it to alternative priorities, including the possibility of equally prioritizing green infrastructure for multiple services by applying weightings in a spatial multi-criteria analysis. Extending the ES landscape evaluation approach (Burkhard et al., 2009) to the urban landscape, we use weighting scenarios in a spatial multicriteria analysis (SMCA) to analyze the distribution of multiple urban ES across the NYC landscape.

1.2. Spatially explicit ES assessment

In order to use the ES approach as a tool for planning and decision-making, new methodologies and tools are needed to map, model and value ES at the local and regional scales (Crossman et al., 2013; Haase et al., 2014). Mapping ES illuminates spatial patterns relating to the distribution of ES potential, and allows an examination of the spatial relationship between ES and benefiting populations (Naidoo et al., 2008; Bastian et al., 2012; Crossman et al., 2013; Burkhard et al., 2012a,b). While the total quantity provided is a meaningful measure of some ES (such as food production), other ES are highly dependent on their spatial context (for example, flood protection is more important in places that are vulnerable to flooding) (Andersson et al., 2015). In these cases, spatially explicit and scale sensitive analysis is essential for ES assessment.

Measuring concurrent change in different ecosystem services over time and space is important to address trade-offs and synergies for the purposes of planning and decision making (Buckland et al., 2005; Weber et al., 2006; Koniak et al., 2010; Müller et al., 2011; Tallis and Polasky 2009; McPhearson et al., 2013b). However, because different ES are measured in different units, are sensitive to scale (Andersson et al., 2015) and are valued in different ways (Erik Gómez-Baggethun et al., 2013), it can be challenging to assess multiple ES in a particular location.

1.3. Landscape approach to ES assessment

The landscape approach to ES assessment suggests that landscape's properties, structure and function are integral to the assessment of the capacity of the landscape to provide different ES (Bastian et al., 2012; Frank et al., 2012; Müller et al., 2011; Burkhard et al., 2009; Larondelle and Haase 2013; Hamstead et al., 2016). Further, it has been proposed that connecting specific landscape properties, at the landscape scale, and the ES they support can help with challenges in ES mapping and assessment of multiples ES (Müller et al., 2011; Burkhard et al., 2009). One approach utilizes land use and landcover as representatives of physical and social processes across the landscape. In this approach, ES values are assigned to landscape units based on expert opinion (Burkhard et al., 2009), by linking land use, land cover and landscape metrics to ES (Frank et al., 2012; Bastian et al., 2012; Kroll et al., 2012), or by modeling the relationship between ecological processes and land use and land cover patterns (Nelson et al., 2009; Larondelle et al., 2014). While approaches differ significantly, there is common agreement that accurate ES assessment requires integrating land use and land cover information with spatially-explicit ecosystem function indicators (Müller et al., 2011). Still, ES assessment at the landscape scale only enables the study of ES individually. To combine different types of indicators into a coherent framework, multicriteria analysis needs to be integrated with the landscape approach to spatial ES assessment.

1.4. Multicriteria and spatial multicriteria ES analysis

Multi-criteria analysis (MCA) is useful for addressing the challenges posed by ES trade-offs and synergies, and the difficulty in communicating ES assessments to planners and decision makers (Koschke et al., 2012; Gret-Regamey et al., 2013). MCA is a methodology and a decision support concept that enables analysis of multiple variables, which are often characterized by limited comparability (Martinez-Alier 1998). The flexibility to analyze multiple variables under the framework of MCA makes it useful for understanding and evaluating social-ecological issues, and has been applied widely in environmental decision making (Martinez-Alier 1998). From a technical perspective, MCA involves scaling, ranking and aggregating variables through weighted optimization procedures. Although there is little guidance in the literature on how best to determine ranks and weights used in ES MCA procedures, there is a growing understanding that such methods are essential for understanding the relationship between ecological processes and societal valuations (Müller et al., 2011). Often, ES are weighted by means of expert and public stakeholder engagement (Bryan et al., 2011; Calvet-Mir et al., 2012). We use current policy and planning priorities in NYC (Hansen et al., 2015) to create a decision-making context to illustrate how the SMCA approach can be useful in elucidating how priorities affect the value of ES across the landscape.

Spatial MCA (SMCA) is a form of multicriteria analysis in which the geographic distribution of criteria or events influences the results of the analysis (Malczewski, 1999). The geographic component can be based on explicit (i.e. where a particular spatial aspect such as location, shape, size is used as the criteria) or implicit (i.e. where the criteria is derived from spatially related phenomenon) spatial criteria (Malczewski, 2006). Further, SMCA analysis can be alternative-based – in which predetermined alternatives are evaluated – or value-based, where preferred alternatives emerge through the assignment of value across space (Zucca et al., 2008), thus allowing for ES trade-off analysis and decision-making support. When evaluating spatial criteria, aggregation is performed in spatial, thematic or both dimensions (Zucca et al., 2008).

Developing SMCA methods for evaluating urban ES is important because it can provide new decision-support tools to identify trade-offs among potentially competing priorities for improving planning for ES. Nonetheless it is challenging. Urban systems are characterized by spatial heterogeneity that complicates spatial analysis (Cadenasso et al., 2007) and requires data at a fine spatial and spectral resolution, which is often unavailable or expensive to obtain. The fragmented nature of urban green infrastructure makes